NAVSARI AGRICULTURAL UNIVERSITY

SOIL CONSERVATION SOCIETY OF INDIA

SOUVENIR

31st National Conference on Innovative Resource Management Approaches for Coastal and Inland Ecosystems to Sustain Productivity and Climate Resilience

October 13–15, 2022

Organized by

Navsari Agricultural University
Navsari, Gujarat, India

In collaboration with

Gujarat State Chapter of SCSI, Navsari, Gujarat
Soil Conservation Society of India (SCSI), New Dehli

Sponsored by

Indian Council of Agricultural Research, Govt. of India, New Delhi
Ministry of Earth Sciences, Govt. of India, New Delhi
National Bank for Agriculture and Rural Development (NABARD)

ICAR

Ministry of Earth Sciences
Government of India

NABARD

International Decade of Soils 2015-2024

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सत्यमेव जयते

प्रधान मंत्री

Prime Minister

MESSAGE

It is a pleasure to learn about the national conference organised by Navsari Agricultural University, Navsari, in association with Soil Conservation Society of India (SCSI) from October 13-15, 2022.

The theme – "Innovative resource management approaches for coastal and inland ecosystems to sustain productivity and climate resilience" – encompasses important environmental issues.

Productivity of agriculture, profitability for farmers and preservation of the environment – these are the three pillars that the future of agriculture rests upon.

The hardworking farmers of India have ensured records in productivity year after year and boosted food security. The government has worked with them to ensure greater profitability, higher incomes, lesser input costs and risk mitigation.

In the third pillar of preservation of the environment through sustainable agriculture, the government has worked with the farmers by providing them crores of Soil Health Cards to track soil health, promoting natural farming, encouraging the growth of millets for climate resilience, and more.

Following India's proposal, 2023 has been declared as the International Year of Millets. This is an initiative that will be immensely helped by discussions and deliberations in such conferences.

There is a nascent socio-economic mass movement shaping up for sustainable agriculture, involving government, farmers, consumers and other such important stakeholders. This movement needs the scientific community to offer leadership.

Such conferences are an excellent opportunity to bring people together to add momentum to sustainable agriculture and good nutrition.

I am positive that the deliberations in this conference will focus on diverse issues and deliberate upon security, sustainability and climate resilience.

As we celebrate Amrit Mahotsav of our Independence, let us work on making agriculture sustainable. The Amrit Kaal of next 25 years is a period to build a strong, healthy and self-reliant nation.

Best wishes to the organisers and participants of the conference.

(Narendra Modi)

New Delhi
आश्विन 20, शक संवत् 1944
12th October, 2022

Bhupendra Patel

Chief Minister, Gujarat State

Apro/jm/2022/09/19/rs

Dt. 19-09-2022

MESSAGE

Agriculture is the backbone of the Indian economy; nearly 60% of the Indian population directly depends on agricultural activities as a source of livelihood. Indian agriculture is dominated by small and marginal farmers, having only 44% of the total arable land. Also, subsistence farming is the norm for marginal and small farmers, for their own consumption, they instinctively concentrate on cereal-based crops, with high risks of climate anomalies or erratic weather conditions, in addition to severe floods and droughts. The modern agricultural production systems are simplified due to specialization and are intensified with high rates of external inputs to keep production conditions favorable to maintain the productivity levels. Instead of low input sustainable agriculture (LISA), ecological, organic, regenerative, biological or simply alternative agriculture approach should be emphasized.

I am much pleased to learn that **Navsari Agriculture University** is organizing a National Conference on *"Innovative Resource Management Approaches for Coastal and Inland Ecosystems to Sustain Productivity and Climate Resilience"* from **13th to 15th October, 2022** at **Navsari**. I hope that the scientific community gathered shall give a thought on these burning issues and work for the welfare of the farming community. I extend my warm welcome in Gujarat, to the scientific community and research scholars from all over India and offer my best wishes to the organizers of the event at Navsari.

(Bhupendra Patel)

રાઘવજી પટેલ

सत्यमेव जयते

ક્રમાંક–મં./કૃ.પ.ગૌ./ VIP/૨૦૨૨
મંત્રી
કૃષિ, પશુપાલન, ગૌસંવર્ધન
ગુજરાત સરકાર
સ્વર્ણિમ સંકુલ–૧, બીજો માળ,
સચિવાલય, ગાંધીનગર.
ફોન –૦૭૯૨૩૨૫૦૧૧૯
Fax- ૦૭૯૨૩૨૫૦૧૨૦
તા. 01/10/2022

MESSAGE

Over the years, due to continuous and mono cropping soil nutrient reserves have depleted significantly, the soils need to be replenished with the essential major and minor plant nutrients. As of now there is hardly any scientific evidence to support detrimental effect of judicious use of fertilizers on soil health, crop productivity or farmers' income. We need to promote farming systems and technologies which enhance income and also prove ecologically sound. Typical mono-cropping system followed in many regions of India is untenable option for sustenance of soil and livelihood of farmers. To overcome the problems encountered by specialized, input driven agriculture, the integration of crops, livestock, fishery components that sustains food and nutritional security with regular and periodic income to farmers is a better option. Integrated farming systems (IFS) that includes temporal and spatial mixing of crops, livestock, fishery, and allied activities in a single farm needs to be encouraged, which is a holistic approach to farming making farms adaptive and resilient. IFS that integrate animal and crop enterprises is already receiving renewed interest in marginal, small and medium farmers who cultivate less than one hectare. Inclusion of tree species along the farm boundaries and Agro-forestry systems that helps in increased carbon sequestration, biomass production, reduced consumption of fertilizers and pesticides, in addition to reduction in greenhouse gas emissions and multiple other benefits needs to be emphasized.

I hope the scientific gathering at Navsari Agricultural University will deliberate at length and come out with recommendations that could be beneficial for the agriculture sector in general and marginal and poor farmers in particular.

Your Regards,

(Raghavji Patel)

डॉ. हिमांशु पाठक
सचिव, एवं महानिदेशक
Dr HIMANSHU PATHAK
SECRETARY (DARE) & DIRECTOR GENERAL (ICAR)

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
कृषि एवं किसान कल्याण मंत्रालय, कृषि भवन, नई दिल्ली 110 001

GOVERNMENT OF INDIA
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INDIAN COUNCIL OF AGRICULTURAL RESEARCH (ICAR)
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MESSAGE

I am happy to know that NAVSARI Agriculture University is organizing National Conference on **"Innovative Resource Management Approaches for Coastal and Inland Ecosystems to Sustain Productivity and Climate Resilience"** during October 13-15, 2022 in collaboration with Soil Conservation Society of India (SCSI), New Delhi and Gujarat State Chapter of SCSI, Navsari. Coastal agricultural areas are particularly exposed to a range of climate-related hazards such as rising sea levels, higher flood levels and storm surges, accelerated coastal erosion and seawater intrusion. These hazards may lead to a series of socio-economic impacts in the coastal zones like reduced agricultural productivity, loss of coastal habitats. Coastal agricultural practices are less stable than upland agriculture because they need to cope with frequent changes in salinity, tidal processes, water stresses and waterlogging. Coastal ecosystems are greatly impacted by location-specific land use. Projections of the precise magnitude, frequency and regional patterns of the impacts from climate change on coastal agriculture are uncertain.

Innovative interventions are required to establish climate resilient agriculture in coastal areas. Application of nano-technology, geospatial technologies, modelling and information technology is required for sustainable agriculture and watershed management. Adoption of natural farming can prove to be a feasible measure for resource conservation in our country. Climatic and non-climatic stressors, such as rise in temperature, rainfall fluctuations, population growth and migration, pollution, land-use changes and inadequate strategies are major challenges to coastal agricultural sustainability. The two most vital natural resources, soil and water, are being affected extensively and therefore, innovative technological interventions are required to be implemented before it is too late. The cascading impacts on the sustainability of coastal agriculture have not been adequately resolved and therefore, scientific studies need to be presented and deliberated in the conference to address these crucial issues.

I wish the conference a grand success.

(Himanshu Pathak)

Dated the 24th August, 2022
New Delhi

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उप महानिदेशक (कृषि शिक्षा)
Dr. Rakesh Chandra Agrawal
Deputy Director General (Agril. Edn.)

PREFACE

I am delighted to learn that Gujarat State Chapter of Soil Conservation Society of India (SCSI) at Navsari Agricultural University, Navsari, Gujarat is organizing the 31st National Conference on "Innovative resource management approaches for coastal and inland ecosystems to sustain productivity and climate resilience", from October 13 to 15, 2022, in collaboration of Soil Conservation Society of India (SCSI), India.

A critical review and insight of the topics of seminar, it clearly that the main topics *viz.*, Conservation, management and reclamation of natural resources; Technological interventions for sustainable agriculture; Socio economic impacts of climate change; Coastal ecosystem and aquaculture; Biodiversity and land use system (Horticulture/Agroforestry) for nutritional and environmental security and Resource Conservation through natural farming are of prime importance in the present context. Our resources, which not only sustain human beings but wild and domestic animals (both aquatic and terrestrial) and floral diversity, at present needs to be debated. Such debates at national and international level will surely provide insight for policy makers, researchers, NGOs *etc,* a path of deep thinking and planning about conservation and sustainable utilization of these valuable natural resources in the era of climate change. I am sure that such conferences with burning topics would lead scientist and policy makers to work in well-defined and focused research to tap these resources in a way so that we as human being at present would be able to sustain them for future generation. In this way we would not be blamed to make our future generation to be deprived from many natural flora and fauna.

Therefore, conservation and sustainable utilization of natural resources, in view of livelihood and environmental security of generation to come, may it be terrestrial or aquatic is the need of hour, particularly in climatic uncertainty which is being witnessed by us with an increasing trend. I am sure that deliberations in a 3 days conference on very apt themes will provide a baseline for research priorities and future development on these aspects to make the nation natural resource rich and conserve for food, nutrition, livelihood and environmental security.

I extend my best wishes for the grand success of this timely and well thought out themes of the national level conference.

(R.C. Agrawal)

Navsari Agricultural University
Navsari - 396 450, Gujarat

NAVSARI AGRICULTURAL UNIVERSITY

Dr. Z. P. Patel
(Vice Chancellor)

MESSAGE

I am very pleased to welcome all of you to participate in the National Conference on *"Innovative Resource Management Approaches for Coastal and Inland Ecosystems to Sustain Productivity and Climate Resilience"* from October 13 to 15, 2022 at Navsari Agricultural University, Navsari.

Agriculture in India is hindered due to small landholdings, inadequate resources and lack of agro-technological information. Under the changing climatic scenarios, agricultural planning and use of agricultural technologies need to be precise for their effective application in management and sustainability of natural resources over different ecosystems. Collaborative and concerted efforts of the organizers of this Conference are the timely steps in right direction to provide a platform where users, experts and policy makers from different part of the country are intended to deliberate on different emerging issues and challenges in the field of natural resources management. I am sure that thought-provoking discussions/deliberations will be held on conservation and management natural resources, technological interventions for sustainable agriculture, socio economic impacts of climate change, coastal ecosystem, biodiversity for nutritional and environmental security and various other issues covering different themes in this conference. The conference will offer the opportunity to interact and develop network in the field of soil & water conservation through sharing views with experts and possible future collaboration across the India.

I hope that the scientific community gathered at Navsari Agricultural University shall give a thought on these burning issues and work for the welfare of the farming community. I extend my warm welcome in Gujarat, to the scientific community and research scholars from all over India and offer my best wishes to the organizers of the event at Navsari.

(Z. P. Patel)
(Vice Chancellor)

Soil Conservation Society of India
New Delhi

Dr. Suraj Bhan
(President)

MESSAGE

I am happy that the Soil Conservation Society of India (SCSI), in collaboration with Gujarat State chapter of SCSI, Navsari, Gujarat is organising 31stNational Conference on "Innovative resource management approaches for coastal and inland ecosystems to sustain productivity and climate resilience" at Navsari Agricultural University, Navsari, Gujarat.

Natural resources are critically important components of life support system, the efficient conservation and management of which are vital for sustainable agriculture and rural development. With increasing demand on land for agriculture, increase in population, urbanization, industrialization and other non-farm uses of farm lands, diversion of land resources takes place not only from wastelands but also from agriculturally and ecologically significant areas including coastal ecosystem. The soil and water conservation technologies play major role for mitigating the impact of climate change on yield of various crops. The degradation of natural resources, soil and water has become a matter of serious concern for the farmers, researchers, academicians, scientists and policy makers, as these in turn affects socio-economic upliftment of rural population and sustaining agricultural productivity.

The Innovative resource management have been major driving force to enhance agricultural productivity, production, profitability and development in the country. In recent times the coastal and inland ecosystems require to be made sustainable which should be acceptable & affordable to the farmers, fisherman, economic viable, sustainable, ensure any harm on bio-health and also mitigate to climate change impact.

I am confident that the National Conference would provide long way solutions to gather professionals working in the field of Agriculture, Soil Science, Soil & Water Conservation Engineering, Forestry, Horticulture and allied agricultural sciences that include Students, Research Scholars, Faculties and Scientists from academic institutions and R&D and Non-government organizations to participate and present their work on sustaining productivity in the era of climate change, while managing the scarce natural resources.

I hope that the deliberations of the conference will result roadmap to support present status along with policy planning for judicious management of resources to mitigate the climate change in both coastal and inland ecosystem. I convey my best wishes for the success of the conference.

(Dr. Suraj Bhan)
(President)

FOREWORD

Water and Food security remain a persistent and overbearing problem for a large proportion of the world population in general and the Indian population in particular. It has an immediate consequence on soil in terms of determining survival strategies of small and marginal farmers in view of declining productivity, loss of surface soil mass, soil degradation, declining water levels and water scarcity. Global environmental problems such as land degradation, desertification, loss of biological diversities and climate change would dominate the overall objective of soil study in this century. Soil and water are the most essential resources for sustained quality of human life and related activities; therefore, soil resources and agro ecology-based agricultural development should be the strategy for exploiting renewable resources on which our nation must build and grow to fulfil all the cherished dreams.

Despite huge investment on the development of canal commands the irrigated area is hardly 37 % and still 63 % is dependent on rainfed or groundwater irrigation. The country neither has more land nor the viability of any bigger dam projects. In this context, for increasing crop productivity the only way out could be through the utilization of know-how available in Universities and Research Organizations on soil and water conservation, water management, integrated nutrient management, precision farming and comprehensive land use planning. Further, the total coastline of India which includes the island is about 7516.6 km, with a flourishing human population all along the coast, the soil and water problems of coastal districts are different from mainland or hilly areas. The land use plan of the coastal watershed has to deal with coastal erosion, soil degradation, sea water ingress, water pollution due to industrial conglomerates, erratic monsoon impacts, loss of vegetative cover, storms and possible tsunami threats. Agroforestry systems need to be implemented, for carbon sequestration, conservation of water and soil, industrial demand for wood, forest products, biodiversity conservation and environmental sustenance. Unless academia moves from working in discipline-wise silos, to adopting a multi-disciplinary and integrated approach for solving the complex problems of degrading natural resources, food, water, nutritional and economic security will remain a distant dream. With these points in view, a National Conference is organized at NAU, Navsari by inviting scientists, college faculty members and students to present their findings as well as to listen to the renowned experts in the field.

The Organizers are grateful to Dr Z P Patel, Hon Vice Chancellor, Navsari Agricultural Universality, for readily accepting the proposal of SCSI, New Delhi for hosting the 31st National Conference at Navsari Agricultural University. His consent and leadership have enabled the Gujarat Chapter to mobilise the participation of a large number of researchers from various Colleges and Research Units as well as availing the infrastructure facilities for the Conference. We also express our deep sense of gratitude to Dr Suraj Bhan, President of Soil Conservation Society of India for having faith in the newly formed Gujarat Chapter at NAU, Navsari and to host the national event. He is the man behind consistent persuasion to involve the scientific community working for soil and water conservation in Gujarat. The financial assistance received from Research and Development Fund of National Bank for Agriculture and Rural Development (NABARD) towards conduct of Conference including publication of proceedings of the Conference is gratefully acknowledged. The financial support and scientific resource from ICAR are the backbone for making the event successful, but also give due authenticity and meaning to the meet. The major financial help provided by the Ministry of Earth Sciences, Government of India has helped in improving the quality of Scientific Conference, is heart fully acknowledged. We are also thankful for the financial assistance from various organizations and cooperatives, listed in the appendix of publication. The organizing team is thankful to the participants and their respective organizations from across the country, for registering and participating in the three-day conference. Lastly, the organizers acknowledge the manpower support from various colleges, research units of Navsari Agricultural University and the Soil Conservation Society of India, New Delhi for making this event successful.

Organizers Desk

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Multifunctional agroforestry for sustainability

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ABSTRACT

An agroforestry system can be conceptualized and designed for different conditions and needs; it can be done at the farm level or landscape level. At the farm level in the existing agricultural lands, agroforestry can be promoted in the form of bund planting, boundary plantation, alley cropping, incorporation of nitrogen-fixing trees, *etc*. At the landscape level, agroforestry practices can be aligned toward the reclamation of degraded lands. Inevitably, any agroforestry system offers more than one output (comprising both tangible and intangible outcomes). Thus, the term 'multifunctional agroforestry' seems to be neither dictum nor jargon. Henceforth, there is a need for an appropriate definition for new terminologies *perse*. Overall, we state that the term 'multifunctional' should be used as a prefix to those agroforestry systems where it is able to provide more than one or several functions apart from its intended primary function.

Keywords: Agroforestry, Terminologies, Definitions, SDG's

INTRODUCTION

"Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos *etc.*) are deliberately used on the same land management unit as crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economic interactions between the different components". Subsequently, the definition of agroforestry was simplified and modified to highlight its contribution to the environment and natural resource management.

"Agroforestry is a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in agricultural landscapes, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels".

"Agroforestry, a combination of agriculture and forestry, is a land use that combines aspects of both, including the agricultural use of trees". (Van Noordwijk, 2019).

It is believed that integrating woody perennials in agricultural land will harness the ecosystem services provided by the perennials and sustainably increase the farm's productivity (Anderson and Sinclair, 1993). Overall, it has the potential to restore degraded lands, which is significant under the context of the UN decade on Ecosystem Restoration (2021-2030) (Crossland *et al*., 2018). However, fundamentally, the difference was the usage of the word "trees" instead of "wood perennials". This subsequently led to contextualizing agroforestry as a forestry-centric subject, but on the contrary, it is more multidisciplinary. Agroforestry per se is more than multidisciplinary, it is multifunctional, and it has been an attractive feature of its popularity.

Definition of Multifunctional Agroforestry

Multifunctional Agroforestry has been explained as a concept. The concept of multifunctional agroforestryrecognizes agroforestry as a multi-outputactivity producing not only commodities (food, wood/timber, fibres, flowers, agrofuels, medicinal products and ornamentals) but also non-commodity outputssuch as environmental services (nutrient cycling, soil formation and retention, carbon sequestration, pollination, waterquality and regulation), landscape amenities and cultural services (agroforestrytourism, walking, educational and scientific knowledge, spiritual value, meditation, *etc*.) (Parthiban *et al*., 2021). Further, it is stated that the four significant multifunctions of an agroforestry system are a) provisional services; b) regulating services; c) cultural services and d) supporting services. As stated earlier, there is a contradiction in explaining multifunctional agroforestry as a concept. Since all agroforestry systems and agroforestry practices provide more than one output, it gives both commodity (tangible) and non-commodity (intangible) outputs. For instance, Jose *et al*.(2019) report that the silvopastoral systems have greater biodiversity and multifunctionality than other livestock production systems. Here, the 'multifunctional' is used as an adjective rather than a noun. The standard error of unification or usage of jargon has crept into science, and without proper definitions, any terms; including 'multifunctional agroforestry' is a jargon. Thus, there is a need to reorient the definition to remove the ambiguity.

To begin with the examples of multifunctional agroforestry practices (models) are homegardens and Dehesas (Nair *et al*., 2021). Home garden is time-tested structural complex agroforestry practices are limited to the regions of the humid tropics like the Western Ghats and North East India as well as South East Asia countries like Indonesia, Thailand and Sri Lanka. At the same time, Dehesaare agrosilvopastoral systems practised in the Iberian Peninsula (southern and central Spain and south Portugal). Comparing these two agroforestry practices, it is evident that the term 'multifunctional' should be used as a prefix to those systems where it can provide more than one or several functions apart from its intended primary function.

Aspect of sustainability

The word sustainability can be traced back to the international conference and treaties in 1972. And the Brundtland Commission in 1987 gave out the definition for the term "Sustainable Development" which is 'development which meets the needs of the present, without compromising the ability of future generations to meet their own needs(Basiago, 1995). The concept of sustainability is based on the precautionary principle (Som *et al*., 2009). However, there are concerns that "sustainability" is just used as a buzzword; thus, there is a need to retrospect its usage in literature (Apetrei *et al*., 2021; Bateh *et al*., 2014). We have used google books (https://books.google.com/) as a database to showcase the usage of words related to sustainability between 1900- 2019(Kousha & Thelwall, 2015; Pechenick et al., 2015). It is evident from the figure that sustainability is one of the key buzzwords of the 20th century.

Agroforestry as a land use practice has been proven to be sustainable owing to certain characteristics like effective utilization of the natural resources whilst avoiding natural resource degradation, ensuring food and nutritional security, and providing cultural services and ecosystem services. A better way will be to examine the role of agroforestry systems in fulfillingthe demands and expectations of food security and, among other things, the related SDGs.

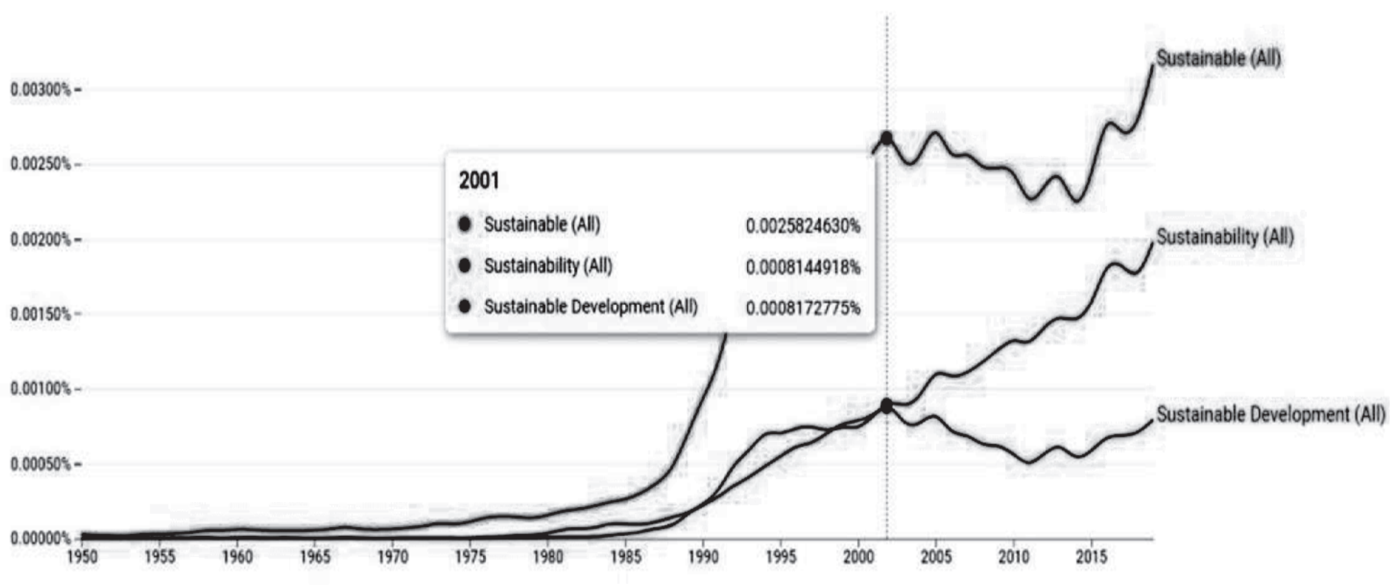

Fig 1. The screenshots depict the frequency of words (y-axis) "Sustainable", "Sustainability" and "Sustainable Development" in Google Books from 1950 to 2019 (x-axis)

The central focal point of all SDG goals is the "land-use"(van Noordwijk *et al.*, 2018). Agroforestry as a land use can be proven to follow all the principles of sustainable landmanagement. As per the World Overview of Conservation Approaches and Technologies (WOCAT), the key principles are the buildup of soil organic matter and related biological activity, integrated plant nutrition management, better crop management, better rainwater management, improvement of soil rooting depth and permeability and reclamation of the degraded land(Sanz *et al.*, 2017). Agroforestry adheres to these principles perfectly. However, agroforestry is less competent in sustainable land management principles than forestry. And also, on comparison between agriculture, forestry and agroforestry in contribution for achieving SDGs, forests are better performing in SDGs 13 (Climate change) and 15 (Life on Land) and agroforestry is the second-best option. However, the contribution of forestry in achieving SDG 2 (Zero Hunger) is minimal, and agriculture plays a major role in achieving SDG 2. However, its contribution to other SDG is lower than forestry (Figure 2).

In contrast to the forestry and agriculture sectors, agroforestry plays a substantial role in achieving 12 out of 17 SDGs. Moreover, in countries like India, where land is a scarce resource, more land cannot be diverted for the forestry sector. Agroforestry, as a multifunctional land use pattern forms a mosaic landscape supporting rich biodiversity inside the matrix of agricultural lands.

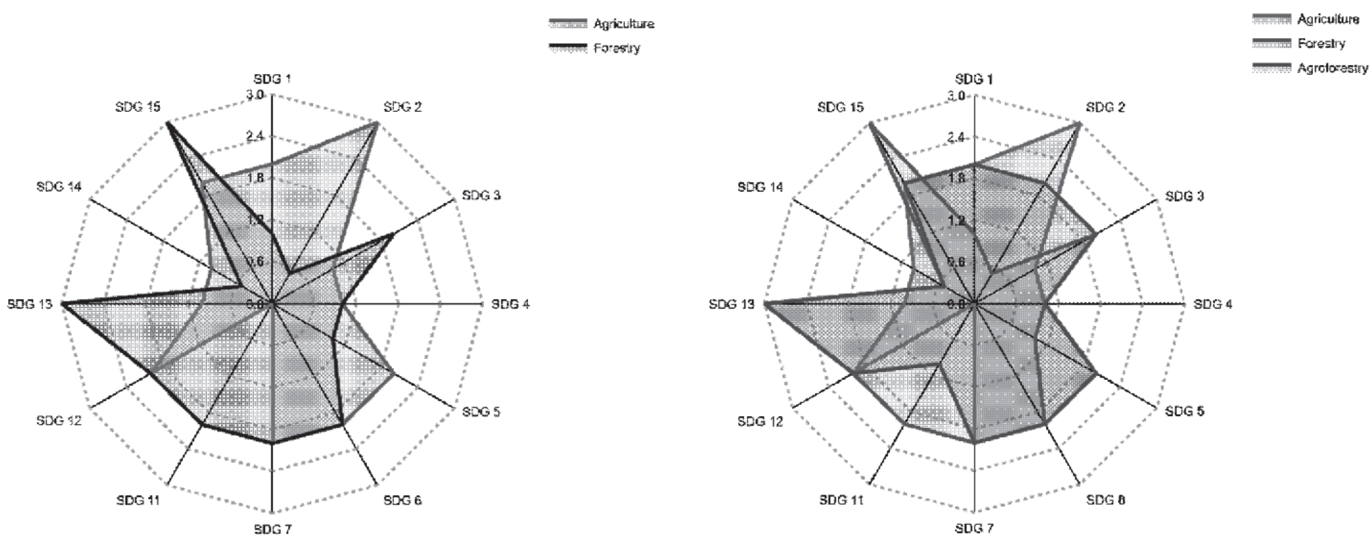

Fig 2. Comparing relevance level and contribution of agriculture, forestry and agroforestry sectors in achieving SDG Goals

Conclusion

Agroforestry is now under the limelight, and it is evident that there is an escalating interest among the stakeholders to adopt/ practice and promote agroforestry. This has inevitably resulted in new terms like agroecology, industrial agroforestry, urban agroforestry, etc. All these terms inexorably emphasize the relevance of agroforestry as landuse in today's world. Irrespective of the origin and usage of the terms, any combination of trees, crops and/or animals to be termed as an agroforestry system: it should satisfy two essential criteria a) the deliberate growing of woody perennials on the same unit of land as agricultural cropsand/or animals, and b) there must be a significant interaction (positive and/or negative) between the woody andnon-woody components of the system, either ecological and/or economical.

REFERENCES

Anderson, L.S., Sinclair, F.L., 1993. Ecological interactions in agroforestry systems. Agrofor. Abstr. 6, 57-91.

Apetrei, C.I., Caniglia, G., von Wehrden, H., Lang, D.J., 2021. Just another buzzword? A systematic literature review of knowledge-related concepts in sustainability science. Glob. Environ. Chang. 68, 102222. https://doi.org/10.1016/j.gloenvcha.2021.102222Basiago, A.D., 1995. Methods of defining 'sustainability.' Sustain. Dev. 3, 109-119. https://doi.org/10.1002/sd.3460030302

Bath, J., Heaton, C., Arbogast, G.W., Broadbent, A., 2014. Defining Sustainability In The Business Setting. J. Sustain. Manag. 1, 1-4. https://doi.org/10.19030/jsm.v1i1.8386

Crossland, M., Winowiecki, L.A., Pagella, T., Hadgu, K., Sinclair, F., 2018. Implications of variation in local perception of degradation and restoration processes for implementing land degradation neutrality. Environ. Dev. 28, 42-54. https://doi.org/10.1016/j.envdev.2018.09.005

Jose, S., Walter, D., Mohan Kumar, B., 2019. Ecological considerations in sustainable

silvopasturedesign and management. Agrofor. Syst. 93, 317-331.https://doi.org/10.1007/s10457-016-0065-2

Kousha, K., Thelwall, M., 2015. An automatic method for extracting citations from Google Books. J. Assoc. Inf. Sci. Technol. 66, 309-320. https://doi.org/10.1002/asi.23170

Nair, P.K.R., Kumar, B.M., Nair, V.D., 2021. An Introduction to Agroforestry. Springer

International Publishing, Cham. https://doi.org/10.1007/978-3-030-75358-0

Parthiban, K.T., Srivastava, D., Keerthika, A., 2021. Design and development of multifunctional agroforestry for family farming. Curr. Sci. 120, 27-28.

Pechenick, E.A., Danforth, C.M., Dodds, P.S., 2015. Characterizing the Google Books Corpus: Strong Limits to Inferences of Socio-Cultural and Linguistic Evolution. PLoS One 10, e0137041. https://doi.org/10.1371/journal.pone.0137041

Sanz, M.J., De Vente, J., Chotte, J.-L., Bernoux, M., Kust, G.S., Ruiz, I., Almagro, M., Alloza,J.-A., Vallejo, R., Castillo, V., 2017. Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification United Nations.

Som, C., Hilty, L.M., Köhler, A.R., 2009. The precautionary principle as a framework for a sustainable information society. J. Bus. Ethics 85, 493-505. https://doi.org/10.1007/s10551-009-0214-x

Van Noordwijk, M., 2019. Sustainable development through trees on Farms: agroforestry in its fifth decade, Bogor: World Agroforestry (ICRAF). ICRAF, Nairobi.

Van Noordwijk, M., Duguma, L.A., Dewi, S., Leimona, B., Catacutan, D.C., Lusiana, B., Öborn, I., Hairiah, K., Minang, P.A., 2018. SDG synergy between agriculture and forestry in the food, energy, water and income nexus: reinventing agroforestry? Curr. Opin. Environ. Sustain. 34, 33-42. https://doi.org/10.1016/j.cosust.2018.09.003

L-2

Initiatives by the Government of Gujarat to mitigate the impacts of Climate Change in the State

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ABSTRACT

Gujarat is the first State to establish a separate and dedicated Department for climate change at the sub-national level in entire Asia. Climate Change Department is working on Climate Change Adaptation and Mitigation actions in Gujarat by implementing various Schemes and Policies.

Gujarat has prepared the State Action Plan on Climate Change (SAPCC) following India's Nationally Determined Contributions and the Sustainable Development Goals. The State Action Plan includes mitigation and adaptation actions incorporating nine thematic areas i.e. Agriculture, Water, Health, Forests and Biodiversity, Sea-level rise and coastal infrastructure, Energy Efficiency and Renewable Energy, Urban Development, Vulnerable Communities and Green Jobs. The SAPCC was recently updated with the help of the Indian Institute of Management, Ahmedabad and the Indian Institute of Technology (IIT) Gandhinagar. This SAPCC aligns with the National Guidelines for the Sustainable Development Goals (SDGs), India's Nationally Determined Contributions (INDC) for the Paris agreement and PANCHAMRIT.

Climate Change Department has been presenting Gujarat's omnibus Climate Change budget by dovetailing activities of various line departments related to climate change adaptation and mitigation. A provision of Rs. 9000 Crore has been made under Climate Change Schemes by 19 other Departments of the State Government in the budget of the current financial year. It covers Climate Actions across line departments in the areas of combating desertification, increasing forest and mangrove cover, biodiversity and wetland conservation, sustainable agriculture, water resources management, reduction of pollution, and supporting green energy infrastructure.

Climate Change Department and Gujarat University jointly develop a Center of Excellence for Climate Change for cross-sectoral studies. The Climate Change Department has also partnered with various International Organizations like UNICEF, GIZ and ICLEI to carry out multiple activities on Climate Change.

The government of India has sanctioned the National Adaptation fund for Climate Change (NAFCC) project of Gujarat, which focuses on Climate Change Adaptation for Natural Resource Dependent Communities in Kachchh, Gujarat: Enhancing Resilience through water and livelihood security and ecosystem restoration. This project is being implemented by Gujarat Ecological Education and Research (GEER) Foundation, Gandhinagar. This project involves 15 activities to ensure water security, livelihood security and ecosystem restoration.

Climate Change Impacts and Research Studies: Climate Change Department is supporting various climate change impact studies to renowned research and academic institutes in the State of Gujarat, including IIM Ahmedabad, IIT Gandhinagar, CEPT, GERMI, Anand Agricultural University, Gujarat University, the M S University etc.Gujarat is preparing its strategy and roadmap for achieving the renewable energy target at the state level in alignment with the national target for 2030. Gujarat is developing new techniques on innovative energy solutions like battery storage and green hydrogen. A roadmap for net zero is being developed in consultation with the IIM & the IIT.Gujarat has recently been ranked one in the NITI Aayog Energy and Climate Index published in 2022 among all the states of India.

Wind Energy Overview: According to the measurements published by MNRE, New Delhi, Gujarat has around 142.5 GW (1,42,50 MW) wind energy capacity installation potential for wind power generation, which is the highest in the country. Gujarat is the first State in the country to declare a Wind Power Policy in 1993-1994. Total 41240.68 MW Wind Power Project Capacity was installed in the country on 31/08/2022. Gujarat holds 2nd rank in country, with an installed capacity of 9566.36 MW, which is 23.2% of the country.

Solar Energy Overview: Gujarat has around 85000 MW Solar energy capacity installation potential for Solar Power generation. Gujarat was the first State in the country to declare Solar Power Policy in 2008-09. Total 59302.70 MW Capacity of Solar Power Projects have been installed in the country as on 31/08/2022. Gujarat holds 2nd rank in country, with installed capacity of 8075.21 MW, which is 13.6 % of the country.

Climate Actions through Departmental Schemes.

1. **Solar Roof Tops Project on Government Buildings:** Under the direction of the Climate Change Department, Gujarat Energy Development Agency (GEDA) is implementing the Scheme of Grid Connected Solar Rooftop project in Government Building since the year 2008-2009. GEDA has undertaken the installation of Grid Connected Solar Rooftop system on various Government buildings such as Collector offices, Mamlatdar Offices, Prant Offices, Police stations and Police Training Institute, RTO offices, Taluka level, District level High Courts buildings, Government Hospitals and Hostels, Government Arts and Commerce Colleges, Government Engineering Colleges, Polytechnics, ITI, Regional Science Museum, Government Schools etc. The system installed on these buildings generates solar power for their use and saves the electricity bill. The government of Gujarat provides 100% of funds for solarization and promotion of Solar Rooftop systems on Government buildings of State Government.
2. Under this project, till date 1771 nos of Government Building has been covered for the installation of a solar Rooftop system with an aggregate capacity of 40,590 kW, which Saves approximate 60 million units of conventional electricity.
3. **Institutional Biogas Plant Scheme:** Beneficiaries of Gaushala / Panjrapol / Educational Institutions / Charitable and Religious Trusts / Hotels / Private Dairies / Agrofood Processing Industries / Co-operative Sugar Industries in the State are selected under Institutional Biogas Plant Scheme. Under this scheme, non-profit organizations are given a subsidy of 75% of the cost of biogas plants and profitable organizations are given a donation of 50% of the cost of the biogas plant.
4. **LED Tube Light in Government Primary Schools:** Under this scheme, energy-efficient LED tube lights are provided in government primary schools. This scheme is being implemented from the year 2017-18. Under this scheme, from 2017-18 till date, total 115434 LED tube lights have been installed in 11690 government primary schools of 23 districts of Gujarat state at an estimated cost of Rs. 3.84 crores. With this installation, till now total 30.79 Mus of electricity was saved, and 30787 tons of cumulative CO_2 emissions were reduced.
5. **Star Rated Fans in Government Primary Schools:** Under this scheme, energy-efficient Star Rated Fans are provided in government primary schools. This scheme is being implemented from the year 2017-18. Under this scheme, from 2017-18 till date, total 76016 Star Rated Fans have been installed in 8769 government primary schools of 20 districts of Gujarat state at an estimated cost of Rs. 9.21 crore. With this installation, till now total 12.56 Mus of electricity was saved, and 12557.21 ton cumulative CO_2 emissions reduced.
6. Plastic Waste Management Scheme: During 2021-22, a provision of Rs. 50.0 lakh for 500 ton of plastic waste collection through rural women of Sakhi Mandal was envisaged and total of 85 ton of plastic waste was collected upto August – 2022. Under this Scheme incentive of Rs. 10 per kg of plastic waste collection has been given to each member of Sakhi Mandal. Moreover, through an Awareness programme about Energy Conservation, Water Conservation and the Effect of plastic use on rural women of Sakhi Mandal

was implemented during 2021-22 in 33 districts. Total 25,740 women of Sakhi Mandal have been trained under the scheme.

7. Solar Water Heating System: GEDA started installing the Solar Water Heating System at Government Hostels of tribal areas in the State from 2015-16. Later on the benefits were extended to all the Government hostels, Residential Schools, Adarsh Ninvasi Salas and VishramGruh of Tirth Dham of the State. From 2015 to 2022, total 540 hostel buildings have been covered for the installation of Solar Water Heating Systems with a total capacity of 2million Litters per day (LPD) to meet the hot water requirement for approximately 80 thousand students, which saves approx. 51.95 Million units of electricity

8. Improved Crematoria Scheme: The Wood-based Improved Crematoria is developed for faster and cleaner cremation of the human body with a saving of wood. Under the scheme, the system is installed at SmashanGruhs of Gram Panchayat/ Taluka Panchayat/ Nagar Palika/ MahanagarPalika, who maintains the SmashanGruhs with a user contribution of Rs. 1000 per system as a token amount. During the years, 2016 to 2022 total 5650 nos. of Improved Crematoria were installed in the State.

9. Subsidy to Students for Battery Operated Electric 2-Wheelers: Utilization of Battery Operated Vehicles for urban mobility in the State of Gujarat has tremendous potential for conservation of petroleum products and is environment friendly. The Battery Operated Vehicles are known for their merits such as:

- It runs without costly petrol & reduces dependency on Fossil fuels
- Pollution-free vehicles & protect the environment from hazardous gases
- No noise pollution.
- Low-speed vehicles are exempted from RTO registration & driving license by the Automotive Research Association of India (ARAI)
- Batteries can be easily charged at home with meager power consumption

Students of 9th - 12th Standard and College Students are being provided with a subsidy of Rs. 12,000/- per vehicle with Lithium-ion Battery. Since 2015-16 total 37968 students have benefited with Rs. 39.65 Cr. subsidy from this scheme.

As result of Gujarat's proactive actions in climate actions, we have received many recognitions and awards. Gujarat is considered the model state for implementing Climate Action at the sub-national level.

L-3

Coastal and Inland Salt Affected Soils and Their Management

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INTRODUCTION

Soil is a natural finite, highly heterogeneous resource base which sustains life on earth. Soil biota is the biological universe that helps the soil carry out its functions. Often soil health is considered independently without referring to inter linked soil functions. Physical condition of soil and biological fertility are over looked in soil health management which needs revisiting of soil users. Recognizing the importance of soil health in all dimensions; 2015 was declared the International Year of Soils by the 68th UN General Assembly. India,the second most populous countryin the world, faces severe problems in agriculture. It is estimated that outof the 328.8 m ha of the total geographical area in India, 173.65 m ha aredegraded, producing less than 20% of its potential yield.

Soil is a three-phase system; from an agriculture perspective,the soil should support all the functions. The soils which possess characteristics that make the muneconomical for the cultivation of crops without adopting proper reclamation measures are known as problem soils. Often we resort to chemical means of reclamation that lead to impairment of ecosystem functions. Resorting to natural means and integrated methods will resolve the issue and prevent causing irreparable damage.

In the case of salt-affected soils, accumulation of excessive salt in irrigated soils can reduce crop yields, reduce the effectiveness of irrigation, ruin soil structure, and affect other soil properties. Understand how sodium, calcium, and magnesium affect soil structure. Appropriate practices for maintaining productivity in salt-affected soils, include leaching, amendments (kindandrate), crop selection and cultural practices (e.g., tillage and bed shaping to improve seed germination). The extent of salt-affected soils is projected to increase to about 16 million ha by 2050 due to climate change and/ or human activities. The estimates suggest India incurs soil salinity-related losses to an extent equivalent to 17 million tons of food grains annually.

Successful salt management requires frequent monitoring of both soil and irrigation water. Management of salt-affected soils is a challenge because salts affect many processes like crop growth (including yield, quality, and economic return), soil physical properties (such asaggregation and water infiltration) and sufficiency and toxicity of nutrients.

Salt Affected Soils

Three general categories of salt-affected soils have been identified for management purposes:

- Saline soils: Salt problems in general
- Sodic soils: Sodium problems
- Saline-sodic soils: Problem with sodium *and* other salts.

Thestate-wise distribution of salt-affected soils in India is presented in Table 1.

Table 1: Extent and distribution of salt-affected soils in India (Area x 1000 ha)

States	Water logged		Salt affected area			Total Area
	Canal Command	Total Area	Canal Command	Outside Canal	Coastal	
A.P.	266	339	139	391	283	813
Bihar	363	363	224	176	Nil	400
Gujarat	173	484	540	327	302	1214
Haryana	230	275	455	Nil	Nil	455
Karnataka	36	36	51	267	86	404
Kerala	12	12	NA	NA	26	26
M.P.	57	57	220	22	Nil	242
M.S.&Goa	6	111	446	NA	88	534
Odisha	196	196	NA	NA	400	400
Punjab	199	199	393	127	Nil	519
Rajasthan	180	348	138	984	Nil	1122
TamilNadu	18	128	257	NA	84	340
U.P.	450	1980	606	689	Nil	1295
W,B	NA	NA	Nil	NA	800	800
Total	2190	4528	3469	3027	2069	8565

These categories are defined in soil classification literature as shown in Table 2 using defined Numerical criteria.

Table 2 : Classification of salt-affected soils

Salt-affected soil classification	Electrical conductivity (EC)	Sodium adsorption Ratio(SAR)	Exch.Sodium Percentage (ESP)	Soil Physical Condition
None	below 4	below 13	below 15	flocculated
Saline	above 4	below 13	below 15	flocculated
Sodic	below 4	above 13	above 15	dispersed
Saline-sodic	above 4	above 13	above 15	flocculated

Occurrence of Salt-affectedSoils

Thesalt-affected soils occur in the aridand semiarid regions where evapotranspiration greatly exceeds precipitation. The accumulatedions causings alinityoralkalinity include sodium, potassium, magnesium, calcium, chlorides, carbonates and bicarbonates. The salt-affected soils can be primarily classified as saline soil and sodic soil.

Salinesoils

Saline soils defined assoils having a conductivity of the saturation extract greater than 4 dSm-1 and an exchangeable sodiumpercentage less than 15. Saline soils are defined as soils having a conductivity of the saturation extract greater than 4dSm-1and an exchange able sodium percentage less than 15. The pH is usually less than 8.5. These soils were called white alkali soils because of the surface crust of whitesalts.

Majorproduction constraints

The presence of salts leads to the alteration of the osmotic potential of the soilsolution.Consequently, waterintakebyplantsis restricted, andnutrient uptake by plants is reduced. Due to high saltlevels, microbial activity is reduced in this soil. Specific ion effects on plants are alsoseen dueto the toxicityof ions like chloride, sulphate,*etc.* The effect of EC on crops yields is shown in Table 3.

Table 3 : Electrical conductivity expected to produce a specified percentage yield reduction for selected crops.*

Crop	Expected yield reduction (%)[a]			
	None	10%	25%	50%
Barley	8.0	10.0	13.0	18.0
Wheat	6.0	7.4	9.5	13.0
Sugar beet	4.0	4.1	6.8	9.6
Alfalfa	2.0	3.4	5.4	8.8
Potato	1.7	2.5	3.8	5.9
Corn (grain)	1.7	2.5	3.8	5.9
Onion	1.2	1.8	2.8	4.3
Beans	1.0	1.5	2.3	3.6
Apples	1.7	2.3	3.3	4.8
Strawberries	1.0	1.3	1.8	2.5
Sudan grass	2.8	5.1	8.6	14.0
Grapes	1.5	2.5	4.1	6.7
Broccoli	2.8	3.9	5.5	8.2
Cucumbers	2.5	3.3	4.4	6.3

***Example:* At soil EC of 13.0 dS/m, barley yield is expected to be reduced by 25 percent.**

a. Plant response to salinity depends on growth stage, soil temperature, soil moisture, and other factors.

b. EC measured from a saturated paste.

Management of salines oils

The reclamation of saline soils involves the removal ofsalts from the saline soil through the processes of leaching with water and drainage. Provision of 60 cm deep and 45m wide lateral and main drainage channels and leaching of salts could reclaim the soils. Sub-surface drainage is an effective tool for lowering the water table, removing excess salts and preventing secondary salinization of ions like chloride,sulphate, *etc.*

Irrigationmanagement

Proportional mixing of good quality (if available) water with saline water and then use for irrigation reduces the effect of salinity. Alternate furrow irrigation favours the growth of plants than flooding. Drip, sprinkler and pitcher irrigation are more efficient thanthe conventional flood irrigation method since less wateris used under these improved methods.

Fertilizermanagement

The addition of an extra dose of nitrogen to the tune of 20-25% of recommended level will compensate for the low availability of N in these soils. Adding organic manures like FYM, compost, etc helps reduce salinity's ill effect due to release of organic acids produced during decomposition. Green manuring (Sunhemp, Dhaincha, Kolingi) and/or green leaf manuring also counter acts the effects of salinity.

Cropchoice/ Cropmanagement

Crops are to be chosen based on the soil salinity level. There lative salt tolerance of different crops is given in Table 4.

Table 4: Relative to lerance of cropstosalinity

Field Crops	Threshold salinity (dSm^{-1})	Vegetables	Threshold salinity ($dSm^{-}1$)
Cotton	7.7	Tomato	2.5
Sugar beet	7.0	Cabbage	1.8
Sorghum	6.8	Potato	1.7
Wheat	6.0	Onion	1.2
Soybean	5.0	Carrot	1.0
Groundnut	3.2	**Fruits**	**Thresholdsalinity ($dSm^{-}1$)**
Rice	3.0	Citrus	1.7
Maize	1.7	-	-
Sugarcane	1.7	-	-

Soil/cultural management

Planting the seed in the center of the raised bed / ridge may affect germination as it is the spot of most significant salt accumulation. A better salinity control can be achieved by using sloping beds with seeds plantedon the sloping side just above the water line. Alternate furrow irrigation is advantageous as the salts can be displaced beyond the single seed row. The application of straw mulch had been found to curtail the evaporation from the soil surface resulting in a reduced salt concentration in the root zone profile within 30 days.

Alkali/Sodic Soils

Alkali or sodic soilis defined as soil having aconductivity of the saturation extract less than 4 dS m-1 and an exchangeable sodium percentage more significant than 15. The pH is usually between 8.5 – 10.0.Most alkalisoils, particularly in the arid and semiarid regions, contain $CaCO_3$in the profile in some form and constant hydrolysis of $CaCO_3$ sustains the release of OH^- ions in soil solution. The OH^- ions so released result in the maintenance of higher pH in calcareous alkali soils than in non –calcareous alkali soils. The effect of ESP on soil productivity is given Table 5.

Table 5: Expected loss of soil productivity due to ESP in different soils

ESP	Lossin productivity(%)	
	Alluviumderivedsoils (Inceptisols/Alfisols)	Blacksoils (Vertisols)
Upto 5	Nil	Upto 10
5-15	<10	10-25
15-40	10-25	25-50
>40	25-50	>50

Major production constraints

Excess exchangeable sodiumin alkali soils affects both the physical and chemical properties of soils.

Reclamation of alkali / sodic soils

Physical Amelioration

This removes sodium from the exchange complex and improves soil's physical condition through infiltration and aeration. Thecommonly followed physical methods include

- Deep ploughing is adopted to break the hard pan developed atthe subsurface due to sodium and improve free-movement water.This also helps in the improvement of aeration.

- Providing drainage is also practised to improve aeration and to remove the further accumulation of salts at the root zone.
- Sand filling reduces the soil's heaviness and increases water'scapillary movements.
- Profile inversion – Inverting the soil benefits in the improvement ofthe physical condition of the soil as thatof deep ploughing.

Chemical Amelioration

Reclamation of alkali/sodic soils requires neutralization of alkalinity and replacing most sodium ions from the soil–exchange complex by the more favourable calcium ions. This can be accomplished by applying chemical amendments (the materials that directly or indirectly furnish or mobilize divalent cations, usually Ca^{2+} for the replacement of sodium from the exchange complex of the soil) followed by leaching to remove soluble salts and other reaction products.

The chemical amendments can be broadly grouped as follows:

Direct Ca suppliers: Gypsum, calcium carbonate, phospho-gypsum,*etc.* The requirement of gypsum and sulphur for reclamation is given in Table 6.

Table 6: Amendment rates of gypsum and elemental sulfur (S) for reclamation of sodic soils

Amendment rate				
Exchangeable Na to be replaced by Ca (meq Na/100 g soil)	**Gypsum (ton/acre) 12 inches**	**Gypsum (ton/acre) 6 inches**	**Elemental Sa (ton/acre) 12 inches**	**Elemental Sa(ton/acre) 6 inches**
1	1.8	0.9	0.32	0.16
2	3.4	1.7	0.64	0.32
4	6.9	3.4	1.28	0.64
8	13.7	6.9	2.56	1.28

a. Elemental sulfur does not supply calcium, but it will dissolve calcium-bearing minerals present in some alkaline soils.

Indirect Ca suppliers : Elemental Sulphur,sulphuric acid, pyrites,$FeSO_4$,etc

Gypsumis, by far, the most commonly used chemical amendment. Calcium carbonate is insoluble and ofno use in calcareous sodic soils(which have already precipitated $CaCO_3$) but can be used in non-calcareous sodic soils (do not have precipitated $CaCO_3$) since pH of these soils are low at surface and favouring solubilization of $CaCO_3$. Some of the indirect suppliers of Ca *viz.* Elemental sulphur, sulphuric acid, iron sulphate are also used for calcareous sodic soils. These materials on application solubilize the precipitated $CaCO_3$ in sodic soils and release Ca for reclamation.

Other sources distillery spent wash

Distillery spent wash is acidic (pH3.8-4.2) with a considerable quantity of magnesium. About 2 lakh litres of distillery spent wash can beadded to an acre of sodic soil in the summer months. Natural oxidation is induced for six weeks with intermittent ploughing once in amonth. Fresh water may be irrigated and drained in the second month (after 45-60 days). Such a treatment reduces the pH and exchangeable sodium percentage

Distillery effluent

Distillery effluent contains macro and micro nutrients. Because of its high salt content, it can be used for one-time application to fallow lands; about 20 to 40 tonnes per ha of distillery effluent can be sprayed uniformly on the fallow land. It should not be allowed for complete drying over 20 to 30 days. The effluent applied field has to bethoroughly ploughed two times for the oxidation and mineralization oforganic matter. Then the crops can be cultivated in the effluent applied fields by conventional methods.

Pulp and paper mill effluents

Pulp and paper effluents contain a lot of dissolved solids and stabilized organic matter and if properly treated, can safely be used for irrigation with a mendments *viz.*pressmud @ 5 tonnes ha^{-1},fortified pressmud @ 2.5 tonne ha^{-1}or dhain chaas in situ green manure.

Crop choice

Rice is the preferred crop in alkali / sodic soil as it can grow undersub mergence, tolerate a fair extent of ESP, and influence several microbial processes in the soil. Agroforestry systems like silviculture, silvipasture*etc.,*can improve the physical and chemical properties of the soil along with additional return on long-term basis. Some grasses like *Brachariamutica* (Para grass) and *Cynodondactylon*(Bermuda grass) *etc.*have been reported to produce50% yield at ESP levels above30.

The sodicity tolerance ratings of different crops is given in table 7 & table 8.

Table 7: Relativetoleranceof cropstosodicity

ESP(range*)	Crop
2-10	Deciduous fruits, nuts, citrus, avocado
10-15	Safflower, black gram, peas, lentil, pigeonpea
16-20	Chickpea ,soybean
20-25	Clover, groundnut, cowpea, pearlmillet
25-30	Linseed, garlic, cluster bean
30-50	Oats, mustard, cotton, wheat, tomatoes
50-60	Beets, barley, sesbania
60-70	Rice

*Relative yields are only 50% of the potential in respective sodicity ranges.

Table 8: Relative tolerance of fruit trees to sodicity

Toleranceto sodicity	ESP	Trees
High	40-50	Ber, tamarind, sapota, wood apple, datepalm
Medium	30-40	Pomegranate
Low	20-30	Guava, lemon, grape
Sensitive	20	Mango, jackfruit,banana

Saline-alkali/ sodic soils

Saline-alkali / sodic soil is defined as soil having a conductivity of the saturation extract greater than $4dSm^{-1}$ and an exchangeable sodium percentage more significant than 15. The pH is variable and usually above 8.5 depending on the relative amounts of exchangeable sodium and soluble salts. When soils are dominated by exchangeable sodium, the pH will be more than 8.5 and when soils are dominated by soluble salts, the pH will be less than 8.5.

Management of saline-alkali soils

The reclamation / management practices recommended for there clamation of sodic soil can be followed for the management of saline–sodicsoil.

Sustaining soil health is the imminent need of the hour

Soil health is defined as the continued capacity of soil to functionas a vital living system, which includes sustaining the biological productivity of soil, maintaining the quality of surrounding air and water environments, and promoting plant, animal, and human health. Soil functions include sustaining biological diversity, activity and productivity, regulating water and solute flow, filtering, buffering, degrading organic and inorganic materials, storing and cycling nutrients and carbon, providing physical stability and support.

Soil health deals with both inherent and dynamic soil quality.The former relates to the soil's natural (genetic) characteristics (e.g.,texture), which result from soil-forming factors. They are generally cannot easily be amended. On the other hand, the dynamic soil quality component is readily affected by management practices. It relates to the levels of compaction, biological functioning, root proliferation, etc, which is of most interest to grower because good management allows the soil to reach its full potential.

Soil quality or health cannot be determined by measuring only crop yield, water quality, or any other single outcome but with indicators which are measurable properties of soil or plants that provide clues about how well the soil can function. The indicators and their relationship to soil health is shown in Table 9.

Table 9: Indicators and their relationship to soil health

Indicator	Relationship to Soil Health
Soil organic matter(SOM)	Soilfertility, structure, stability, nutrient retention; soil erosion
Physical: soilstructure, depth of soil, infiltration and bulk density; water holding capacity	Retention and transport of water and nutrients; habitat for microbes; estimate of crop productivity potential; compaction, plow pan, water movement ;porosity; work ability
Chemical:pH; electrical conductivity; extractable N-P-K	Biological and chemical activity thresholds; plant and microbial activity thresholds; plant available nutrients and potential for N and P loss
Biological: microbial biomass C and N; potentially mineralizable N; soilrespiration.	Microbial catalytic potential and repository for C and N; soil productivity and N supplying potential; microbial activity Measure

In the International Year of soils, policy makers, scientists and allstake holders should pledge to really protect the soil through a multi faceted approach, including input management like water, manures, fertilizers and revamping soil health management programme sand evolving more soil health indicators specific to a region and resort to more of physical and biological fertility management and precise agriculture which naturally will take care of all other functions. Many interactions hither to neglected involving soil, plant, microbe, water and atmosphere should be focused. Sustainable soil management is essential for food, feed, fiber, fuel, medicines and ecosystem services. It is a non-renewable resource and managing sustainably needs increasing soil organic matter content,using nutrients wisely, keeping soil surface vegetated, promoting crop rotations and diversification and reducing erosion. It is imperative to solve the soil constraints and make the lands highly productive on asustainable basis, we need to develop technologies suitable to specific locations which will be economically feasible and workable at the farmer'sfield. Though the emphasis is on increasing the current yield level, attention should also be given to preventing soil degradation and also develop suitable technologies to reclaim the problem soils.

Conclusion

Saline soils contain large amounts of water-soluble salts. The salts are white, chemically neutral and include chlorides, sulphates and sometimes calcium, magnesium, sodium, and potassium nitrates. Sodic soils with high amount of exchangeable Na, water intake is usually poor, especially in soils high in silt and clay. The soil's pH is usually high, often above nine, and plant nutritional imbalances may occur.

Saline soils cannot be reclaimed by any chemical amendment, conditioner or fertilizers. Only leaching can remove salts from the plant root zone. The amount of water necessary is related to the initial salt level in the soil, the final salt level desired and the quality of the irrigation water. Adequate drainage prevents salts leached from the surface by irrigation from returning to the plant root zone by upward capillary action. Regular irrigation and drainage provide successful reclamation of this type of soil

Sodic soils are treated by replacing adsorbed sodium with a soluble source of calcium. Native gypsum, calcium in irrigation water or commercial amendments can supply the calcium. Adequate drainage also must be present. An amendment aims to provide soluble calcium to replace exchangeable sodium adsorbed on clay surfaces.

There are two main types of amendments: those that add calcium directly to the soil and those that dissolve calcium from calcium carbonate ($CaCO_3$) already in the soil. Calcium amendments include gypsum (hydrated calcium sulphate) and calcium chloride. Gypsum is moderately soluble in water. Good land management methods prevent salt build-up. Levelling the land and using heavy irrigation prevents salt accumulation in high spots.

Acid-forming or acidic amendments include sulfuric acid, elemental sulphur and calcium carbonate-sulphur. Sulfuric acid reacts immediately with the soil calcium carbonate to release soluble calcium for exchange with sodium. Elemental sulphur must be oxidized by soil bacteria and react with water to form sulfuric acid.

Technological interventions to bring the salt-affected soils under productive use can play an important role in increasing national agricultural productivity and farmers welfare.

REFERENCES

Annual Reports. (2015-2020). ICAR- CSSRI, Karnal & Regional Centre, Bharuch.

Biswas, T.D. and S.K. Mukherjee .1995.Text book of Soil Science. Tata McGraw-Hill Publishing Company Limited, New Delhi.

Brady, N.C. and R.R. Well. 2007. The Nature and Properties of soil. 13th edition. Dorling Kindersley (India) Pvt. Ltd., New Delhi – 110092

Govt. of India 1990.Indian agriculture in brief, 23 rd edition, Ministry of Agriculture and Cooperation, New Delhi, pp 160.

Horneck, D.A., Ellsworth, J.W., Hopkins, B.G., Sullivan, D.M. and Stevens, R.G. 2007.

Managing Salt-Affected Soils For Crop Production. Published by Oregon State University, Extension Services, USA.

Kumar, R., Singh, A., Bhardwaj, A. K., Kumar, A., Yadav, R. K. and Sharma, P. K. 2022. Reclamation of salt affected soils in India: Progress, emerging challenges and future strategies. Land Degrad Dev. 1-12.

L-4

Geospatial technologies for watershed development

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ABSTRACT

Monitoring and evaluating natural resources is a critical first step in creating a strategy for long-term development.In semi-arid tropical areas, watershed management has become an established technique for the development of rainfed agriculture. The introduction of various modern geospatial techniques and tools like Remote Sensing (R.S.), Geographic Information System (GIS), Global Positioning System (GPS), and information technology (I.T.) have provided natural resource monitoring, and assessment is a vital step in formulating a sustainable development plan. The import of these tools in the watershed areas is now well understood and recognized. Spatial and temporal resolution satellite data could be effectively used for watershed management and monitoring activities at the land ownership level. Techniques are also successfully used for preparing detailed thematic maps, watershed development plans and continuous monitoring of the natural resources in watershed areas. Major applications of geospatial technologies related to watershed development are Land use-resource inventory and land evaluation for optimum use, soil fertility and its quality assessment, generation of soil fertility thematic maps using GIS technology, soil quality assessment, land degradation assessment erosion modelling, land use land cover change detection, digital soil mapping, digital terrain modelling, soil-landscape Modeling, land use/land cover mapping, agricultural land use planning, etc., can have a significant impact on crop and land resource mapping, monitoring, and management on a sustainable basis. The review demonstrates that these strategies have great potential and are already being applied in various waysof land resourcesinventory, such as digital terrain analysis, soil resourceinventory, soil quality assessment,estimation of soil erosion, and land use/land cover mapping.

Keywords: Geospatial techniques,remote sensing, GIS, GPS

INTRODUCTION

Land resources are fundamental to sustainable life and development in the face of major concerns such as agriculture, food production, poverty and the effects of climate change (Muller and Munroe 2014).The majority of India's agriculture is rain-fed. It is characterized by highly erratic rains, poor soils, low yields, and inadequate infrastructure development.The fragile ecologies of these rain-fed regions are likewise severely degraded.Population growth has resulted in the overexploitation of land, water, and other natural resources, leading to water scarcity, soil degradation, and the rapid depletion of groundwater tables.As a result, the agricultural growth rate is stagnant, and food price inflation is soaring.At this time, watershed management is an accepted strategy for the development of agriculture that depends on rainfall.The operational application of R.S. and GIS in watershed management increased significantly and made quick strides in the latter decade of the 20^{th} century.The increasing integration of R.S., GIS, GPS, and crop model (CM) approaches is mainly responsible for this rise in operational use. The use of R.S. data to feed new GIS databases, update current databases, and track land use changes has steadily increased in watershed management. The R.S. data enables significant improvements in classification accuracy and serves as input to GIS databases.

Additionally, GPS capabilities give the GIS database strong cartographic management and make it possible to quickly and precisely find field plots within the data set. For alternative land use planning in the watershed, integrating GIS and C.M.s has been particularly effective. The operationalization of remote sensing in the field of watershed management, from resource appraisal to implementation and monitoring, was demonstrated by projects like the Integrated Mission for Sustainable Development (IMSD), National Agricultural Technology Project (NATP), and Sujala watershed project (NRSA, 1995; NRSA, 2002; Rao *et al.,* 2010).

The nature, extent, and geographical fluctuations of the Earth's surface must be repeatedly observed with a high spatial resolution to address issues such as increasing agricultural productivity, soil conservation, deforestation, land degradation, and climate change (Buchanan *et al.,* 2008; Huang *et al.,* 2018; Pandey and Palmate 2018; Pandey *et al.,* 2021a).Another significant use of geospatial technologies in the management of land resources is soil resource mapping.GIS application in watershed management has changed from operational support (e.g., inventory management and descriptive Mapping) to prescriptive modelling and tactical or strategic decision support system.Geospatial technologies play a pivotal role in monitoring and managing land resources.Digital Terrain Modeling (DTM), which uses digital elevation models (DEMs) to characterize the topography of any place, is one of the most often used applications (Zhou *et al.,* 2007).The usage of DEM products at various spatial resolutions is common in topographic Mapping, relief mapping, and terrain analysis (Yang *et al.,* 2011).

Additionally, the morphometric characterization of watersheds makes considerable use of DEMs (Wang *et al.,* 2010).Slope, aspect, contours, and curvature are effective parameters generated from the DEMs (Gajbhiye *et al.,* 2014).The current study's application of GIS, R.S., and models for watershed development comprises the following:

- Land use-resource inventory and planning for optimum use;
- Soil fertility and its quality assessment;
- Geospatial Modeling for Soil Quality Assessment;
- Land Degradation Assessment Erosion modelling;
- Land Use Land Cover Change Detection by using Geospatial Techniques.

Application of Remote sensing and GIS for Land resource Inventory:

Land Resources refer to a delineable area of the Earth'sterrestrial surface, encompassing all attributes of the biosphereimmediately above or below this surface, including those ofthe near-surface climate, the soil and landforms, the surfacehydrology (including shallow lakes, rivers, marshes andswamps), the near-surface sedimentary layers and associatedgroundwater and geo-hydrological reserve, the plant andanimal populations, the human settlement pattern and physicalresults of past and present human activity (terracing, waterstorage or drainage structures, roads, buildings, etc(FAO/UNEP, 1997).Information regarding the potentials, scope, composition, evolution and pace of change to various uses is implied by the inventory of land resources. For planning, management, conservation and optimal use of land resources for future growth in a sustainable way, it is necessary to collect reliable data (Shaw *et al.,* 2015;Akike and Samanta 2016).Advances in satellite remote sensing technologies have completely transformed the methods for monitoring the surface of the Earth. In order to understand complicated environmental issues and find solutions for sustainable development, geospatial techniques combine Remote Sensing (R.S.), Geographic Information Systems (GIS), Global Positioning Systems (GPS), cartography, and spatial statistics.

When interpreting satellite images for soil resource mapping, it is crucial to correctly identify the terrain type, drainage pattern, vegetation, land use, slope and relief (Dwivedi 2001). Two categories of GIS applications for soil mapping and surveying can be made. First off, base maps and database generation for pre-survey and Mapping can be done using GIS programs. Analyzing topographical maps, satellite images, and DEMs can provide a precise landform map that can be used for soil resource mapping and inventory. The comprehensive landform maps show the spatial variations of terrain features, which greatly aid in the stock and Mapping of soils and in establishing the soil mapping units in the area (Reddy *et al.,* 2013).Secondly, Mapping and post-survey applications can benefit from using GIS. To create an integrated soil coverage that includes spatial and descriptive information about soil mapping units, the soil mapping units, which form the framework of the soil database, are then labelled using the proper GIS functions to tabular data bases containing crucial soil characteristics.

Digital elevation model (DEM)/digital terrain model (DTM) and IRS-P6 LISS-IV high-resolution remote sensing data have been extensively employed in LRI. A DEM can provide information that will help the surveyor map and derive quantitative characteristics of the landform (Ardak *et al.,* 2010; Sankar *et al.,* 2010). To carry out soil conservation programs, irrigation planning and precision agriculture, DEM (NBSS&LUP 2015) can deliver exact and quantifiable information on the slope's degree, length and curvature. Data about the slope's degree, size and curvature, as well as its contours and drainage, are crucial for calculating the potential for water harvesting (Lin *et al.,* 2006). DEM offers a 3D terrain picture, allowing for more accurate contour creation and landform delineation. Soil characterization in depth with other site-specific data can serve as the foundation for any land-based planning approach.

Behrens and Scholten (2006) created a digital soil map to generate spatial soil information in response to the rising need for high-resolution soil maps worldwide.Farmers and planners are aided in their decision-making and land use planning by the location-specific availability of information regarding soil and its suitability.Using satellite image data in a GIS context, Nagaraju *et al.* (2015) analyzed the grounds of the Saraswati watershed in Buldhana district of Maharashtra and distinguished between four physiographic units: plateau, pediments, broad and narrow valley.Pediment soils are incredibly shallow, plateau soils are shallow to reasonably shallow, and wide and narrow valley soils are deep.Singh *et al.* (2014) used IRS-1C LISS-III data of the Mohanrao watershed, which spans two states and includes the districts of Saharanpur in Uttar Pradesh and Haridwar in Uttarakhand, to delineate various physiographic units, including the Siwalik hills, Piedmont plain, Alluvial plain, and Residual Hills.Sahu *et al.* (2014) used DEM created from Cartosat-1 stereo data of two seasons to interpret IRS-P6 LISS-IV in Miniwada Panchyat, Nagpur district, on the basaltic terrain of central India.They identified seven primary landforms: plateau top, scarp slopes, plateau spurs, pediments, undulating plains, valley, and floodplain.To provide critical inputs for site-specific soil and land resource management and agricultural land use planning, the ICAR-National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur, India, has taken a significant initiative to conduct a land resource inventory (LRI) on a 1:10,000 scale at the national level.Different types of remote sensing data, including digital terrain models (DTM), 5.8 meter resolution IRS-P6 LISS-IV data, etc., were employed in LRI.

The improved temporal, radiometric, spatial and spectral resolution of the European Space Agency (ESA) launched Sentinel-2 A + B twin platform is paving the way to their popularization in precision agriculture. Remote sensing and soil data analysis techniques strongly depend on the dimensionality (i.e., number of spectral variables) of the soil spectral data. They can identify soil properties, such as clay and O.M. content.Gholizadeh *et al.* (2018) worked on the capabilities of sentinel-2 data for monitoring and mapping of SOC and soil texture (clay, silt and sand content) measurements at four agricultural sites in the Czech Republic. The SOC and clay maps derived from the airborne and space borne datasets showed similar trend, with both performing better where SOC levels were relatively high. Sentinel-2 created the SOC map more precisely than the airborne sensors. Meti *et al*. (2019) reported that alkaline soil of study area showed distinct variation in reflectance in SWIR and NIR bands of Landsat 8 and Sentinel- 2 satellite. Reflectance in SWIR band showed significant negative correlation with pH, E.C. and exchangeable Na. Ratioing of SWIR bands with blue and green bands significantly improved the correlation with soil salinity parameters. However, the rationing of SWIR bands with visible blue has dramatically improved the correlation with soil pH and E.C. (r= 0.60* to 0.70*).Farah ***et al.* (2021)** conducted a study using sentinel-2 data to map and evaluate the current land degradation status. The SAM classification revealed that 18.44 per cent of the soils are weakly degraded, 36.45 per cent are moderately degraded and 27.74 per cent are highly degraded. However, the SVM classification showed that about 36.16 per cent of the soils are weakly degraded, 17.85 per cent are moderately degraded and 29.35 per cent are strongly degraded.

To study spatial variability of soil available nutrients by Geospatial technologies:

A statistical or mathematical model is developed as part of digital soil mapping (DSM) to estimate soil class or attributes at unsampled places utilizing data on spatial variation of soil properties and various factors impacting soil formation process.The traditional method for mapping soil attributes involves surveying work followed by laboratory examination.The soil maps created using the conventional method are often hard-copy maps, making them difficult for end users to access.Additionally, these maps' mapping units are established using information about soil profiles and the surveyor's practical expertise.The geostatistical technique, the state-factor (clorpt) approach, and the pedotransfer function (PTF) approach are the three basic approaches used in DSM.Burgess and Webster (1980) introduced geostatistics into soil research in the 1980s, allowing us to study these structures and predict soil classes, characteristics, and behaviour as well as evaluate the degree of uncertainty in those predictions.The geostatistical approach begins by identifying the spatial variation parameters (nugget, sill, and range) from a spatial soil database using a semi-variogram, and then uses kriging to estimate the unbiased soil properties at an unsampled location (Fig. 3.1).

Fig. 3.1. Digital soil mapping approach

Geostatistical Approach of Digital Soil Mapping: The three basic parameters, nugget, sill and range, which represent the spatial structure, are the building blocks of semi-variograms, a crucial tool in the theory of regionalized variables. Half of the average squared difference between the components of two data pairs is used to calculate the semi-variogram (Webster and Oliver, 2007). Both traditional and geostatistical methods were used to identify the spatial variability in soil parameters. Maps of spatial variability were created using the kriging interpolation method. The geostatistical kriging technique was used to interpolate the results of soil tests at unsampled regions.

Characteristics of semi-variogram: The nugget (C_0), which is the semi variance at a distance zero, the sill (C), which is the y-value at which the semi-variogram approaches an asymptote, and the range (R) were all derived from the fitted models (the distance [x-value] at which this leveling occurs) (Fig. 3.2).

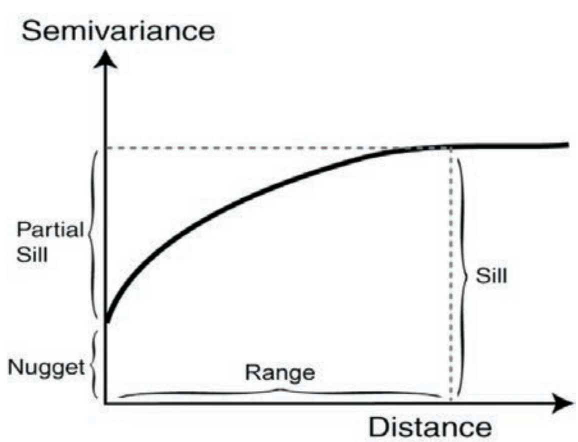


Fig. 3.2.Characteristics of semi-variogram

According to Hassinipak (2007), a semi-variogram is a function that describes the spatial variations of a variable. Its definition is as follows:

$$\hat{\gamma}(h) = \frac{1}{2\,N(h)} \sum_{i=1}^{N(h)} [Z(Xi) - Z(Xi + h)]^2$$

Where, h= lag distance

$\hat{\gamma}$ (h) = variance for interval distance class h

N(h) = Number of data pairs within a given class of distance and direction

Z (X_i) = measured sampled value at point X_i

Z (X_i+ h) = measured sampled value at point X_i+ h

In order to generalize deduction and estimate variables at the sites where samples have not been obtained, a theoretical model fitting procedure was carried out after the semi-variogram calculation.Spatial variability and dependence are based on the nugget-to-sill ratio.The soil property was considered to be strongly spatially dependent, or distributed in patches, if the nugget to sill ratio was less than or equal to 0.25 percent; moderately spatially dependent, or distributed in patches, if the ratio was between 0.26 and 0.75 percent; and weakly spatially dependent, or distributed in patches, if it was greater than 0.75 percent (Cambardella *et al.,*1994).The semi-variogram model with the lowest value of fitting error is chosen as the best fit.The mathematical expressions of four popular semi-variogram models—spherical, exponential, Gaussian, and linear-are shown below:

$$\text{Spherical model : } \gamma(h) = C_0 + C\left[1.5\frac{h}{a} - 0.5\left(\frac{h}{a}\right)^3\right] \text{ if } 0 \le h \le a; \text{ otherwise } C_0 + C$$

$$\text{Exponential model : } \gamma(h) = C_0 + C_1\left[1 - \exp\left\{-\frac{h}{a}\right\}\right] \text{ for } h \ge 0$$

$$\text{Gaussian model : } \gamma(h) = C_0 + C\left[1 - \exp\left\{\frac{-h^2}{a^2}\right\}\right] \text{ for } h \ge 0$$

$$\text{Linear model : } \gamma(h) = C_0 + C_1\left[\frac{h}{a}\right] \text{ if } h < a; \text{otherwise} = C_0 + C_1$$

In each of these semi-variogram models, the parameter specifies the range of observations between which there is a spatial correlation but further observations between which there is no spatial correlation.The practical range for these two semi-variogram models, in contrast to the exponential and gaussian models, is the lag distance at which the semi-variogram value achieves 95% of the theoretical range.In each of the aforementioned semi-variogram models, nugget (C_0) represents the amount of variation that can be characterized by spatial correlation structure. In contrast, partial sill (C) represents the amount of variation that is quantified by microscale variation and measurement error for the corresponding soil property.The variogram parameters, nugget, sill, and range form the basis for all other geostatistical processes, such as krigingor simulations. Thus, the correct Modeling and interpretation of the variogram are extremely important.Thekriging principle consists of determining the weights of thevariable values in neighbouring points to estimate the variable value in the target point or spatial domain. The variogram determines the weight of each point. Theweights are selected to obtain an unbiased estimate(all weights sum up to 1) of the target value and the minimum variance of the estimate:The closer the specific testing site to the point or domain forwhich the parameter should be determined, the more substantial is its contribution to the target value.

Denis *et al.* (2015) conducted study on knowledge of spatial variability for sitespecific nutrient management. In the present study, spatial variability in properties thatinfluence soil fertility such as soil organic carbon, available N, available P_2O_5 and availableK_2O in 133 surface samples (comprising of 108 soil samples from red soils and 25 soilsamples from black soils) from farmers' fields in Singhanhalli-Bogur microwatershed ofDharwad taluk in Dharwad district of Karnataka (India) were quantified. Based on the ratingsof soil nutrients, the respective thematic maps (soil fertility maps) were prepared using ArcMap 10.1 with the spatial analyst function of Arc GIS software through the spline interpolationmethod.Sagar *et al.* (2018) studied spatial variability quantification through semi-variogramanalysis using geostatistics and kriged maps generated in Geographic Information System(GIS). The results indicated that organic carbon was highly variable followed bycation exchange capacity, while pH was the least variable. The soil fertility indicated thatavailable K was found to be highly variable followed by available P, while available N wasfound to be least variable. All the micronutrients showed moderate variability. The spatialmaps indicated that the available N, P and K were low to medium, medium to very high andmedium to high, respectively. DTPA-Fe and DTPA-Zn was found deficient in 93.1% and53.8% of area of the watershed.

Digital soil mapping using kriging tool in ArcGIS: A Case study (Panday *et al.*, 2018):

The study was carried out across 12,516 hectares in the southern Terai region of Nepal's Bara district, including 23 Village Development Committees (VDCs). The pH, organic matter (O.M.), nitrogen (N), phosphorus (P, expressed as P_2O_5), potassium (K, expressed as K_2O), zinc (Zn), and boron (B) statuses of a total of 109 surface soil samples (0 to 15 cm depth) were determined. The dataset was analyzed using descriptive statistics and geostatistics, and descriptive statistics and a normality test were carried out using SAS software.The GIS program ArcMap (version 10.2) and its extensions for the spatial analyst and geostatistical analysis were used to create all of the maps.Through the use of semi-variograms, the structure of spatial variability was examined.Kriging interpolation was used to assess the spatial distribution.

Results and discussion:Digital maps of soil chemical properties were produced (Fig. 3.1 here we given only Soil N) by using kriging on the log-transformeddataset, and the results were grouped into various classesbased on the range representing their magnitude in the soil. The semi-variogram model and some of the geostatistical parameters of soil chemical properties are shown in Table 3.1. Based on the lowest root mean square error (RMSE), different theoretical semi-variogram models were selected for the significant fit of soil chemical properties. An exponential model provided the best fit to the semi-variogram of pH, O.M., N, and Zn. The spherical model was the best fit to the semi variogram of $K_2O$and B, whereas Gaussian was the best fit forP_2O_5.Many findings suggest that the exponential model is the most suitable for assessing spatial variability in soil chemical properties because it explains the maximum variability in the spatial dataset. Table 3.1 shows that Sp. D of soil parameters ranged from 0.3 (in N) to 0.92 (in Zn). There was a moderate (in N, O.M.,P_2O_5, and pH) and weak (in K_2O,Zn, and B) Sp. D. of the krigingmodel, which could be attributed to external factors such as variable rates of fertilizer application and incorporation of amendments by farmers within a cropped region. The spatial dependencies range ranged between 4951 m for O.M. and 5945 m forP_2O_5indicatingthat the optimum sampling interval varies significantly among different soil properties. Determining the range values provides an idea of the correlation between other sampling locations, along with the maximum spatial dependence distance between them. Fluctuation in the range with different lag sizes indicates that spatial structure may merely be regarded with a single model for semivariogram. This difference may not be important for semivariancecalculation, but it may be important if the purpose is to understand the underlying spatial structure of the data.

Table 3.1. Semi variance analysis of spatial structure in soil chemical properties.

Property	ME	RMSE	Model	Range	Lag size	Nugget	Partial	Sill	Nugget/Sill	Sp. D
pH	-0.03	0.057	E	5132	635.35	0.57	0.43	0.99	0.57	M
OM	0.01	0.026	E	4951	682.59	0.16	0.39	0.57	0.31	M
N	0	0.012	E	5209	675.64	0.16	0.37	0.53	0.3	M
P_2O_5	0.08	0.109	G	5038	661.78	0.15	0.14	0.29	0.513	M
K_2O	0.01	0.061	S	5831	661.93	0.45	0.13	0.58	0.78	W
Zn	0	0.06	E	5945	800.11	0.33	0.03	0.35	0.92	W
B	-0.03	0.43	S	5113	634.73	0.04	0.013	0.06	0.77	W

ME = mean error, RMSE = root mean square error, E = Exponential, G = Gaussian, S = Spherical,M = Moderate, and W= Weak. Unit for range and lag size, m.

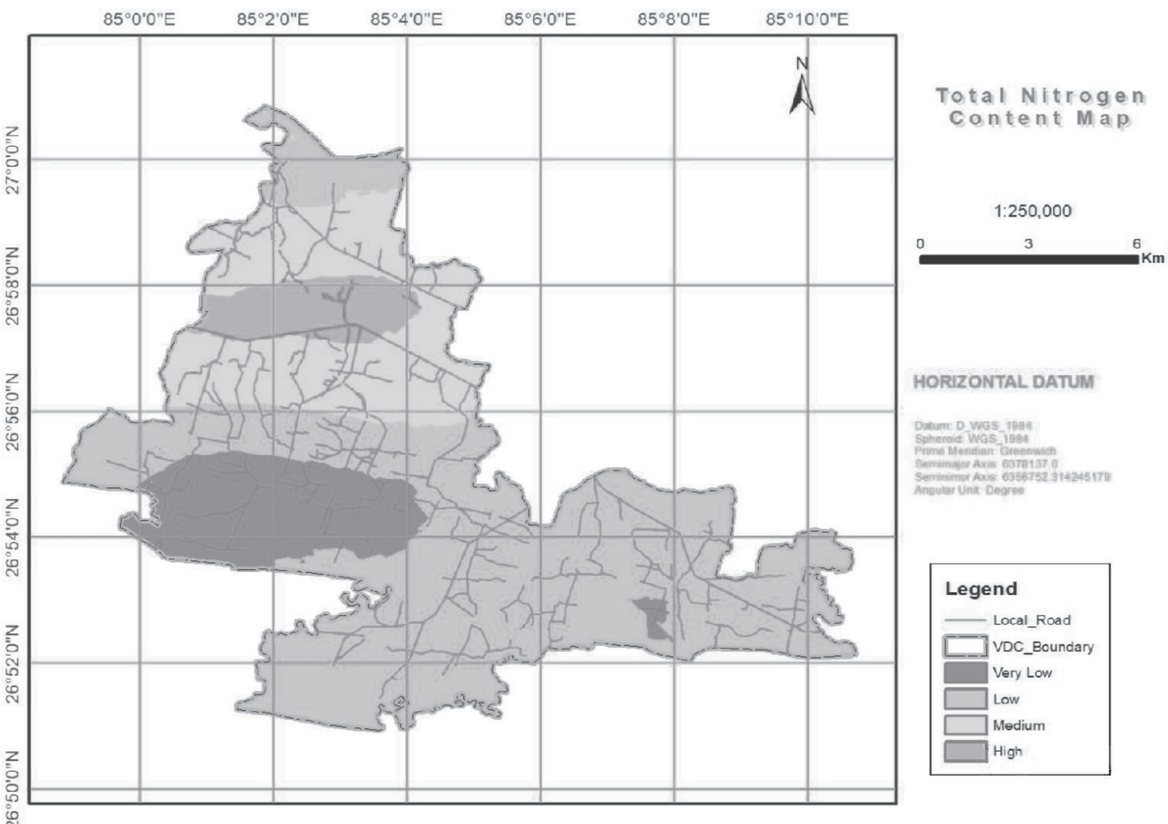


Fig 3.1. Soil N spatial variability map in the southern part of Bara district, Nepal.

Geospatial Modeling for Soil Quality Assessment:

Soil quality is defined as "the capacity of a soil to function within land use andecosystem boundaries, to sustain biological productivity, maintain environmental quality andpromote plant, animal and human health". Severalconceptual frameworks for monitoring soil quality have been proposed by variousresearchers (Viscarra Rossel *et al.,* 2006;Biswas *et al.,* 2017).Geospatial techniques involving the use of R.S., Global Positioning System (GPS) and GIS, provide new approaches for studying various soil quality aspects in different spatial as well as temporal domains (Schiewe 2003). Soil Quality Index (SQI) estimation is an indirect method based on the weighted integration of soil quality indicators.SQI calculation involves three steps: soil quality indicatorselection, scoring of indicator and weightage of each soil quality indicators, and thenintegration into a soil quality index.Principal component analysis (PCA) isa method used to identify suitable physical, chemical and biological indicators inthe ecosystem for soil quality assessment (Govaerts *et al.,* 2006). It aims to decreasethe data dimensionality while retaining the maximum possible variation inthe dataset. The score value of each soil quality indicator is estimated using scoringfunctions. A simple nonlinear polynomial framework was used for defining thescoring functions. Each soil property value was converted into a unitless score(0–1) using a scoring algorithm (Karlen *et al.,* 2001, 2003).The analytical hierarchy process (AHP) is a method commonly used to assignindicator weights (Qi *et al.,* 2009). AHP measures the degree of consistency;if found unacceptable, pairwise comparisons can be revised (Saaty 1990). AHPrules are applied to derive the final weightage ratings. Numerical weights of eachindicator are multiplied by the corresponding indicator scores (estimated usingstandardized scoring functions which normalize indicator measurements between0 and 1.0) to yield index values. The index values range between 0 and 1. Soils withlow values indicate poor soils, whereas high values indicate healthy soils.

SQI is computed as a function of summation of the product of weight and score ofeach indicator:

$$\mathrm{SQI} = \sum_{i=1}^{n} \mathrm{Wi} \times \mathrm{Si}$$

where W is the weight assigned for each soil quality indicator through AHP, S is thescore value of each indicator, and n is the number of soil samples in each ecosystem/land use type.

Soil quality indicators, which reflect the changes due toland management practices, may include various chemical, physical, and biologicalsoil properties. At any given point in time, a baseline or reference value of these soilquality indicators is essential to identify the impact of the different managementpractices (Bunemann *et al.,* 2018).Mukherjee andLal (2014) used various physical indicators, namely, potential AWC, soil penetration resistance, B.D., mean weight diameter (MWD), aggregate size distributions, a fraction of water-stable aggregates (WSA), and geometric mean diameter (GMD) along with other chemical indicators for assessing soil quality. Ezeaku (2015) assessed soil quality based on variousbiological and physico-chemical soil quality indicators to study the sustainabilityof various management and land-use systems. The most sensitive indicatorsobserved in the study were soil pH, porosity, CEC, available P, B.D., TOC, earthworm population, and plant available water holding capacity (PAWC). However,total N, exchangeable K, total P, and K were found to be moderately sensitive andpercentage base saturation was observed to be a weaker indicator.Sofi *et al.* (2016) used various SOC fractions as well as activities of different soil enzymes such asdehydrogenase, phosphatase, aryl sulphatase, and fluorescein diacetate hydrolases (FDAse) as biological indicators for soil quality assessment under diverse croppingsystems in the northwestern Himalayas. Bhaduri *et al.* (2017) have reported the effectiveness of biological indicators for soil quality assessment under a long-term rice-wheat cropping system in the semi-arid Indo-Gangetic plains with different tillage-water-nutrient management scenarios. They used MBC, dehydrogenase activity (DHA), soil respiration, PMN, and qCO2asquality indicators. In addition to the various indicators discussed above, Stefanoski*et al.* (2016) used macroporosity, microporosity, SHC, MS, effective saturation, aggregate size distribution, ASI, exchangeable Ca and Mg, exchangeable acidity, potential acidity, aluminum saturation, basal respiration, C stock, and N stock also aspotential soil quality indicators.

Soil Quality Assessment in a Watershed: A Case Study (Denis and Parameshgouda (2014))

The study AreawasSinghanhalli-Bogur micro-watershed is located about10 km away from Dharwad between 15°31'30.30" to15°34'49.45" N latitude and 74°50'47.46" to 74°53'35.67"E longitude in Dharwad taluk of Dharwad district in thenorthern transition zone of Karnataka, India. A detailed soil survey of the study area was carried out using IRS P6 LISS-IV image and Dharwad district toposheet. The image and scanned toposheet were geocoded, and subsets were created in ArcGIS 10.1 on a 1:12,500 scale.

Assessment of Soil Quality Index

The MDS was selected following PCA of 20 soil properties (Table 1). All 20 variables were subjected to PCA because all the variables had limitations for at least one sampling site. The PCA ofthe 20 variables resulted in 6 P.C.s, which had eigen values > 1 and accumulated to account for 87.11% of the variance in the data (Table 4.1).The principal components analysis (PCA) identified fivesoil attributes contained in six P.C.s. To determine this, we added the absolute value ofthe factor loadings in each ofthe 6 P.C.s for each variable. Variables having an absolutesummation value within 10% ofthat ofthe variable with the highest absolute sum were includedin the MDS.These five soil attributes constituted the soil quality indicators for the minimum data sets (MDS), which were used to construct the soil quality index (SQI) for the different soil mapping units and land uses. These five soil quality indicators were clay, silt, porosity, exchangeable Mg and organic carbon. Silt was the most important soil quality indicator in the study area because it appeared twice (in PC2 and PC5) in the factor reduction process.The clay% variable had the highestabsolute summation value and was the greatestcontributor to PC1. Coarse sand, total sand, field capacity (%), maximum water holding capacity (%), and base saturation all had absolutesummation values within 10% ofthat ofthe clay %. The maximum correlation coefficient (i.e. r>0.6) (table 4.2) was observed between the variables of clay and others which had absolutesummation values within 10% ofthat ofthe clay %, and, hence, clay % was only included in the MDS.The MDS variables for each sampling location were transformed to a score using linear scoring functions so that each variable had a score between 0 and 1. The scores for all five indicators were added to get the SQI value for each ofthe 17 profile sampling sites. The SQI map ofthewatershed was prepared by summing up the five kriged maps and each kriging map was generated by the score values of MDS in dicators for all the sites.The SQI value for each samplingsite was extracted from the SQI map and compared with the calculatedvalues. The soil quality index (SQI) was calculatedbased on the assumption that 0.40< SQI > 0.59 is low; 0.60 <SQI > 0.75 is medium and SQI > 0.76 is high (Hermiyanto *et al.,* 2003). The results revealed that the soil quality of mappingunits ranged from low to high (Fig. 4.1). A major portion of the study area was under medium (355.6 ha) and high (306.6) soil quality but largerportion was under medium soil quality(82.3 ha of land under low soil quality).

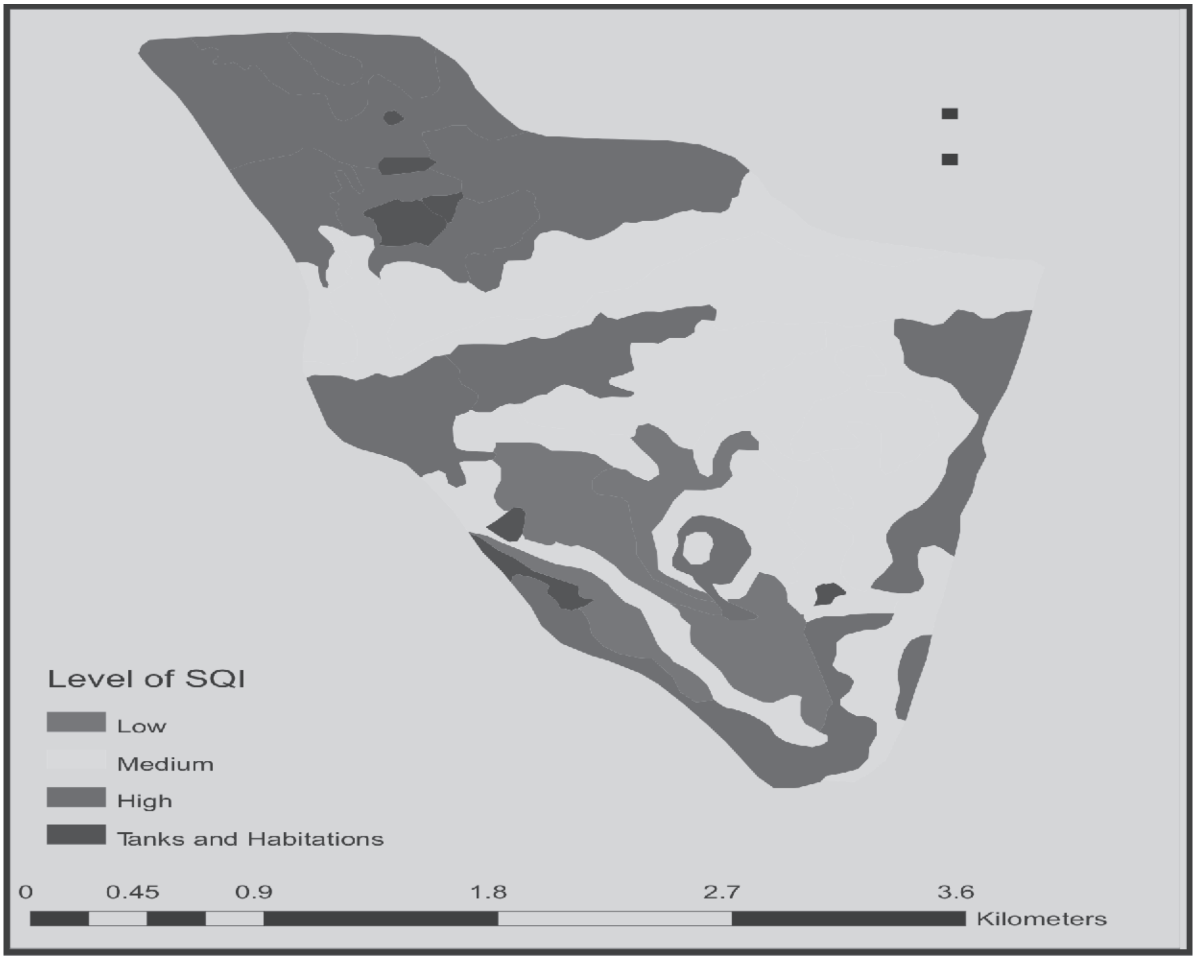
Table 4.1. The principal component (P.C.) analysis of soil quality indicators

Statistic	P.C. 1	P.C. 2	P.C. 3	P.C. 4	P.C. 5	P.C. 6	Communalities
Proportion of variance, %	50.342	11.034	9.385	7.117	4.792	4.439	
Cumulative proportion, %	50.342	61.376	70.761	77.878	82.67	87.109	
Computed factor weightings	0.58	0.13	0.11	0.08	0.06	0.05	
Factor loading or eigenvector variables							
Coarse fragments	-0.805	0.086	-0.174	-0.107	0.135	0.356	0.842
Coarse sand	-0.926	0.242	-0.044	0.19	0.105	0.134	0.983
Fine sand	0.429	0.492	-0.045	-0.475	0.097	-0.369	0.799
Total sand	-0.878	0.371	-0.1	0.072	0.136	0.092	0.95
Silt	0.424	**-0.558**	-0.168	-0.122	**-0.571**	0.164	0.887
Clay	**0.932**	-0.279	0.093	-0.081	0.00	-0.08	0.969
Bulk density ($Mg\ m^{-3}$)	-0.767	0.286	0.398	-0.041	0.208	-0.12	0.887
Field capacity (%)	0.905	-0.307	0.013	-0.011	0.24	0.00	0.971

Maximum water holding capacity (%)	0.928	-0.281	0.04	-0.065	0.171	-0.011	0.975
Porosity (%)	0.468	-0.01	**-0.704**	0.388	0.217	0.148	0.934
pH	0.814	0.389	0.05	-0.075	-0.02	0.157	0.848
Electrical conductivity	-0.143	-0.296	-0.225	0.607	0.214	-0.213	0.618
Organic carbon	-0.623	-0.256	0.375	0.199	0.086	**-0.528**	0.824
Free $CaCO_3$	0.226	0.446	-0.593	-0.309	-0.189	-0.132	0.75
Ex. Ca	0.82	0.381	-0.075	0.078	0.012	-0.277	0.907
Ex. Mg	0.155	0.198	0.238	**0.643**	-0.484	0.05	0.771
Ex. Na	0.694	0.303	0.53	0.144	0.024	0.16	0.901
Ex. K	0.619	0.42	-0.286	0.23	0.00	0.088	0.702
Cation exchange capacity	0.549	0.133	0.622	-0.045	0.152	0.392	0.886
Base saturation	0.855	0.356	0.00	-0.016	0.053	0.191	0.898

Table 4.2 : Pair-wise correlation between soil quality indicators

Soil properties	Coarse fragments	Coarse sand	Fine sand	Total sand	Silt	Clay	Bulk density
Coarse sand	.784**						
Fine sand	-0.29	-0.426					
Total sand	.796**	.960**	-0.195				
Silt	-0.319	-.588**	-0.106	-.620**			
Clay	-.800**	-.976**	0.303	-.965**	.510*		
Bulk density	.538*	.752**	-0.141	.744**	-.649**	-.739**	
Field capacity	-.732**	-.883**	0.292	-.855**	0.403	.922**	-.712**
MWHC	-.753**	-.920**	0.326	-.895**	0.443	.945**	-.728**
Porosity	-0.179	-0.28	0.031	-0.243	0.199	0.313	-.633**
pH	-.579**	-.664**	.520*	-.587**	0.184	.644**	-.508*
Electrical conductivity	0.156	0.127	-0.282	0.054	-0.027	-0.083	-0.051
Organic carbon	0.293	.495*	-0.355	0.401	-0.284	-.476*	.607**
Free $CaCO_3$	0.023	-0.187	.508*	-0.064	0.077	0.083	-0.295
Ex. Ca	-.717**	-.672**	.546*	-.586**	0.103	.663**	-.547*
Ex. Mg	-0.259	-0.027	-0.087	-0.053	0.059	0.049	-0.097
Ex. Na	-.487*	-.554*	0.316	-.528*	0.093	.582**	-0.277
Ex. K	-.496*	-0.41	0.253	-0.384	0.074	0.432	-0.407
Cation exchange capacity	-.697**	-.548*	0.351	-.520*	0.075	.562**	-0.384
Base saturation	-.615**	-.642**	.493*	-.549*	0.123	.652**	-.564**



To estimate the potential of soil erosion by Geospatial technologies and Modeling:

Erosion models allowed for the comprehensive examination of soil erosion and sedimentation processes as well as the evaluation of on-site soil erosion and its effects on soil quality. After being altered as the Modified Universal Soil Loss Equation, the Universal Soil Loss Equation (USLE) was revised as the Revised Universal Soil Loss Equation (RUSLE). Empirical models are easy to use and require less data for estimating soil loss than process-based models, which are more sophisticated and require extensive information on the climate, soil, terrain, vegetation, and management practices. Despite being an excellent predictor of average yearly erosion, the USLE is a poor predictor of specific storm soil erosion because it lacks variables related to the hydrologic state of the soil at the time of the storm. Additionally, the USLE does not anticipate sediment yield and considers deposition on a field, two necessary factors for many applications.

The management of natural resources in India has greatly benefited from inputs from satellite-based remote sensing. Geospatial information can be successfully combined with conventional databases to model runoff and sediment loss and put in place the necessary soil and water conservation measures (Pandey *et al.* 2007, 2021). Srinivasan *et al.* (2021) used the weighted index overlay technique to identify the soil erosion probability zones in a dry area of India's South Deccan Plateau. Das *et al.* (2021a) employed R.S. and GIS approaches to prioritize the Gomti River basin to conserve soil and water resources. Negash *et al.* (2021) computed the annual amount of soil loss using soil data, satellite pictures, ASTER DEM, and rainfall data. Bouamrane *et al.* (2021) developed the soil erosion hazard map for the Mellah watershed in northern Algeria using RUSLE, AHP, and frequency ratio. Prioritizing essential areas within a watershed that require interventions is vital in order to maximize investments while realistically achieving the necessary goals. An excellent opportunity for this endeavor is modelling.Rao *et al.* (1994) undertook a study to develop a watershed priority scheme for conservation planning based on the sediment yield potential estimates of the several sub-watersheds of the Saluli watershed in the Western Ghats of India.Das *et al.* (2021b) used the Revised Universal Soil Loss Equation and the Modified Morgan-Morgan-Finney (MMF) model to calculate soil loss (RUSLE).They found that compared to the USLE model, the MMF model underestimated erosion by 7.74 percent. In the context of this, the study was carried out with the specific aims of (i) assessment of soil erosion in the study watershedusing USLE model, while remote sensing and GIS techniques are used for parameterization, (ii) monitoring nutrient losses through surface runoff from the study watershed, and (iii) recommend a management strategy for the watershed's erosion-prone area.

To estimate the potential of soil erosion for Prioritization of soil and water conservation: A Case Study (D Souza 2021):

Study area was Kanamadi South sub-watershed (Vijayapura taluk, Vijayapura district) is located in between 160 51' – 160 55' 30'' North latitudes and 750 21' -750 26' 30'' East longitudes, covering an area of about 4170.17 ha, bounded by Kanamadi village on the North, Bijjaragi village on the East, Honawada village on the South and Belagavi district on the West.For delineation and Mapping of land degradation classes, IRS P6 LISS-IV image of 2010, acquired from the National Remote Sensing Agency (NRSA), Hyderabad, was used. In the preparation of land degradation map, ancillary data, including topographic map, soil survey maps, land and forest management plans and documents, existing wasteland data were used. The topographic maps used for the planning ground data collection was on 1: 50,000 scale. Sample points were identified for various land degradation classes from interpreted map of ground truth collection and for accuracy assessment. Soil samples were collected from 0-20 cm depth on a 320 x 320 m grid using a hand-held GPS device for noting down the latitude-longitude position of the sample points. The preliminary interpreted land degradation maps were finalized in the light of ground truth data and soil analysis data and also ancillary data on forests, wasteland and land use/land cover at the final Mapping.

Estimation of soil erosion potential using Universal Soil Loss Equation (USLE):The average annual soil loss in tons/acre, (A) is calculated as,

$$A= RKLSCP$$

Where, A is the average annual soil loss in tons/acre, R is rainfall erosivity factor, K is soil erodibility, L.S. is a slope length and steepness factor, C is a cropping factor and P is conservation practice factor.

Rainfall pattern and rainfall erosivity factor (R factor): The rainfall erosivity (R) factor indicates the soil loss potential of a given storm event. The parameter was calculated as the product of storm energy multiplied by the maximum 30 minute storm intensity and summed up all the storms in the year. The kinetic energy (K.E.) of a storm was calculated by the equation developed by Wischmeier and Smith (1958)

$$EI_{30} = KE \times I_{30}$$

Where, K.E. is rainfall kinetic energy and I_{30} is rainfall intensity for 30 minutes. In this study, the erosivity factor (R) was calculated using rainfall data collected from the nearest meteorological station located at Vijayapur. The average annual and seasonal rainfall from the 11 years were computed from the daily and monthly rainfall data and used to estimate annual and seasonal rainfall erosivity factor (R). Linear correlations were then established between annual erosivity indexes (Ra) and annual rainfall (Pa) and seasonal erosivity index (Rs) and seasonal rainfall (Ps). The regressional equations developed were as given below:

$$Ra = 79.15018 + 0.362258\ Pa \quad (r = 1.0)$$

$$Rs = 50 + 0.389\ Ps \quad (r = 1.0)$$

Where, Ra is annual R- factor, Rs is seasonal R- factor, Pa is the annual rainfall (mm) and Ps is seasonal rainfall. The highest total annual rainfall of 646.7 mm and least total rainfall of 337.45 mm were received during the year 2019 and 2012 respectively. The rainfall erosivity ranged from 447.3 to 306.7 MJ ha^{-1} mm^{-1} h^{-1}. The highest annual rainfall erosivity (447.3 MJ ha^{-1} mm^{-1} h^{-1}) was observed in 2018 due to the highest rainfall received from 2009 to 2017. While, the lowest rainfall erosivity (306.7 MJ ha^{-1} mm^{-1} h^{-1}) was recorded during 2011 owing to the lowest rainfall received in the same period. Over 11 years (2009 to 2019) the mean annual rainfall erosivity was 369.8 MJ ha^{-1} mm^{-1} h^{-1}. There was close correlation between the rainfall characteristics and soil loss.

Soil erodibility factor (K factor): The K factor was determined using data on inherent soil properties (Parysow *et al.,* 2003) and methodology described by Wischmeier and Smith (1978) from the relationship:

$$K= 1.2917\{2.1x10^{-4}\ M1.14(12-a) + 3.25\ (b-2) +2.5\ (C-3)\}/100$$

Where M is (% silt + very fine sand) (100 – clay%); 'a' is percent organic matter; 'b' is the soil structure code used in soil classification and 'C' is the permeability class. Singh and Khera (2008) reported that cultivated soils were more prone to erosion than forest and grasslands. In this study, soil erodibility was estimated using the formula Wischmier and Smith developed (1978). Soils having higher K factor values are highly susceptible and with low value are less susceptible to erosion. Based on the K values, the erodibility classes for soils originated from basalt have been defined (Satisha *et al.,* 2008). Soils with erodibility factor < 0.1 was classified as low, 0.1 to 0.2 as moderate, 0.2 to 0.3 as moderately high, 0.3 to 0.4 as high and > 0.4 as very high.Based on these groupings, majority of the mapping units viz., DMTmB2g1, DMTmB2g1Ca, KGRmB2g1, NHLmB2, THLmB2, THLmB2g1Ca, THLmB2g2Ca, RPRmB2, KRJmB2, KRJmB2g1Ca, NDNmB2, NDNmB2g1Ca, TSLmB2g1Ca and SRDmB2 were categorized as soils having K factor in the range between 0.1< K > 0.2 and grouped under moderate category. The mapping units such as DMTmB2g2Ca, KGRmB2, BBLmB2 and SRDmB2g1Ca were characterized as moderately high erodible soils due to their K factor in the range of 0.2 < K > 0.3. It was observed that soils with higher content of intermediate particle-size showed more erodibility risk than the soils with higher clay and higher sand content.

Slope length and steepness factor (L.S. factor): Slope gradient map was prepared from Digital Elevation Model (DEM) derived from satellite imagery. The LS-factor was derived by Gitas *et al.* (2009) using the calculation of the S (slope steepness) and L (slope length) factors as follows:

$$L = 1.4\ (As/22.13)^{0.4}$$

$$S = (\sin ß\ /\ 0.0896)^{1.3}$$

Where, As: catchment area (m^2), ß : slope angle in degrees

The L.S. factor of mapping units ranged from 0.19 to 0.80. The lower L.S. factor was attributed to the general slope of the landscape which was gently undulating (1-3 % slope). The mapping units with lower L.S. value indicating lesser susceptibility to erosion which included KGRmB2 and KRJmB2g1Ca. The higher LS factor of > 0.30 in DMTmB2g1, DMTmB2g1Ca, DMTmB2g2Ca, KGRmB2g1, NHLmB2, THLmB2, THLmB2g1Ca, THLmB2g2Ca, RPRmB2, BBLmB2, NDNmB2, NDNmB2g1Ca, TSLmB2g1Ca, SRDmB2, SRDmB2g1Ca, KRJmB2 and HNTmB2g1Ca mapping units was attributed to higher slope degree or length. Texture is not ideal for soil loss in mapping unit because of greater slope steepness factor resulted in high soil loss. The data further indicated that lands with steep slope had higher L.S. values while lower alluvial plains had lower L.S. values because of field bunds.

Crop cover and conservation practice factor (C and P factor): The crop cover (C) factor is related to the land use, vegetation type, growth stage and vegetation cover percentage. It is calculated as the ratio of soil loss from specific crops to the equivalent loss from tilled, bare plots. Lower the C factor value, better the soil cover and lower will be the soil loss. Therefore, it is very important to gauge the land use pattern in the basin to generate reliable C factor values. The crop cover factor of the study area ranged from 0.18 to 1.0. Potdar *et al.* (2003) assigned the C factor value of 0.38 for soils dominated by single crop, 0.35 for double cropped fields, 0.20 for wastelands and 1.0 for fallow land for the assessment of soil loss. Based on these guidelines, C factors were assigned for the mapping units of the study area. The mapping unit belonging to upland recorded the lower C factor of 0.20 due to nearly level landscape with scrubs. The highest C factor (1.0) was assigned to mapping units because of its fallowness.The conservation practice factor of the mapping units was 0.6 (0-2% slope). Conservation practice factor was assigned to mapping units based on slope following the guidelines given by Shinde *et al.* (2010). The conservation practice factor reflects the effect of soil and water conservation practices which reduce the amount and rate of the water runoff and amount of erosion. The selection of a support practice that has the lowest possible factor associated with it will result in lower soil losses (Sujata, 2012).

Prediction of soil loss and erosion risk assessment (A): After estimating different USLE factors (R, K, L.S., C and P), the total soil loss (A) was estimated by multiplying all the factors. Annual erosion classes were made as per guidelines suggested by Singh *et al.* (1992) for Indian conditions and were categorized into different erosion classes. Based on the estimated soil loss, mapping units of the sub-watershed were grouped under slight and moderate soil loss category. The lack of complete ground cover by crops as observed in barren and scrub lands was the main reason for higher soil loss in study area. The soil loss remained relatively low (< 5 t ha^{-1} yr^{-1}) in KGRmB2g1, NHLmB2, BBLmB2, NDNmB2g1Ca, SRDmB2g1Ca and KRJmB2 mapping units. This might be due to the topographic position of the land (lower L.S. factor) coupled with varying vegetation cover and soil erodibility factor of the site. Moderate erosion rate (5-10 t ha^{-1} yr^{-1}) was recorded in DMTmB2g1, DMTmB2g1Ca, DMTmB2g2Ca, THLmB2, THLmB2g1Ca, THLmB2g2Ca, RPRmB2, NDNmB2, SRDmB2, TSLmB2g1Ca and HNTmB2g1Ca. This might be due to lack of proper soil conservation measures especially in denuded uplands with little or no vegetation and also cultivation along the slope on moderate sloping lands. The problem was aggravated due to soil type (black soil with low infiltration rate), cultivation along the slope, no proper bunding etc.The Mapping of erosion (Fig. 5.1) showed that 2705 ha (64.86 %) of area was affected by moderate erosion and 1416 ha (33.97 %) of study area is affected by slight erosion. The study area is vulnerable for erosion so, proper soil and water conservation methods helps to reduce the land degradation by erosion.

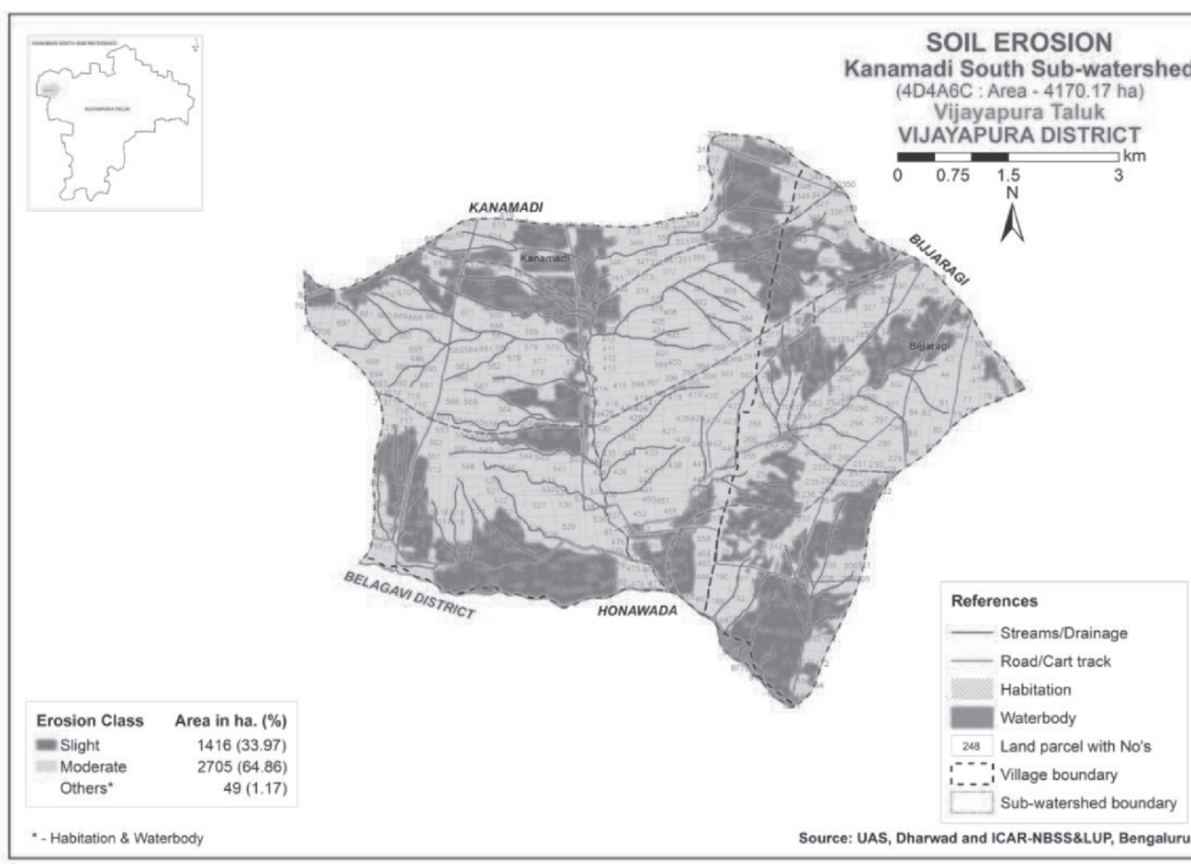


Fig. 5.1. Soil erosion potential of Kanamadi South sub-watershed

Land Use Land Cover Change Detectionby Geospatial technologies:

The two distinct but connected concepts of land usage and land cover are the two main features of the land.Land use relates to the objective for which a piece of land is utilized, whereas land cover describes the kind of cover that is present on a piece of land.Over the years, changes in land use and land cover (LULC) can be brought on by both natural and human-caused forces. Recently, however, the rate of change has accelerated due to fast urbanization and population growth.Decision-makers must therefore have information of past, present and future LULC in order to plan for land use more effectively (Palmate *et al.,* 2017a, b; Berihun *et al.,* 2019; Chamling and Bera 2020).Because it has contributed to an increase in natural disasters together with other anthropogenic activities, current global LULC change is a significant cause for concern.The location, kind and quantification of changes in LULC are all easily detected using remote sensing (R.S.) and geographic information system (GIS) approaches.For 40 years, from 1985 to 2015, Kalurav *et al.,* 2022 examined the LULC change of the Tons river basin, a subbasin of the Ganges river basin.The built-up area (0.34%) and open forest area both underwent significant change (1.42 percent).Other classes experienced less substantial changes.The recent rapid urbanization can be linked to the growth in the built-up area.The agricultural area's decline is primarily the result of it becoming more developed.Open forest is now taking the place of dense forest and shrubland.

Using remote sensing and geographic information systems, Swain et al. (2022) report an assessment of land use/land cover (LULC) changes over the Tehri watershed in the lower Himalayan region (GIS). With the aim of obtaining data on various LULC classes, imageries are gathered from the Landsat 5, Landsat 8 and Sentinel 2 satellites for the years 2008, 2014 and 2020, respectively. Remote sensing and GIS methods are used to extract LULC information from the imageries. In this work, various image processing and geospatial operations were carried out using the two softwares, ERDAS IMAGINE and ArcGIS. The sophisticated LULC classification uses multi-temporal remotely sensed imageries. Water features, agricultural land, dense forest, open forest, shrub land, settlement, barren land and snow are among the several types of land coverings that make up the catchment area. Most of the classes show significant LULC changes between 2008 and 2014, but between 2014 and 2020 there are no discernible changes in classes other than snow and arid terrain (Table 6.1). In contrast to a decline in dense forests and a rise in settlements, there has been an increase in open forests, water bodies, shrubland, snow, and settlements between 2008 and 2020.

Table 6.1: Areal coverage details of LULC classes over the Tehri catchment

Sl. No.	LULC class	2008		2014		2020	
		Area (km^2)	% Area	Area (km^2)	% Area	Area (km^2)	% Area
1	Open forest	648.5	8.89	713.5	9.78	712.7	9.77
2	Dense forest	2197.3	30.12	2140.4	29.34	2139.6	29.33
3	Water bodies	23.3	0.32	27.0	0.37	35.0	0.48
4	Shrubland	1691.7	23.19	1780.0	24.4	1773.4	24.31
5	Agriculturalland	176.5	2.42	172.9	2.37	171.4	2.35
6	Settlement	4.4	0.06	5.1	0.07	5.8	0.08
7	Barren land	1591.0	21.81	1486.7	20.38	1434.2	19.66
8	Snow	962.2	13.19	968.8	13.28	1022.0	14.01
Total		7295	100	7295	100	7295	100

REFERENCES

Akike S and Samanta S. (2016). Land use/land cover and forest canopy density monitoring of wafi-Golpu project area, Papua New Guinea. Journal of geosciences and Environment protection, 4: 1-14.

Ardak AS, Nagaraju MSS, Prasad J, Srivastava R, Barthwal AK (2010) Characterization and evaluation of land resources in Khapri village of Nagpur district, Maharashtra using high resolution satellite data and GIS. Agropedology 20:7–18

Berihun ML, Tsunekawa A, Haregeweyn N, Meshesha DT, Adgo E, Tsubo M, Yibeltal M et al (2019) Exploring land use/land cover changes, drivers and their implications in contrasting agroecological environments of Ethiopia. Land Use Policy 87:104052

Bhaduri D, Purakayastha TJ, Patra AK, Singh M, Wilson BR (2017) Biological indicators of soil quality in a long-term rice-wheat system on the Indo-Gangetic plain: combined effect of tillage–water–nutrient management. Environ Earth Sci 76(5):202

Biswas S, Hazra GC, Purakayastha TJ, Saha N, Mitran T, Roy SS, Basak N, Mandal B (2017) Establishment of critical limits of indicators and indices of soil quality in rice-rice cropping systems under different soil orders. Geoderma 292:34–48.

Bouamrane A, Bouamrane A, Abida H (2021) Water erosion hazard distribution under a semi-arid climate condition: case of Mellah Watershed, North-eastern Algeria. Geoderma 403:115381

Buchanan GM, Butchart SH, Dutson G, Pilgrim JD, SteiningerMK, Bishop KD, Mayaux P (2008) Using remote sensing to inform conservation status assessment: estimates of recent deforestation rates on New Britain and the impacts upon endemic birds. Biol Cons 141(1):56–66

Bünemann EK, Bongiorno G, Bai Z, Creamer RE, De Deyn G, de Goede R, Fleskens L, Geissen V, Kuyper TW, Mäder P, Pulleman M (2018) Soil quality – a critical review. Soil Biol Biochem 120:105–125

Burgess, T.; Webster, R. Optimal interpolation and isarithmic Mapping of soil properties. I. The semivariogram and punctual kriging. J. Soil Sci. 1980, 31, 315–331.

Cambardella, C. A., Moorman, T. B., Novak, J. M., Parkin, T. B., Karlen, D. L., Turco, R. F. and Konopka, A. E.,1994, Field-scale variability of soil properties in central lowa soils. Soil Sci. Soc. Am. J., 58: 1501-1511.

Chamling M, Bera B (2020) Spatio-temporal patterns of land use/land cover change in the Bhutan–Bengal foothill region between 1987 and 2019: study towards geospatial applications and policy making. Earth Syst Environ 1–14

D SOUZA A. 2021. Land Resource Inventorization of Kanamadi South Subwatershed of Tikota Hobli of Vijayapura District.University of Agricultural Sciences, Dharwad.

Das B, Singh S, Jain SK, Thakur PK (2021a) Prioritization of sub-basins of Gomti river for soil and water conservation through morphometric and LULC analysis using remote sensing and GIS. J Indian Soc Remote Sens 1–20

Das S, Deb P, Bora PK, Katre P (2021b) Comparison of RUSLE and MMF soil loss models and evaluation of catchment scale best management practices for a mountainous watershed in India. Sustainability 13(1):232

Denis, M. K. A., Sheikh, D. A. M., and Parameshgouda, L. P., 2015, Characterization of soils in hot semi-arid agro-ecological region of India: a case study of Singhanhalli-Bogur microwatershed in northern transition zone of Karnataka, AshEse J. Agric. Sci., 1(8): 54- 60.

Denis, M.K. A. and Parameshgouda, L. P., 2014, Soil quality under different land uses in hot semiarid agro-ecological region of India. Asian J. Soil Sci., 9(2):158-164.

Dwivedi R.S. (2001) Soil resource mapping: a remote sensing perspective. Remote Sens Rev 20:89–122.

Ezeaku PI (2015) Evaluation of agro-ecological approach to soil quality assessment for sustainable land use and management systems. Academic J 10(15):501–512

FAO/UNEP (1997). Negotiating a sustainable future for land - Structural and institutional guidelines for land resources management in the 21st century.FAO: Rome, Italy.

Farah A, Algouti A, Ifkirne M and Ezziyan A, 2021, Mapping of soil degradation in semi-arid environments in the ouarzazate basin in the south of the central High Atlas, Morocco, using sentinel- 2A data. *Remote Sensing Applications: Society and Environment*, *23*(1): 1-13.

Gajbhiye S, Mishra SK, Pandey A (2014) Prioritizing erosion-prone area through morphometric analysis: an R.S. and GIS perspective. Appl Water Sci 4(1):51–61

Gholizadeh A, Zizala D, Saberioon M and Boruvka L, 2018, Soil organic carbon and texture retrieving and Mapping using proximal, airborne and sentinel-2 spectral imaging. *Remote Sensing of Environment*, *218*(1): 89-103.

Gitas, I. Z, Douros, K, Minakou, C, Silleos, G. N. and Karydas, C.G, 2009, Multi-temporal soil erosion risk assessment in Chalkidiki using a modified USLE raster model. EARSeL eproc. pp. 25-35.

Govaerts B, Sayre KD, Deckers J (2006) A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. Soil Til Res 87(2):163–174

Hassinipak, A. A., 2007, Geostatistics. Tehran Univ. Press, p.314.

Hermiyanto, B., Zeobisch, M.A., Singh, G. and Agus, F. (2003). Soil quality of three small watersheds in central Java, Indonesia, Internat. J. Agric. Rural Dev., 4: 28-33.

Huang Y, Chen ZX, Tao YU, Huang XZ, Gu X.F. (2018) Agricultural remote sensing big data: management and applications. J Integr Agric 17(9):1915–1931

Kalura P, Pandey A, Chowdary V M and Raju P V (2022) Land Use Land Cover Change Detection of the Tons River Basin Using Remote Sensing and GIS. A Pandey, V M Chowdary, M D Behera and V P Singh (eds.) - Geospatial Technologies for Land and Water Resources Management, Springer Nature Switzerland AG. 53-66.

Karlen DL, Andrews SS, Doran JW (2001) Soil quality: current concepts and applications. Academic Press, Adva Agron, pp 1–40

Karlen DL, Ditzler CA, Andrews SS (2003) Soil quality: why and how? Geoderma 114 (3–4):145–156

Lin H, Bouma J, Pachepsky Y, Western A, Thompson J, Genuchten R, Van V, H.J., & Lilly, A. (2006) Hydropedology: synergistic integration of pedology and hydrology. Water Resour Res. https://doi.org/10.1029/2005WR004085 Behrens T and Scholten T. (2006). Digital Soil Mapping in Germany - a review. Journal of Plant Nutrition and Soil Science. 169(3):434-443.

Meti S, Lakshmi P D, Nagaraja M S and Shreepad V, 2019, Sentinel-2 and Landsat-8 bands sensitivity analysis for Mapping of alkaline soil in northern dry zone of Karnataka, India. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(1): 307-313.

Mukherjee A, Lal R (2014) Comparison of soil quality index using three methods. PLoS One 9(8)

Muller D, Munroe DK (2014) Current and future challenges in land-use science. J Land Use Sci 9(2):133–142. https://doi.org/10.1080/1747423X.2014.883731

Nagaraju M.S.S., Ganesh H.B., Srivastava R., Nasare R.A. and Barathwal A.K. (2015). Charecterazation and evaluation of land resources for management of Saraswati watershed in Buldhana district of Maharashtra. Indian Journal of Soil Conservation. 43(1):102-109.

Negash DA, Moisa MB, Merga BB, Sedeta F, Gemeda DO (2021) Soil erosion risk assessment for Prioritization of sub-watershed: the case of Chogo Watershed, Horo Guduru Wollega, Ethiopia. Environ Earth Sci 80(17):1–11

NRSA (National Remote Sensing Agency), 1995. Integrated mission for sustainable development – Technical guidelines. NRSA, Hyderabad. Pp.134.

NRSA (National Remote Sensing Agency), 2002. Integrated mission for sustainable development. Project report, NRSA, Hyderabad.

Palmate SS, Pandey A, Kumar D, Pandey RP, Mishra SK (2017b) Climate change impact on forest cover and vegetation in Betwa Basin, India. Appl Water Sci 7(1):103–114

Palmate SS, Pandey A, Mishra SK (2017a) Modelling spatiotemporal land dynamics for a transboundary river basin using integrated cellular automata and Markov Chain approach. Appl Geogr 82:11–23

Panday D, Maharjan B, Chalise D, Shrestha RK, Twanabasu B (2018) Digital soil mapping in the Bara district of Nepal using kriging tool in ArcGIS. PLoS ONE 13(10): e0206350. https://doi.org/10.1371/journal.pone.0206350

Pandey A, Bishal KC, Kalura P, Chowdary VM, Jha CS, Cerdà A (2021a) A soil water assessment tool (SWAT) modeling approach to prioritize soil conservation management in river basin critical areas coupled with future climate scenario analysis. Air, Soil Water Res 14:11786221211021396

Pandey A, Chowdary VM, Mal BC (2007) Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS, and remote sensing.Water Resour Manage 21(4):729– 746

Pandey A, Gautam AK, Chowdary VM, Jha CS, Cerdà A (2021) Uncertainty assessment in soil erosion modelling using RUSLE, multisource and multiresolution DEMs. J Indian Soc Remote Sens 49(7):1689–1707

Pandey A, Palmate S.S. (2018) Assessments of spatial land cover dynamic hotspots employing MODIS time-series datasets in the Ken river basin of Central India. Arab J Geosci 11(17):1–8

Parysow, P. W., Guangxing, G., George, A. and Alan., 2003, Spatial uncertainty analysis for mapping soil erodibility based on joint sequential simulation, Catena., 53: 65-78.

Potdar, S. S., Rajeev, S., Nagaraju, M. S. S., Jagdish, P. and Saxena, R. K., 2003, Mapping of erosional soil loss in Nanda-Khairi watershed of Nagpur district of Maharashtra using remotely sensed data and GIS techniques. Agropedology, 13(2): 10-18.

Qi Y, Darilek JL, Huang B, Zhao Y, Sun W, Gu Z (2009) Evaluating soil quality indices in an agricultural region of Jiangsu Province, China. Geoderma 149(3–4):325–334

Rao KV, Venkateswarlu B, Sahrawat KL, Wani SP, Mishra PK, Dixit S, Srinivasa Reddy K, Manoranjan Kumar and Saikia U.S. (Eds.). 2010. Proceedings of national workshop-cum-brain storming on rainwater harvesting and reuse through farmponds: Experiences, issues and strategies. 21-22 April 2009. CRIDA, Hyderabad, pp. 242.

Rao VV, Chakroborti AK, Vaz N, Sarma U (1994)Watershed Prioritization based on sediment yield modelling and IRS-1A LISS data. Asian-Pacific Remote Sens J 6(2):101–105

Reddy GPO, Nagaraju MSS, Ramteke IK, Sarkar D (2013) Terrain characterization for soil resource mapping in part of semi-tract of Central India using high resolution satellite data and GIS. J Indian Soc Remote Sens 41(2):331–343.

Saaty TL (1990) How to make a decision: the analytic hierarchy process. European J Operat Res 48:9–26

Sagar, N. I., Nagaraju, M. S. S., Nisha, S., Rajeev, S., Pramod, T., Sen, T. K. and Nasre, R. A., 2018, Mapping of spatial variability in soil properties and soil fertility for sitespecific nutrient management in Bareli watershed, Seoni district of Madhya Pradesh using geostatistics and GIS, Int. J. Curr. Microbiol. Appl. Sci., 7(10): 2299-2306.

Sahu N., Reddy GPO, Nirmal K., Nagaraju M.S.S., Srivastava R. and Singh S.K. (2014). Characterization of landforms and land use/land Cover in basaltic terrain using IRS-P6 LISS-IV and Cartosat-1 DEM data: A case study. Journal of Agropedology. 24(2):166-178.

Sankar M, Sivasamy R, Dadhwal KS (2010) Land resource data and its evaluation for village level land use planning. Agropedology 20:1–6

Satisha, G. C., Ulaganathan, A., Karthikakutty, M. and Nair, A. N. S., 2008, Erodibility assessment of rubber-growing soils of Kerala, India. Agropedology, 18(2): 116-123.

Schiewe J (2003) Concepts and techniques of geographic information systems. By CP Lo and Albert KW Yeung (Upper Saddle River, New Jersey: Prentice Hall, 2002).[pp. xii+ 492]. ISBN: 0-13-080427-4. Price U.S. $71 Hardback. Int J Geogr Inf Sci 17(8):819–820

Shaw S.K., Panda S., Londhe S. and Vinod V.H. (2015). Remote sensing and GIS for natural resource inventory of hilly terrain-acase study of Kakrorasa subwatershed, Ranchi district, Jharkhand. International Journal of Scientific Engineering and Applied Science. 1(3): 122-131.

Shinde, V. K., Tiwari, N. and Singh, M., 2010, Prioritization of micro watersheds on the basis of soil erosion hazard using remote sensing and Geographical Information System. Int. J. Water Res. Environ. Eng., 2(3):130-136.

Singh S. (2014). Land Irrigability Classification for Mohanrao Watershed using Remote Sensing and GIS. International Journal of Remote Sensing and GIS. 3(1): 21-27.

Singh, G., Babu, R., Narain, P., Bhushan, L. S. and Abrol, I. P.,1992, Soil erosion rates in India. J. Soil. Water. Conserv.,47(1) :97- 99.

Singh, M. J. and Khera, K. L., 2008, Soil erodibility indices under different land uses in lower Shiwaliks. Trop. Ecol., 49(2): 113-119.

Sofi JA, Bhat AG, Kirmai NA, Wani JA, Lone AH, Ganie MA, Dar GI (2016) Soil quality index as affected by different cropping systems in northwestern Himalayas. Environ Monit Assessment 188(3):161

Srinivasan R, Karthika KS, Suputhra SA, ChandrakalaM, Hegde R (2021) Mapping of soil erosion and probability zones using remote sensing and GIS in Arid part of South Deccan Plateau, India. J Indian Soc Remote Sens 1–17

Stefanoski DC, de Figueiredo CC, Santos GG, Marchão RL (2016) Selecting soil quality indicators for different soil management systems in the Brazilian Cerrado. Pesquisa Agropecuaria Brasileira 51(9):1643–1651

Sujata, B., 2012, Estimation of soil erosion using remote sensing and GIS and Prioritization of catchments. Int. J. Emerging Tech. Adv. Engg., 2(7): 2250- 2459.

Swain S, Mishra S K and Pandey A (2022) Appraisal of Land Use/Land Cover Change Over Tehri Catchment Using Remote Sensing and GIS. A Pandey, V M Chowdary, M D Behera and V P Singh (eds.) - Geospatial Technologies for Land and Water Resources Management, Springer Nature Switzerland AG. 37-52.

Viscarra Rossel RA, Walvoort DJJ, McBratney AB, Janik LJ, Skjemstad JO (2006) Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties.Geoderma 131(1–2):59–75.https://doi.org/10.1016/j.geoderma.2005.03.007

Wang D, Laffan SW, Liu Y,Wu L (2010) Morphometric characterization of landform from DEMs. Int J Geogr Inf Sci 24(2):305–326

Webster, R. and Oliver, M. A., 2007, Geostatistics for environmental scientists. John Wiley and Sons, Chichester, UK.

Wischmeier, W. H. and Smith, D. D., 1958, Predicting rainfall-erosion losses from cropland west of the rocky mountains: a guide for selecting practices for soil and water conservation. USDA Agricultural Handbook No. 282. U.S. Dept. Agric. Sci. Edu. Adm., Washington DC, USA.

Wischmeier, W. H. and Smith, D. D., 1978, Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook No. 537. U.S. Dept. Agric. Sci. Edu. Adm., Washington DC, USA

Yang L, Meng X, Zhang X (2011) SRTM DEM and its application advances. Int J Remote Sens 32(14):3875–3896

Zhou H, Sun J, Turk G, Rehg JM (2007) Terrain synthesis from digital elevation models. IEEE Trans Visual Comput Graphics 13(4):834–848.

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Bio engineering forsoil and water conservation

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ABSTRACT

Land use changes and management have resulted in land degradation problems worldwide. Land degradation is estimated to affect 3.5 Bha, or 23.5% of the global land area. Soil erosion is the major contributor for land degradation. While it contributes to 32 per cent of the global land degradation problem - in China, Africa and Europe its contribution has been reported to be nearly 31 per cent, 16 per cent and 17 per cent, respectively(Bai ZG, et.al 2008)

Globally 56 % of the degraded land (1100 million ha) is affected due to water erosion and 28 per cent due to wind erosion.

It is estimated that in India120.4 Mha (45 % of total geographical area) is degraded through one or more degradation types; the earliest assessment of the area affected by land degradation, made by the National Commission on Agriculture, was 148 Mha). Subsequently, the Ministry of Agriculture (Soil and Water Conservation Division) estimated it 175 Mha. The National Bureau of Soil Survey and Land Use Planning (NBSS &LUP) projected an area of 187 Mha as degraded lands in 1994, and revised it to 147 Mha in 2004. The National Wasteland Development Board estimated an area of 123 Mha as wastelands. The estimates vary as these were not based on standard and uniform criteria and methodology (Anon.2022)

In India erosion problem contributes to nearly 70 per cent of the degradation problem, and water erosion's share is 63 per cent. The next major degradation is due to chemical deterioration with a contribution of around 15 per cent.

Water Erosion: Estimated soil loss due to water erosion:

Soil erosion by water is one of the most severe degradations in the Indian context. Existing soil loss data were analyzed, and it was concluded that soil erosion was taking place at an average rate of 16.35 t ha-1 yr-1totalling 5334 MT yr-1..(Milkha S. Aulakh))

The estimated soil loss due to water erosion in different regions of the country, as reported three decades ago, is as below:

- The annual water erosion rate values ranged from less than 5 Mg/ha/yr for the dense forest, snow-clad cold deserts, and the arid region of western Rajasthan to more than 80 Mg/ha/yr in theShiwalik hills.
- Ravines along the banks of the Yamuna, Chambal, Mahi, Tapti, and Krishna Rivers and in the shifting cultivation regions of Orissa and the northeastern states also revealed soil losses exceeding 40 Mg/ha/yr
- The annual erosion rates in Western Ghats coastal regions varied from 20 to 30 Mg/ha
- Erosion rates in the country's black soil region (vertisols), occupying a 64-million-ha area in Karnataka. Andhra Pradesh, Madhya Pradesh, and Maharashtra states generally were 20 Mg/ha/yr.
- Red soils of Chhota Nagpur plateau also recorded a soil loss value of 10 to 15 Mg/ha/yr. The northwestern hills of Jammu and Kashmir, Himachal Pradesh, and Uttar Pradesh and the northeastern hills of Bengal and the northeastern states contribute more than 20 Mg/ha/yr.
- The Himalayas and the Doon Valley foothills produced 20 Mg/ha/yr of soil loss.

- Erosion rates on alluvial Indo-Gangetic Plains of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal are moderate (5-10 Mg/ha/yr).
- The salt-affected saline and sodic soils of these plains were within limits of 5 Mg/ha/yr(Singh, G., R. et.al. 1992)

Combating soil erosion through appropriate flora selection: There are many ways to prevent the degradation of soils and reclaim/rejuvenate the degraded soils. These include physical, chemical, mechanical and biological methods.

Vegetative bunds: Among different methods of runoff control measures, vegetative bunds play an important role. But the necessity of vegetative bunds is dependent on the seasonal rainfall. It will be more effective when the seasonal rainfall is more than 750mm.

Vegetative Barriers: Vegetation that can form a thick hedge established along contours can obstruct surface water flow. As a result, soil particles settle on the upstream side and filtered relatively clear water oozes through the barrier more uniformly across the field at decreased velocity.

Vegetative hedges act as barriers to runoff flow, which slow down the runoff velocity resulting in the deposition of eroded sediments and increased rainwater infiltration. Species of vegetative barrier to be grown, number of hedge rows, plant-to-plant spacing and method of planting are very important and should be decided based on the main purpose of the vegetative barrier (Pathaketal).

The Glyricidia plants grown on bunds not only strengthen the bunds while preventing soil erosion but also provide N-rich green biomass, fodder and fuel. The cross-section of earthen bund can also be reduced. (P Pathak et.al),

Vetiver roots for increasing soil strength: The potentiality of vetiver grass in improving different parameters of soil strength in a land slide-prone area has been established by Sawant etal.(2017) Generally, the region's dominant grass or shrub species should be preferred for the vegetative barrier.

Himalayan range: Through selection of appropriate crops and cropping, the soil loss through water erosion can be reduced, Shardaetal, 2009outlined present generation vegetative measure technologies for soil conservation/watershed intervention for the Indian Himalayan Region.

In the western Himalayan region (Dehradun) : Vegetative barriers have been reported (Birendra Nath Ghosh (2011) to reduce the runoff losses and soil losses to the tune of 18-21 and 23-68 per cnt, respectively. Under different slopes varying from 2 to 8 per cent further, the maize-wheat crop equivalent yield and net returns also increased considerably due to the vegetative barriers and the increase in net profit. Provision of the vegetative obstacles could increase the net gain to about € 135, 95 and 52 per hectare per year on 2, 4 and 8 % slopes, respectively. Guinea grass and Khuskhus grass are more effective than Babbar in reducing erosion and soil deposition. On-site fodder availability, particularly during the winter season, is an additional advantage without sacrificing the yields of maize or wheat crops.

At Dehradun, Uttarakhand, in the Indian Himalayan region, in a 2% slope condition. Soil loss and runoff were significantly lower ($P < 0.05$) in plots under palmarosa vegetation strips than without vegetation strip treatment. Mean soil loss of 3.4, 5.2 and 7.1 t/ha was recorded from palmarosa, panicum and without vegetative strips (VS) treated plots, respectively. Mean runoff was 234, 356 and 428 mm from plots under palmarosa+, panicum and without VS, respectively. Maize yield is higher in vegetation strips plot over control. The succeeding rainfed wheat yield was significantly greater in plots under palmarosa followed by panicum and without vegetation strips (Sur, and Sandhu, 1994)

Vegetative barriers decreased runoff and sediment loss in the order of kanna (Saccharum munja) >Napier> bajra hybrid (Pennisetum purpureum) > vetiver (Vetiveriazizanioides) >babbar (Eulalioposisbinata) > without barrier

In another study, vetiver barriers,as an inter-terrace treatment on an average reduced runoff by 19% and soil loss by 41%, compared with no barriers.

Arid zone of Rajasthan: For reduce soil erosion and improve moisture storage, the arid zones of Rajasthan Central Arid Zone Research Institute suggested different vegetative barriers

Sharma et al. (1997) reported that because of contour vegetative barriers (CVB with Cymbopogon jwarancusa, Cenchrus ciliaris and Cenchrus setigerus), the runoff volume was reduced by 28 to 97%. The CVB plots stored about 2.5 times more soil moisture than control and improved theclusterbean and pearl millet yield by 37-51% and 19-40% over control, respectively.

In another study, vegetative barriers of different grasses were established at a horizontal interval of 30 m, and pearl millet was sown in between. For the cumulative rainfall of 105 mm only, about 36.5, 72.1 and 54.2% higher moisture storage was observed as compared to control under the alleys of Cenchrus anguistifolia, Lasirussindicus and Saccharum munja, respectively. The average yield of pearl millet improved by 39.1% over control (CAZRI, 1998)

Semi-arid condition of middle Gujarat: A field study was conducted at Vasad, Gujarat, India, from 2014 to 2017 to evaluate the efficacy of selected bioengineering treatments on cotton crop production and runoff and soil loss (Krishna Rao *et al.,* 2022).

- The filter strip of Guinea sp. at 2 m width was most effective, reducing runoff by 30%, soil loss by 66%, nutrients loss by 69%, sediment concentration to 1/3rd, and soil organic carbon loss by 65%.
- The lowest runoff coefficient value of 0.209 observed among the filter strips in this treatment indicated about 79% of rainwater was conserved in situ.
- The available soil nutrients increased by up to 42%, SOC concentration by 61%, and cotton equivalent yield by 25% more than the conventional system.
- It was concluded that Guinea grass filter strips of 2 m width planted at 45 m spacing in cultivable lands having 2% slope minimized runoff, soil loss, nutrient loss, improved soil fertility and enhanced cotton productivity.

In middle Gujarat: D. annulatum can be used as a filter in watercourses to prevent runoff and soil losses from crop fields and thereby reducing the sedimentation of downstream water bodies. The optimum grass coverage, i.e. 50% of the channel length, can maintain maximum grass production with minimum soil loss.The experimental results reveal that the grass filter strips can reduce the sediment concentration in the runoff water by six times (from 4.2 to 0.65 g/L). The filter strips can reduce the runoff water's velocity by two times (from 1.06 to 0.47 m/s) and convert the supercritical flows into subcritical flows. The filter strips can increase the Manning's coefficient from 0.0323 to 0.1006 under various discharges. Krisna Rao etal.2014.

Western Ghat region : A field experiment was conducted on lateritic soil of Western Ghat region in Goa State.The study revealed that the bioengineering measures influenced cashew's runoff, soil and nutrient losses, and growth parameters. The runoff reduction varied from 3.2 to 7.6% of the annual rainfall under different conservation treatments. Minimum run-off(3.5%) and soil loss (3.7 t/ha/year) were recorded under the treatment viz. continuous contour trench + Vetiveriazizanioides + Stylosanthesscabra. Minimum Nitrogen (13.95 kg/ha) and phosphorous (16.53 kg/ha) losses were recorded till the treatment of continuous contour trenches with Stylosanthesscabra and Vetiveriazizanioides. Growth performance of cashew was better under the combination of vegetative barriers with continuous contour trenches, graded trenches and staggered contour trenches. Overall, continuous contour trenches with Stylosanthesscabra and Vetiveriazizanioides was found to be the best soil and water conservation treatment among all other bioengineering measures for cashew plantations in Western Ghat region.(Manivannan et.al 2007)

Konkan area of Western Maharashtra: Mane et al. (2009) evaluated the effect of four different grasses on the run off and soil losses in the steep slope of Konkan area (table 10)

The maximum runoff control efficiency (%) and soil loss control efficiency (%) was achieved by graded bund + vetiver grass (T7). Thus, graded bund plus vetiver grass conserved basic resource i.e. soil and water significantly along with minimum losses to the resources. It has also sustained productivity of ragi crop on sloping agricultural lands which is be of immense benefit for the region.

Hyderabad Telengana: Experiments conducted at ICRISAT, Hyderabad, with grass slipsatdiffeent slope conditions revealed that:

When 1, 2, and 3% slopes were treated with a 2 m strip of Brachiariaruziziensis and Stylosantheshamata at the lower end of the field, a 2 m strip of Brachiariaruziziensis and Stylosantheshamata at the lower and upper ends of the experimental plot

- Soil loss from the field was reduced by 65% and 70% downstream of the 2 m grass strips on the upper and lower slopes for the four observation seasons Soil loss was limited to 1500–1000 kg/ha, whereas it reached 2000 and 2500 kg/ha when no grass strip was sown in all the slopes.
- Soil quality like, soil organic carbon, available nitrogen, phosphorous, potassium, micronutrients and macronutrients, soil aggregates, infiltration, etc. improved due to grass strip on the slopes The fields with grass strips improved in their soil quality from 0.39 to 0.52 in over the measured period of time. The combination of runoff infiltration
- Brachiaria strips at the upper and lower sides of a field resulted in higher BC ratios in 1per cent (2.50 in deficit rainfall years and 3.38 in normal rainfall years) 3per ecent (2.59 deficit ranfall years and 3.42 in normal rainfall years) slopes, In strips of Stylosanthes at the upper and lower sides had 2.66 (deficit rainfall years) and 3.50 (normal rainfall years) at a 2 per cent slope. Castor–redgram rotations in cropping systems with stripped grass on the upper and lower sides of the slopes fetched better crop production.

Karnataka: Trials on the live hedge with khus (Vetiver) at Kabbalanala Watershed in Karnataka indicated high moisture availability in the root zone in plots with live hedge, resulting in higher crop yields compared to the control. In another study, Krishnegowdaet al.(1990) reported that using vegetative barriers as inter-terrace management markedly decreased soil losses. Soil erosion was 1.86 t/ha on the khus vegetated bund, 2.24 t/ha on the Pennisetum hohenackeri bund and 3.2 t/ha on the control plot.

North West Tamilnadu: An experiment was conducted during 2007–2009 in the farmer's field in the Nilgiris, the Northwestern part of Tamil Nadu to evaluate different bioengineering measures in conserving runoff and soil loss under new tea plantation (Sahu *et al.,*2014)

- Minimum runoff of 112.2 mm in contour staggered trenches (CST) with cover crop of beans followed by CST (118 mm) was obtained in the slope range 8–12%. The trend remained same in the slope of 30–35%.
- Minimum soil loss was found in the treatment under CST (4.9 t ha^{-1} yr^{-1}) followed by CST with cover crop of beans (5.3 t ha^{-1} yr^{-1}) in 8–12% slope. Similar trend with about 25% more annual soil loss in treatments under 30–35% slope was observed due to higher percentage of runoff (23.7%).
- Variation in tea canopy due to treatment effect was observed in post monsoon period with maximum (34.5%) in CST with cover crop of beans and CST (35.6%) in 8–12% and 30–35% slope, respectively showing the effect of CST in canopy development.
- Northeastern Ghat zone of Odisha: Mishra et al. (1999) studied different vegetative barriers, including vetiver, napier, jatropha and agave, planted at 8 m intervals in the northeastern Ghat zone of Odisha during 1994. Vetiver proved to be the most efficient vegetative barrier in conserving soil and water. It decreased runoff by 20.3% and soil loss by 51.4% and increased soil moisture storage by 26.6% compared with the control.

WIND EROSION:

Wind erosion is a natural process that moves soil from one location to another by wind power. It can cause significant economic and environmental damage.

Management and Control of Wind Erosion:

Wind erosion can be managed in two major ways - either by decreasing soil erodibility or by reducing the erosive energy of wind, which can be achieved by erecting barriers.

Five major control measures include:

- Sand-dune stabilization,
- Surface cover,
- Wind breaks and shelterbelts;
- Tillage; and
- Crop Management (e.g., mixed cropping, intercropping and strip cropping systems)

Sand dune stabilization: Sand dunestabilization is necessary to prevent the movement of the sand long enough to enable either natural or planted vegetation to become established. Sand dune fixation is a unique sector of soil conservation with specific techniques.

Since 1961 CAZRI has developed sand dune stabilization techniques. The steps used in dune stabilization are:

- protection from biotic interferences,
- erection of micro windbreaks in the form of checker board or parallel strips
- establishment of a vegetation cover through direct seeding or by transplanting of adapted species and
- after care of the newly established dune.

Dune stabilization prevents sand drift and can also be turned in to an economic activity by providing 15–20 t/ha of wood five years after plantation.

All these practices are designed to either absorb some of the wind energy and/or trap sediment.

Afforestation of dunes: Afforestation of dunes needs be done to stabilize them. Any of the two methods can do this: (a) by direct seeding and (b) by transplanting. Transplanting has been found to be more advantageous.

Planting suitable vegetation on denuded dune surfaces decreases surface wind speeds, prevents scouring action and ameliorates soil conditions, which improves micro-climatic conditions. In view of the limited water, high percolation rates, high ambient temperatures and high potential evapo-transpiration rates in arid regions, it is important to select plants with the ecological ability to survive in such demanding situations.

Basically, they should be able to survive in (i) extreme temperature conditions; (ii) a variety of salinity conditions; (iii) variable speed and direction of wind; (iv) severe sand storm events; (v) very low soil moisture conditions (i.e. xerophytes); and (vi) biotic stress situations.

Much research effort has been devoted to wind erosion control in the Thar Desert of India.Most of these studies reported sand-dune stabilization by vegetation cover using the checkerboard method, which became a popular wind erosion control technology in the region.

The suggested vegetation for different rainfall situations are as below

Micro wind breaks: Affected dunes must be treated by fixing micro windbreaks across the wind direction in parallel strips or in checker board design at the spacing of 2 m apart on the crest and, 5 m apart on the middle and heel of dunes to save the seedlings from the over deposition of moving sands or frorp the exposure of roots. For erecting the micro-wind breaks the locally available bushes like Zizyphusnummularia, Crotolariaburhia, Leptadeniapyrotechnica, Calotropis proqera, etc. are used.

More recently Pratap Narainetal. (2005) suggested that locally available brushwood such as Crotalaria burhia, Leptadeniapyrotechnia, Ziziphus nummularia, Callgonumpolygonoides, Lasiurus sindicus, Panicum turgidum, Erianthusmunja can be used to bury vertically downwards in lines 2m to 3m apart on windward slope of a dune in arid areas.

Surface Cover: Use of surface cover is another technology to control wind erosion. Thecover may be either vegetative or non-vegetative. Protection of the land surface through the vegetative surface cover of grasses or crops is perhaps the most effective, easy and economical method.

Grasslands of Lasiurus Sindicus and Cenchrus Ciliaris and maintenance of cover crops such as Citrullus Colocynthis have major roles in decreasing wind erosion on sandy plains. In addition to the standing vegetation, crop residues are often placed artificially on the soil to provide temporary cover until establishment of permanent vegetation. Permanent grass cover in rangelands is more effective than crop cover, as it exists in the field for short periods only. Among crops, dense row crops and creeping crops are more preferable.

Grass cover in rangeland management with grass cover it is important to see that the grazing is properly controlled. The aeolian mass transport rate was almost three-times more at the overgrazed site than at the controlled grazing site from mid-June to mid-July, as observed from a field study at two grazing situations in the Thar Desert(Mertia*et al.,* 2010)

Strip cropping: Strip plantation of crops and grass or shrub with fodder value, is useful for control of wind and water erosion. The strips' plants are chosen so they do not compete for moisture, nutrients, etc. The width of strips depends on the type of soil and crop. On the sandy loam soil in arid areas, the strips may vary from 6 to 30 m. Strips of Lasiurus sindicus(Sewan grass) and Ricinus communis (castor) between two rows of kharif crops help to reduce wind erosion and increase crop production.

The perennial grass strips of *L. sindicus*,*Cenchrus biflorus* and *Pennisetum turgidum* reduce wind erosion and help form surface crusting which binds the soil particles. Jindal et al. (1990) reported that clusterbean, cowpea and mothbean crops failed when grown with Acacia tortilis, while these crops performed better in association with Prosopis cineraria and Tecomellaundulata..

Wind Breaks and Shelterbelts:

To minimize the erosion hazards of speedy winds and optimize agricultural production, various efforts have been made in the past by adopting different soil and water conservation measures. The shelterbelt plantation has been found to be an essential technology to minimize erosion hazards and increase farm productivity through moderation of the micro-environment at the field level, Adoption of shelterbelts on farm in the arid region of western Rajasthan is considered as one of the most important technological intervention for minimizing the harmful effects of strong winds on one hand and increasing the farm productivity on the other hand through moderation of micro-environment at field level.

Shelterbelt technology in IGNP canal: Shelterbelt technology is a must especially in the wind erosion-prone IGNP canal (Stages I and II). Some progress has been made in this direction

- The Central Arid Zone Research Institute (CAZRI), Jodhpur has developed sustainable tested technology. CAZRI has recommended a three-row wind break of Acacia tortilis, Cassia siamea and Prosopis sp. as the side rows and Albizzia lebbek as the central row.

CAZRI, suggests to plant trees and vegetative hedges, on field boundaries across the direction of wind. This also serves the purpose of protecting crops from the animals etc

Shelterbelt technology is widely adopted in the Thar Desert, where water resources are available either through the tube-well command area (*e.g.,* Lathi series in Jaisalmer) or the Indira Gandhi Nahar Project (IGNP) command area. About 20% of the total 20,000 ha tube-well irrigated area in villages of the Lathi series has been put under shelterbelts, whereas only 5% of 9.25 lac ha area of IGNP-Phase II is covered with such plantations (Mertia,2006)

Shelter belts for canal protection: Sitation of the canals due to wind erosion is a major problem in arid areas prone to wind erosion. Adoption of shelterbeds will be a boon to reduce this menace. Te shelter bed technology has been found to reduce the sand deposition in IGNP canal network

Impact and economics of shelterbelts: Creation of tree shelterbelts along farm boundaries has been proven beneficial in protecting crops from extreme weather and improving field microclimates. Shelterbelt technology is also adopted by IGNP canal command area authorities and road maintenance engineering staff. Sand deposition in IGNP canals has been considerably decreased by planting tree shelterbelts along canals. The corresponding savings on removing deposited sand is estimated to be Rs 6156–12,276 per km. The problem of road blockage by blowing sand has also been considerably avoided by planting trees along roadsides by the General Reserve Engineering Force (GREF) in Jaisalmer.

Economics of shelterbelt in a cropping system: The economics of shelterbelts under tube well irrigated and canal irrigated situations over the unsheltered condition in Rajasthan was reported by Mertia et.al. 2006.

It is clearly seen that when compared to control, the net returns wassignificantly higher due to shelterbelts. The dense shelterbelt recorded more returns than the partial shelterbelt. Between the two crops, the additional benefit from shelterbelt was more under groundnut than mustard.

Soniet al.(2013)have reported that in Bikaner, strip cropping of Cenchrus cilliaris with clusterbean in a 5:15 meter row: width ratio decreased the soil loss 9 and 4.5fold during 2006 and 2007 respectively. It was 67.5 and 33.0 t/ha during 2006 and 2007 under no strip cropping while it was 7.5 t/ha under strip cropping during both the years.

The economics of shelter belt inJaisalmer district (Mertia et.al. 2006)indicated an increase of 430.8 per cent in the net returns due to shelterbelt plantation, in which shelterbelt technology alone has contributed about 399 per cent of the returns.

Micro shelterbelts: Wind erosion in agricultural fields may also be controlled using micro-shelterbelts of tall growing crops. In this method, a few rows of relatively tall crops (e.g., pearl millet (*Pennisetum glaucum*), sesame (*Sesamum indicum*) or castor (*Ricinus communis*) are sown 15–20 m from relatively short crops to shelter them. Such short crops include mung bean (Vigna radiata), cluster bean (*Cyamopsistetragonoloba*) and groundnuts (Arachishypogaea).

Economics of micro shelterbelt: The impacts of micro-shelterbelts have been studied by Gupta et.al (1984) at ICAR-Central Arid Zone Research Institute, Jodhpur. Three rows of pearl millet could increase the summer yield of cowpea and okra by 21% and 44%, respectively, compared with unsheltered crops. Sheltered fields provided additional income from pearl millet fodder.

CHEMICAL DEGRADATION

Salt affected Soil Management:

According to a recent estimate, India accounts for 6MHa of salt affected soils, which occur mostly in arid, semi-arid and sub humid regions of the country. In some instances, the land has gone out of cultivation due to salinity, alkalinity, or both. These lands are categorized as wastelands. Normally these soils are reclaimed through physical, chemical and biological methods

Grasses for soil reclamation:

Apart from this many grasses due to its voluminous fiber root system play an important role in reducing salinity/ sodicity of the soil.

Some studies conclude that the cultivation of Karnal grass, with or without gypsum application, leads to steady reductions in pH and ESP of degraded sodic soil (Batra et al. 1997; Kumar et al. 1994).

Kumar and Abrol reported the ameliorative effect of grasses on crop production in rice-wheat system (Table15)

Growing of either of the grasses for two years comprehensively inversed the productivity of both crops, better than gypsum application. Between the two Karnal grass was better.

The grasses like D. pinnata and Rhode grass were also found to be effective in reducing the pH and increasing the organic C as well as dehydrogenase activity in the alkali soils of Karnal (Batra and Kumar, 1992).

Gatton panic grass as an ameliorant crop: As early as in 1990s, gatton panic was identified as the most suitable grass for reclaiming heavy coastal salt-affected soils of South Gujarat. It was observed that subsequent to the growing of this grass for a couple of years, the land could be brought to arable condition while nothing could be grown unreclaimed. Suitable land configurations were developed for cultivating this crop as a rainfed one in the unreclaimed coastal salt-affected soils of South Gujarat. (Anon.1995). The results are presented in table 16

In general, narrow bed width and deeper furrow enhanced the reclamation process in the presence of gatton panic grass (Anon. 1995).

Different crops were evaluated as subsequent crops after bio reclamation through gatton panic at the coastal salt affected soils of South Gujarat.

It is seen that both cotton and sorghum performed reasonably well under those conditions, with a net return of 9.8 and 4.3 thousand rupees, respectively. Castor could not thrive. All three crops failed in the unreclaimed condition.

Verma *et al*., 2010 evaluated five different grass species to assess their suitability as a biological reclaiming agent and vegetative barriers for reclaiming and reducing soil erosion and enhancing in situ water conservation in moderate sodic clay soil. The order of performance for Adoption of different grass species with regards to fodder and commercial value for sodic Vertisols was Marvel grass (Dichanthiumannulatum), Para grass (Brachiriamutia), Napier (Pennisetum perpurium), Karnal (Diplachnefusca) and Vetiver (Vetiveriazizinoides). Planting of these grasses in sodic clay soils protect natural resources (sediment and nutrient losses) and help reclaim these soils.

In an 8-year field trial on alkali soil (Singh,1995), growth and biomass production of Prosopis juliflora was more significant in the sole stand than when interplanted with the grassLeptochloafusca. But soil improvement was greater for the mixed tree-grass treatment. Less salt tolerant but more palatable fodder crops such as Trifoliumresupinatum, T. alexandrium and Melilotusdenticulata were successfully grown with Prosopis. TheProsopis-Leptochloa system combines production with biological reclamation, and is an appropriate system for reclamation agroforestry of alkali lands.

Medicinal and aromatic plants:

Yadav et al. (2018) reported the beneficial effect of some aromatic and medicinal plants

It is seen that all four crops have the potential to ameliorate the soil. But the effect of 2 year old palmarosa was superior to others could ameliorate the soil especially in lowering the soil salinity.

Jatropha, a potential biodiesel plant, has been observed to be a very good crop to reclaim sodic soils (Singh, et al. 2013). After six years (2011) of plant growth, though seed yield was not economically viable; however, soil properties like Soil bulk density, pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP) decreased and soil organic carbon (SOC), nitrogen (N), phosphorus (P), microbial biomass (MB-C, MB-N and MB-P) and enzyme activities (dehydrogenase, â-glucosidase and protease) increased significantly. The soil pH, EC and ESP has been noticed to decrease from 8.6 to 7.6, 1.29 to 0.98 dSper meter and 20.7% to 13.8%, respectively.

Trees:

Three separate field experiments were conducted at Agricultural Research Station, Danti Dist.: Navsari (Gujarat) with Acacia auriculiformis, Casurinaequisetifolia and Prosopis juliflora. At the end of three years, all three tree species have beneficial effects on the hydraulic conductivity, bulk density, water stable aggregates, organic carbon content, EC, pH and ESP of the heavy textured salt-affected soils (Anon., 1994 and 1995).

Similar types of beneficial effects with P. Juliflora, eacalyptus, a nilotica, Dalbargia sissoo on pH and organic C content in the loamy soils of Karnal were also reported by Batra and Kumar (1992). They have also reported increase in microbial activity as judged by dehydrogenase activity in salt affected soil as compared to barren alkali soils.

Singh *et al.* (2011) noticed that Prosopis juliflora, Acacia niloticaand Casuarina equisetifoliaplantations significantly reduced soil pH, EC, ESP, and increased SOC and available NPK than control soil (pH2: 8.8-10.5, ESP: 85-92). Further, they also observed that these trees improved the soil physical condition(table19)

All the physical properties like B.D, soil porosity and cumulative infiltration rate improved due to the growing of the different tree species. Among them P. juliflora and C. equisetifolia were better than others

Halophytes:

Phytodesalination using halophytes will be a sustainable approach in the field of agriculture in saline lands, and it will also be helpful for the reclamation of salt-affected lands.

Several halophyte species, including grasses, shrubs, and trees, can remove the salt from different kinds of salt-affected problematic soils by excluding, excreting, or accumulating. Walter has classified halophytes based on their mode of action (Table21).Based on a study made in Haryana, Mishra and Sangwan (2016) inferred that Chenopods, particularly Suaedanudiflora, Suaedafruticosa all the three Atriplex spp., Haloxylonrecurvum, Salsola baryosma and to some extent Portulaca oleracea (Portulacaceae) were able to phytoremediate the saline soils very efficiently and effectively.

However, the use of halophytes for soil reclamation is still in an exploratory stage. Only a few field studies for bio-reclamation of saline soil using halophytes have been carried out so far; therefore, more research is needed study the utilization of halophytes to remove excess salinity added by irrigation.

Bio Drainage:

In drainage engineering, bio drainage is a process wherein the transpiration requirement of a crop is met by withdrawing groundwater. Alternatively, drainage can be defined as the "pumping of excess soil water by deep-rooted vegetations through evapo-transpiration using their bio-energy". Bio-drainage could be a viable option for lowering water table in a water-logged area as most prevalent in canal command areas. It is a combined drainage-cum-disposal system. Biodrainage can be defined as the "pumping of excess soil water by deep-rooted vegetations through evapo-transpiration using their bio-energy"

Case Studies on Bio Drainage in India:

Large-scale adoption of bio drainage is very less in India. Some of the successful adoptions are outlined below:

Bio drainage in waterlogged areas of Haryana: Studies were conducted on abandoned waterlogged degraded land in Haryana, India to lower down water table found trees like Eucalyptus hybrid, Eucalyptus tereticornis C10, Eucalyptus tereticornis C-130 and Prosopis juliflora fast bio drainers, Eucalyptus tereticornis C-3, Callistemon lanceolatus and Melia azedarach in the category of medium biodrainers whereas Terminalia arjuna and Pongamia pinnata slow bio drainers. Tree species vary in their 'biodrainage potential' as evidenced by the extent of lowering of water table immediately beneath the plantations. Eucalyptus species have a higher bio drainage potential than relatively slow biodrainers like T. aphylla and P. pinnata. Even within Eucalyptus, E. tereticornis C-10 being far more efficient than E. tereticornis C-3. In absence of pit plantation in water logged fields, a ridge or bund plantation technique has been successfully followed. Leaf area was found to be a cardinal component of drainage potential. (Toky et al., 2011).

Biodrainage in Indira Gandhi Nahar Project, Rajasthan, India:

To protect the canal form sand drift and meet the timber, fuel and fodder need of the locals, plantations were raised in the area. The afforestation schemes included canal side plantation, block plantation, sand dune stabilization, pasture development, roadside plantation and environmental plantation. The main trees planted in irrigated areas were Eucalyptus camaldulensis, Dalbergia sissoo and Acacia nilotica, whereas Prosopis cineraria, Tecomellaundulata and Ziziphus in unirrigated areas. Lasiurus sindicus grass was planted for pastures and in between mulch lines for stabilization of sand dunes. Along the canal, the width of the plantation was 100m on the right side and 200 m on the left. Amongst different trees, growth of Eucalyptus camaldulensis was the fastest whereas Prosopis cineraria was the slowest. Plantations made along the canal and around the submerged areas removed excess water through bio-drainage and the groundwater table fell by about 15 m after six years. As a result, inundation disappeared from most of the affected areas. Considering the annual rate of transpiration of 3000 mm, for maintaining water balance roughly 5% of the area needs tree plantation. Sharma, K.D. 2001

In another location of the Indira Gandhi Nahar Project (IGNP), Rajasthan (India) tree plantations established along the canal lowered the groundwater table by 14 m in six years (Kapoor, 2001).

Eucalyptus based agroforestry system for waterlogged soils at Puthi, Haryana, India:

Two plantations 350 m apart comprising 18 years old Eucalyptus tereticornis (Mysure gum) raised at a spacing of 3m x 3m along the road and railway line on alluvial sandy loam soil at Dhob-Bhali, Rohtak (Haryana), lowered groundwater table by 0.91 m but no increase in salinity underneath the plantations than the groundwater table underneath the adjacent fields without plantation Ram et al. (2007).

The spatial extent of lowering of groundwater table in the adjacent fields was up to a distance of more than 730 m from the edge of a plantation.

Eucalyptus tereticornis (Mysure gum) spaced at 66 m and each strip-plantation contained two rows of trees at a spacing of 1m x 1m resulting in a density of 300 plants ha-1 lowered the groundwater table underneath the strip-plantations by 85 cm compared to adjacent unvegetated fields in 3 years (Ram et al., 2011)

After effective results shown by the bio-drainage system in checking waterlogging in Haryana, the Punjab Government is replicating the bio-drainage system in 3000 hectares of waterlogged area in Muktsar district (The Tribune, 19th April, 2013).

Biodrainage for reclamation of waterlogged deltaic lands of Orissa,

Biodrainage potential of Casuarinas on land at two sites with groundwater table at 102 and 127 cm in coastal delta, Orissa suffering from waterlogging due to seawater intrusion and Eucalyptus at another two sites on waterlogged soils having groundwater at 150 and 167 cm, respectively caused due to topographical depression were compared by Roy Chowdhury, et al (2011). At all four sites, the effects of bio-drainage plantation on the water table were clear and lowered by 15 to 25 cm compared to the non-vegetated area.

As far as the efficiency of drainage by plantation or tree water use per se is concerned, a more significant decline of the water table underneath Eucalyptus was observed compared to Casuarina. This accelerated drainage has helped the farmer to advance *rabi*cultivation by a period of 15-20 days. Due to this, farmers were able to take watermelon in Casuarina and groundnut in Eucalyptus plantations and earned additional benefits. Roy Chaudhury *et al.,* 201.

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Sustainable management of inland systems for restoring and sustaining soil health and recarbonization of the terrestrial biosphere (Online lecture)

Padma Shri Dr. Rattan Lal

Distinguished University Professor of Soil Science and Director, CFAES Rattan Lal Center for Carbon Management and Sequestration at The Ohio State University, USA

Rattan Lal, Ph.D., is a Distinguished University Professor of Soil Science and Director of the CFAES Rattan Lal Center for Carbon Management and Sequestration at The Ohio State University, as well as an Adjunct Professor of University of Iceland and the Indian Agricultural Research Institute (IARI), India. He received a B.S. from Punjab Agricultural University, Ludhiana, India (1963); M.S. from Indian Agricultural Research Institute, New Delhi, India (1965); and Ph.D. from the Ohio State University, Columbus, Ohio (1968). He served as Sr. Research Fellow with the University of Sydney, Australia (1968-69), Soil Physicist at IITA, Ibadan, Nigeria (1970-87), and Professor of Soil Science at OSU (1987 to date). He has authored/co-authored over 1000 refereed journal articles and more than 550 book chapters, has written and edited/co-edited more than 100 books. He was included in the Thomson Reuters list of the World's Most Influential Scientific Minds (2014-2016), and he is among Clarivate's Highly Cited Researchers in Agriculture (2014-2021), as well as ranked #1 in Agronomy and Agriculture overall, #34 globally for the year 2020, and #73 globally for career from 1973-2020 among the top 2% of scientists by Stanford's Ioannidis (2019, 2020, 2021). He has received an Honoris Causa degree from nine universities throughout Europe, USA and Asia; the Medal of Honor from UIMP, Santander, Spain (2018); the Distinguished Service Medal of IUSS (2018); and is fellow of the five professional societies. Dr. Lal has mentored 115 graduate students and 182 visiting scholars from around the world. He was President of the World Association of Soil and Water Conservation (1987-1990), International Soil and Tillage Research Organization (1988-1991), Soil Science Society of America (2006-2008), and the International Union of Soil Sciences (2017-2018). He is Chair in Soil Science and Goodwill Ambassador for Sustainability Issues for the Inter-American Institute for Cooperation on Agriculture (IICA), and member of the 2021 United Nations Food Security Summit Science Committee and Action Tracks 1 & 3. Dr. Lal is laureate of the GCHERA World Agriculture Prize (2018), Glinka World Soil Prize (2018), Japan Prize (2019), U.S. Awasthi IFFCO Prize (2019), Arrell Global Food Innovation Award (2020), World Food Prize (2020), and India's Padma Shri Award (2021).

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Remediation strategies of heavy metals in soil ecosystem

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ABSTRACT

The accumulation of toxic elements in soils is an important issue because it deteriorates the soil-water ecosystem safety, affecting agricultural products, water quality, and animal and human health. Various in situ (on-site) and ex-situ remedial methods have been used to restore soils contaminated with heavy metals. These include excavation and landfilling, solidification, stabilization, thermal treatment, electrokineticreclamation, phytoextraction, phytovolatilization, soil washing etc.These general approaches can be used for many types of contaminants. Still, the specific technology selected for the treatment of a metals-contaminated site will depend on the form ofthe contamination and other site-specific characteristics.One or more of these approaches are often combined for more cost-effective treatment. A number of the available technologies have been demonstrated in full-scale applications and are commerciallyavailable presently.A comprehensive list of these technologies is available (USEPA, 1996). Several other technologies are being tested for application to metals-contaminated sites. Use of microorganisms, hyper accumulator plants, or other biological systems offers cost-effective and environment-friendly metal cleanup methods. Studies on bacterial diversity in heavy metal contaminated sites have demonstrated a high diversity of microorganisms adapted to the new environment. Bacteria resistant to and grow on metals play an important role in the biogeochemical cycling of those metal ions. In pursuit of identifying bacteria that are tolerant to different heavy metals and can have potential in bioremediation.

INTRODUCTION

Heavy metalsare generally defined as metals with relatively high densities, atomic weights, or atomic numbers. Examples of heavy metals include mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), lead (Pb), nickel (Ni), iron (Fe), zinc (Zn) and copper (Cu). Remediation refers to the environmental clean up of contaminated sites and the techniques to reduce or eliminate contamination from soil or groundwater. Remediation is generally subject to an array of regulatory requirements. It can also be based on assessments of human health and ecological risks where no legislated standards exist or where standards are advisory. The removal techniques developed over the years can be divided into physical, chemical and biological. Heavy metal pollution is a great concern for the environment and human health, especially in developing countries like India. Owing to their toxic, non-degradable and bio-accumulative nature, the health burden on the population has increased significantly.

Heavy metals are naturally occurring hazardous metals with a density greater than 4 g/cm3 (Tchounwou et al., 2012). These metals are used in several industries and agricultural activities, leading to increased environmental contamination and human exposure. Due to anthropogenic activities, deep-buried heavy metals in the earth's crust have now been exposed in the air, agricultural soil and drinking water.

Various metals, like chromium, aluminium and iron are essential for multiple biochemical and physiological processes in plants and animals, but they can become toxic when ingested in large amounts. Nearly 718 districts have contaminated groundwater with arsenic, cadmium, chromium, and lead (Mohan, 2018). Arsenic-contaminated groundwater covers significant states such as Bihar, West Bengal, Uttar Pradesh, Jharkhand, Assam, Manipur, and Chhattisgarh (WHO,2019).Industrialization is one of the significant contributors of contamination to sites like Vadodara (Gujarat), Ranipet (Tamil Nadu), Talcher (Orissa), Ratlam (Madhya Pradesh), Ganjam (Orissa), Singrauli (Madhya Pradesh), Balai (Uttar Pradesh) and Malanjkhand (Madhya Pradesh) (Dotaniya and Jayanta, 2016).

Recently, high concentrations of heavy metals like As, Cd, Cu, Pb and Zn in soil have been reported in several countries. e.g. significant adverse impacts of As on human health have been recorded in Bangladesh, India and China, and it is claimed that millions of people are potentially at risk from As poisoning. Similarly, Cd accumulation in the system (mainly kidney and liver) of grazing animals in New Zealand and Australia made it unsustainable for human consumption. It affected access to meat products overseas (Robert *et al.*, 1994).

UNEP reported that2 billion hectares of once biologically productive land has been irreversibly degraded due to contamination and inaccessibility in the past 100 years (Adejumo, 2010).Such contamination threatens sustainable agricultural development and food security in developing countries. Heavy metals can affect the quality of agricultural soils, including phytotoxicity and transfer of heavy metals to the human diet from crop uptake.

SOURCES OF HEAVY METALS TO AGRICULTURAL SOILS:

There are two ways by which heavy metals reach agricultural soils i. e. pedogenic (geogenic) and anthropogenic.

1. **Geogenic or pedogenic:**

Soils are derivative of parent material, so naturally, if parent material is rich in one or two heavy metals, they will be inherited to the soil in due course of soil development. Since their mobility is lower due to higher densities, they accumulate in soils over the years. For example, if the parent material is rich in As, like pyromorphite, so the soils will be contaminated with As.

2. **Anthropogenic:**

1. **Industrialization:** The advancement of technology and industries led to higher metal concentration in the wastewater**e.g.** Chromium is found to be higher in effluents of textile industries, Cd contamination is another problem by effluents of Zn smelting industries etc.
2. **Waste disposal:** Increasing population results into the generation of waste which is one of the sources of heavy metals in agricultural soils
3. **Urban effluents:** Wastewater out of metropolitan cities contains higher amounts of heavy metals, often used as a source of irrigation water for crop production in peri-urban areas.
4. **Agricultural activities:** Adding fertilizers and applying pesticides to increase crop production simultaneously adds heavy metals to soils.
5. **Mining and smelting plants**
6. **Waste incineration:** Direct combustion of waste to produce ash for their disposal contains heavy metals, and the addition of such material causes heavy metal contamination.
7. **Traffic emissions:** Fuel containing heavy metals like Pb is emitted after combustion of such fuel and deposited in nearby areas.
8. **Military activities:** Explosions
9. **Atmospheric deposition**

METALS AT CONTAMINATED SITES

Contamination of heavy metals in India has been observed across the nation. Nearly718 districts have contaminated groundwater with arsenic, cadmium, chromium andlead (Mohan, 2018). Arsenic-contaminated groundwater covers major states such asBihar, West Bengal, Uttar Pradesh, Jharkhand, Assam, Manipur and Chhattisgarh (WHO,2019). On the other hand, polluted air and crop fields have also been reported, especiallyselenium toxicity, in 9% of people in Hoshiarpur and Nawansahar districts of Punjab(Jamwal, 2015). Industrialization is one of the significant contributors to the contamination of sites like Vadodara (Gujarat), Ranipet (Tamil Nadu), Talcher (Orissa), Ratlam (MadhyaPradesh), Ganjam (Orissa), Singrauli (Madhya Pradesh), Balai (Uttar Pradesh) andMalanjkhand (Madhya Pradesh) (Dotaniya and Jayanta, 2016). Ganga, the national riverof India, is polluted with chromium, copper, nickel, leadand iron (Pandey et al. 2019).Ministry of Environment, Forest and Climate Change (MoEF&CC) has identified 320locations with a high probability of contamination with heavy metals (Cr, Pb, Hg, As and Cu)and pesticides in India, as represented in Figure 1 and Table 1.

Figure 2: Location of the 320 probably contaminated sites in India (Adopted from, MoEF&CC, 2015)

Table 1: Location of the 320 probably contaminated sites in India

Sr. No.	States	No of sites
1	Uttar Pradesh	40
2	West Bengal	36
3	Odisha	31
4	Delhi:	28
5	Karnataka	24
6	Gujarat	23
7	Jharkhand	14
8	Tamil Nadu:	13
9	Kerala	11
10	Telangana	9
11	Punjab	9

Source: (Adopted from, MoEF&CC, 2015)

SOIL CONCENTRATION RANGES AND REGULATORY GUIDELINES FOR SOME HEAVY METALS

The Department of Petroleum Resources (DPR-EGASPIN, 2002) has recommended guidelines for remediation of contaminated land based on two parameters intervention values and target values (Table 2). The intervention values indicate the quality for which soil functionality for human, animal and plant life is or threatened with being seriously impaired. Concentrations over the intervention values correspond to severe contamination. Target values indicate the soil quality required for sustainability or expressed in remedial policy, the soil quality needed for the complete restoration of the soil's functionality for human, animal and plant life.

Table 2: Target and intervention values for some metals for standard soil

Metal	Target value (mg kg^{-1})	Intervention value (mg kg^{-1})
Ni	140.00	720.0
Cu	0.30	10.00
Zn	-	-
Cd	100.00	380.00
Pb	35.00	210.00
As	200	625
Cr	20	240
Hg	85	530

Source:DPR-EGASPIN, 2002

FATE AND MOBILITY OF HEAVY METALS

The fate and transport of metal in soil depend significantly on the chemical form and speciation of the metal (Allen *et al.*, 1994). The mobility of metals inground-water systems is hindered by reactions that cause metals to adsorb or precipitate or chemistry that tends to keep metals associated with the solid phase and prevent them from dissolving. These mechanisms can retard the movement of metals and providea long-term source of metal contaminants (NRC, 1994).The chemical form and speciation of some of the more important metals found at contaminated sites are discussed below. The influence of chemical structure on fate and mobility of these compounds is also discussed.

Lead

Lead is a primary industrial source of contamination; it include metal smelting and processing, secondary metals production, lead battery manufacturing, pigment and chemical manufacturingand lead-contaminated wastes. Widespread contamination due to the former use of lead in gasoline is also of concern. Theprimary processes influencing the fate of lead in soil include adsorption, ion exchange, precipitation and complexation with sorbed organic matter. These processes limit the amount of lead that can be transported into the surface water or groundwater. The relatively volatileorgan lead compound, tetramethyl lead may form in anaerobic sediments due to alkylation by microorganisms (Smith *et al.,* 1995).

Chromium

Chromium (Cr) is one of the less common elements and does not occur naturally in elementalform but only in compounds. Chromium is mined as a primary ore product in the form ofthe mineral chromite, FeCr2O4. Major sources of Cr contamination include releases fromelectroplating processes and the disposal of chromium-containing wastes (Smith *et al.,*1995). Cr(VI) is the form of chromium commonly found at contaminated sites. Chromium can alsooccur in the +III oxidation state depending on pH and redox conditions. Cr (VI) is thedominant form of chromium in shallow aquifers where aerobic conditions exist. Chromium (VI) canbe reduced to Cr(III) by soil organic matter, S2-and Fe2+ ions under anaerobicconditions often encountered in deeper groundwater. Major Cr(VI) species include chromate (CrO42-)and dichromate (Cr2O72-), which precipitate readily in the presence of metal cations(especially Ba2+, Pb2+, and Ag+). Chromate and dichromate are also adsorbed on soil surfaces,especially iron and aluminium oxides. Chromium (III) is the dominant form of chromium at low pH(<4). Chromium (III) forms solution complexes with NH3, OH-, Cl-, F-, CN-, SO42-, and soluble organicligands. Chromium (VI) is the more toxic form of chromium and is also more mobile. Chromium (III) mobilitydecreased by adsorption to clays and oxide minerals below pH 5 and low solubility above pH 5 due to the formation of Cr(OH)3(s) (Chrotowski et al., 1991).

Chromium mobility depends on sorption characteristics of the soil, including clay content,iron oxide content and the amount of organic matter present. Chromium can be transportedby surface runoff to surface waters in its soluble or precipitated form. Soluble and

Unadsorbed chromium complexes can leach from soil into groundwater. The leachabilityof Cr(VI) increases as soil pH increases. However, most chromium released into natural waters isparticle-associated and is ultimately deposited into the sediment (Smith et al., 1995).

Cadmium

Cadmium (Cd) occurs naturally in the form of CdS or CdCO3. Cadmium is recovered as aby-product from the mining of sulfide ores of lead, zinc and copper. Sources of cadmium contamination include plating operations and the disposal of cadmium-containing wastes(Smith *et al.,* 1995).The form of cadmium encountered depends on the solution, soil chemistry, and waste treatment before disposal. The most common forms of cadmium include Cd2+, cadmium-cyanide complexes or Cd(OH)2 solid sludge (Smith et al., 1995). Hydroxide(Cd(OH)2) and carbonate (CdCO3) solids dominate at high pH, whereas Cd2+ and aqueoussulfate species are the dominant forms of cadmium at lower pH (<8). Under reducingconditions, the stable solid CdS(s) is formed when sulfur is present. Cadmium will alsoprecipitate in the presence of phosphate, arsenate, chromate and other anions, althoughsolubility will vary with pH and other chemical factors.Sorption is also influenced by the cation exchangecapacity (CEC) of clays, carbonate minerals, and organic matter in soils andsediments. Under reducing conditions, precipitation as CdS controls the mobility ofcadmium (Smith et al., 1995).

Arsenic

Arsenic (As) is a semi-metallic element that occurs in a wide variety of minerals, mainly asAs2O3 and can be recovered from the processing of ores containing mostly copper, lead, zinc,silver and gold. It is also present in ashes from coal combustion. Arsenic exhibits fairlycomplex chemistry and can be current in several oxidation states (-III, 0, III, V) (Smith *et al.,*1995).

In aerobic environments, As(V) is dominant, usually in arsenate (AsO43-) invarious protonation states H3AsO4, H2AsO4-, HAsO42-, AsO43-. Arsenate and other anionicforms of arsenic behave as chelates and can precipitate when metal cations are present(Bodek et al., 1988). Metal arsenate complexes are stable only under certain conditions.Arsenic (V) can also coprecipitate or adsorb onto iron oxyhydroxides under acidic andmoderately reducing requirements. Coprecipitates are immobile under these conditions butarsenic mobility increases as pH increases (Smith *et al.,* 1995).

Under reducing conditions As(III) dominates, as arsenite (AsO33-) and its protonatedforms: H3AsO3, H2AsO3-, HAsO32-. Arsenite can be absorbed or co-precipitated with metal sulfidesand has a high affinity for other sulfur compounds. Elemental arsenic and arsine, AsH3,may be present under extreme reducing conditions. Biotransformation (via methylation) ofarsenic creates methylated derivatives of arsine, such as dimethyl arsine Has(CH3)2 andtrimethylarsine-As(CH3)3, which are highly volatile.

Mercury

The primary source of mercury is the sulfide ore cinnabar. Mercury (Hg) is usually recovered as a by-product of ore processing (Smith et al., 1995). The release of mercury from coal combustion is a major source of mercury contamination. Massage from manometers at pressure measuring stations along gas/oil pipelines also contributes to mercury contamination.

After releasing to the environment, mercury usually exists in mercuric (Hg2+), mercurous (Hg+), and elemental mercury or alkylated form (methyl/ethyl mercury). The redox potential and pH of the system determine the stable forms of mercury that will be present. Mercurous and mercuric mercury are more stable under oxidizing conditions. When mildly reducing conditions exist, organic or inorganic mercury may be reduced to elemental mercury, which may then be converted to alkylated forms by biotic or abiotic processes. Mercury is most toxic in its alkylated forms which are soluble in water and volatile in the air (Smith et al., 1995).

Hg(II) forms strong complexes with various inorganic and organic ligands, making it very soluble in oxidized aquatic systems (Bodek et al., 1988). Sorption to soils, sedimentsand humic materials is an important mechanism for removing mercury from solution. Sorption is pH-dependent and increases as pH increases. Mercury may also be removed from the solution by coprecipitation with sulfides (Smith et al., 1995). Under anaerobic conditions, organic and inorganic forms of mercury may be converted to alkylated formats by microbial activity, such as by sulfur-reducing bacteria. Elemental mercury may also be formed under anaerobic conditions by demethylation of methyl mercury or by reduction of Hg(II). Acidic conditions (pH<4) also favour the formation of methyl mercury, whereas higher pH values favour precipitation of HgS(s) (Smith *et al.,* 1995).

REMEDIATION STRATEGIES OF HEAVY METAL-CONTAMINATED SOILS

Heavy metals in soils are in the form of cations and retained on soil particles by electrostatic attraction or forming chemical bonds with organic or inorganic ligand ions. The overall objective of any soil remediation approach is to create a final solution that protects human health and the environment.Remediation is generally subject to an array of regulatory requirements. It can also be based on assessments of human health and ecological risks where no legislated standards exist or where standards are advisory.

The physical and chemical form of the metal contaminant in soil strongly influencesthe selection of the appropriate remediation treatment approach.

Several technologies exist for the remediation of metals-contaminated soil and water. These Technologies are contained within five categories of general approaches to remediation: solation, immobilization, toxicity reduction, physical separation and extraction. These arethe same available approaches used for many types of contaminants in the subsurface (LaGrega *et al.,* 1994). As is usually the case, combinations of one or more of theseapproaches are often used for more cost-effective treatment of a contaminated site. Table3 summarizes vital factors discussed in this paper that influenced theapplicability and selection of available remediation technologies.

Table3: Technologies for remediation of heavy metal contaminated soil

Soil washing	The process separates coarse soil (sand and gravel) from fine soil (silt and clay), where contaminants tend to bind and sorb. This soil fraction must be further treated with other technologies.
Soil vapor extraction	Involves the installation of wells in the area of contamination. Vacuum is applied through the wells to evaporate the volatile constituents of the contaminated mass, which are subsequently withdrawn through an extraction well. Afterwards, the extracted vapours are adequately treated.

Soil flushing	"Floods" contaminate soils with a solution that moves the contaminant to an area where they can be removed. Soil flushing is accomplished by passing an extraction fluid through soils using an injection or infiltration process. Recovered fluids with absorbed contaminants may need further treatment.
Solidification	Encapsulates the waste materials in a monolithic solid of high structural integrity.
Stabilization/immobilization	Reduces the risk posed by waste by converting the contaminant into a less soluble and immobile one.
Vitrification	It uses a powerful source of energy to "melt" soil at extremely high temperatures (1600–2000 oC), immobilizing most inorganics into a chemically inert, stable glass product and destroying organic pollutants by pyrolysis.
Electrokinetics	Removes contaminants from soil by application of an electric Field.
Thermal desorption	Contaminated soil is excavated, screened, and heated to temperatures such that the boiling point of the contaminants is reached, and they are released from the soil. The vaporized contaminants are often collected and treated by other means.
Encapsulation	Physical isolation and containment of the contaminated material. Low permeability caps or walls isolate the impacted soils to limit the infiltration of precipitation.

BIOREMEDIATION

Remediation means getting rid of an issue, and if it is associated with taking care of an ecological issue like soil and groundwater contamination is called bio-remediation. Bioremediation is a mechanism which utilizes the living microorganisms to reduce natural contaminations or to anticipate contamination. It is an evolution towards eliminating toxins from the climate, reestablishing the first characteristic environmental factors and forestalling further contamination. Bioremediation also can be permanent in situ solution for contamination instead of simply translocating the problem. Remediation of heavy metals, metalloids, or other inorganic pollutants from soil or water can be done by this technique. It is a cost-effective, efficient, novel, eco-friendly, and solar-driven technology with good public acceptance compared to other engineering techniques.

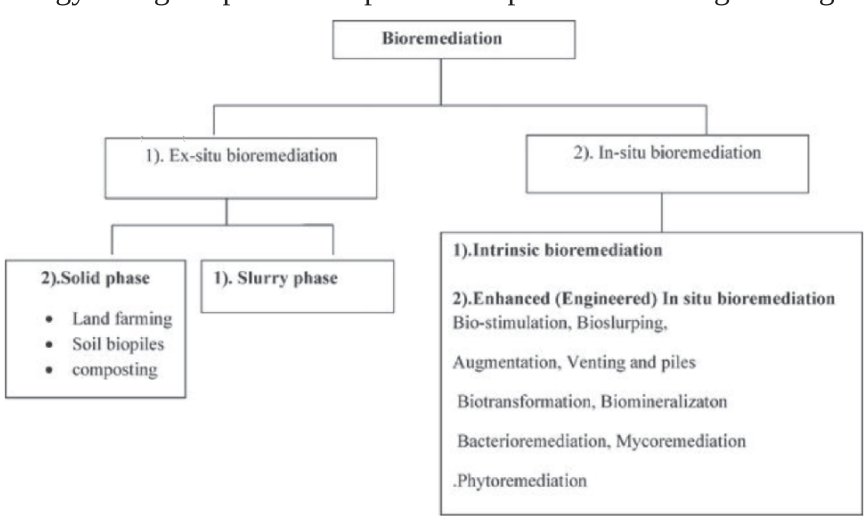

Table 4: Various yeast, bacterial and algal species used for metal biosorption

Microorganism	Metal adsorbed
Yeast	
Saccharomyces cerevisiae	**Uranium**
Saccharomyces cerevisiae, Kluyveromyces fragilis	**Cadmium**
Saccharomyces cerevisiae	**Methyl mercury and Hg(II)**
Bacteria	
Bacilluspolymyxa	Cu
Bacilluscoagulens	Cr (VI)
Eschereriacoli	Hg
Eschereriacoli	Cu, Cr, Ni
Pseudomonasspecies	Cr(VI),Cu(II),Cd(II),Ni(II)
Algae	
Chlorellaemersonii	Cd
Sargassummuticum	Cd
Ascophyllumsargassum	Pb, Cd
brownseaweeds	Cr
Eckloniaspecies	Cu(II)

Source: Hima *et al*. (2007)

ISOLATION AND IDENTIFICATION OF HEAVY METAL TOLERANCE ACTERIA FOR BIOREMEDIATION OF HEAVY METALS

The decontamination of polluted land through the application of immobilized microbial enzymes and the use of resistant microorganisms like bacteria, fungi and vesicular-arbuscular mycorrhizae are ecologically and economically sound. The isolates to resist heavy metals and samples were collected from Ankleshwar and Ahmedabad and promising bacterial isolates using cultural and morphological characteristics for microbiological traits.

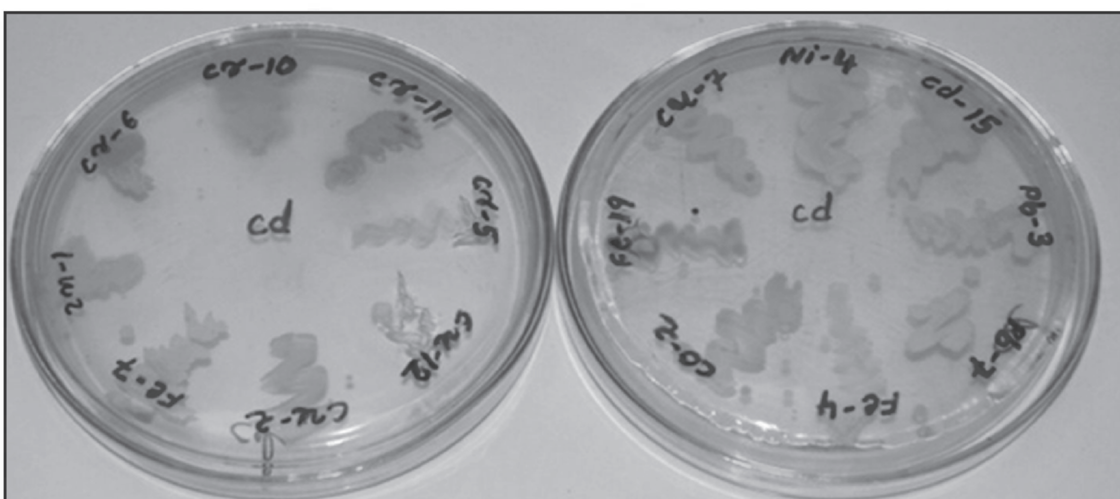

Fig.2: Colonial appearance of Heavy Metal resistant isolates on media supplemented with cadmium (3 ppm)

Screening of isolated 56 bacteria of different locations of Ahmedabad, Kheda, Ankleshwar Vadodara-Bharuch districtwas done at AAU, Anand, Gujarat for screening of different heavy metal tolerance (individually) and multi heavy metal tolerance by 16 S rRNA sequencing. It is characterized as Pseudomonas azotoformans, Bacillus infantis, Bacillus megaterium, and Micrococcus terreus.p as heavy metal tolerant bacteria (Anon.,2021).

Indigenous organisms can adopt themselves according to the prevailing environments and could flourish under these conditions (Haq and Shakoori, 2000). Some microorganisms have developed variety of mechanisms to deal with high concentrations of heavy metals and usually is specific to one or a few metals (Piddock,2006).

Raja et al.(2006) performed a study for the isolation and characterization of metal tolerant Pseudomonas aeruginosa strain and found that isolate showed biosorption potential against all four tested metals (Cd, Cr, Pb and Ni) and the biosorption pattern was found as: Cr (30%) < Cd (50%) < Pb (65%) < Ni (93%).

Heavy metals' microbiological transformations are oxidation, reduction, methylation and demethylation reactions. The enzymatic systems of microorganisms take part in reactions. Practically useful may be reactions of significantly toxic or valuable metal reduction, like bacteria Grampositive isolated from tannery sewers, caused the reduction of highly toxic chromium (VI) to less toxic chromium (III), which may be removed from the environment (Kisielowskaet al., 2010).

PHYTOREMEDIATION

Phytoremediation refers to the specific ability of plants to aid in metal remediation. Someplants have developed the ability to remove ions selectively from the soil to regulate theuptake and distribution of metals. Most metal uptake occurs in the root system, usually viaabsorption, where many mechanisms are available to prevent metal toxicity due to the highconcentration of metals in the soil and water. Potentially useful phytoremediationtechnologies for remediation of metals-contaminated sites include phytoextraction, phytostabilization and rhizofiltration (US EPA, 1996).

Phytoextraction

Phytoextraction employs hyperaccumulating plants to remove metals from the soil byabsorption into the roots and shoots of the plant. A hyperaccumulator is defined as a plantwith the ability to yield 0.1% chromium, cobalt, copper or nickel or 1% zinc, manganesein the aboveground shoots on a dry weight basis. The aboveground shoots can be harvestedto remove metals from the site and subsequently disposed of as hazardous waste or treatedfor the recovery of the metals.

Phytostabilization

Phytostabilization involves using plants to limit the mobility and bioavailability of metalsin soil. Phytostabilizers are characterized by high tolerance of metals in surrounding groundsbut the low accumulation of metals in the plant. This technique may be used as an interimcontainment strategy until other remediation techniques can be developed or as treatmentat sites where other methods would not be economically feasible.

Rhizofiltration

Rhizofiltration removes metals from contaminated groundwater via plant roots' absorption, concentrationand precipitation. This technique is use to treat contaminated water ratherthan soil and is most effective for large volumes of water with low levels of metal contamination. Terrestrial plants are more effective than aquatic plants because they develop a more extended, more fibrous root system that provides a larger surface area for interaction. Wetlands construction is a form of rhizofiltration that has been demonstrated as costeffective treatment for metals-contaminated wastewater.

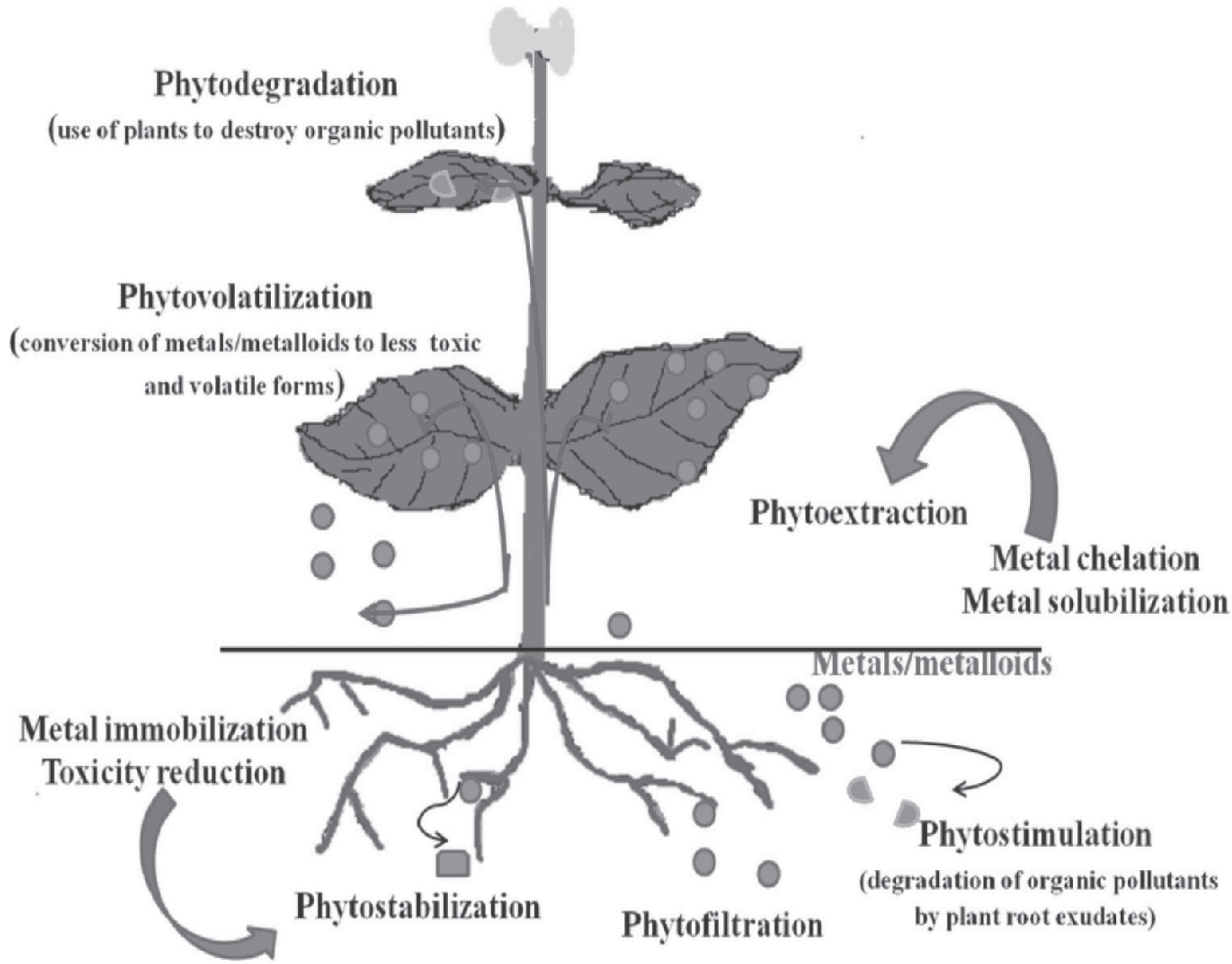

Table 5: Some metal hyper accumulating plants

Agronomical plants	**Common Weed**
Perennial Ryegrass	Hemp dogbane
Sunflower	Ragweed
Pea	Lowly weed
Forage Brassica	
Tarnip	
Rape	
Tyfon	
Other plants	
Leptospermum scoparium.	*Sutera fodina*
Sporbolus pectinatus H	*Dicoma niccolifera*
Cassinia spp	*Leptospermum scoparium*
Phragmites karka	*Arabidopsis thaliana*
Bacopa monnieri	*Scirpus lucustris*

Source: Chhonkar (2004)

Phytostabilization

Phytostabilization involves the use of plants to limit the mobility and bioavailability of metalsin soil. Phytostabilizers are characterized by high tolerance of metals in surrounding soilsbut low accumulation of metals in the plant. This technique may be used as an interimcontainment strategy until other remediation techniques can be developed, or as treatmentat sites where other methods would not be economically feasible.

Table 6: Important and widely reported hyper-accumulators used for metal remediation

Heavy metals	Plant species	Maximum reported concentration (ppm)
Cd	*Thlaspi caerulescens*	500
Cu	*Ipomoea alpina*	12300
Co	*Haumaniuastrum robertii*	10200
Pb	*Brassica juncea, Zea mays*	8200
Ni	*Alyssum lesbiacum, Sebertia acumunata*	47500
Cr	*Brassica juncea, Helianthus annus*	1400

Source: Chhonkar (2004)

CONCLUSION

Background knowledge of the sources, chemistry and potentialrisks of toxic heavy metals in contaminated soils is necessaryto select appropriate remedial options. Remediationof soil contaminated by heavy metals is necessary to reduce the associated risks, make the land resourceavailable for agricultural production, and enhance food securityand scale down land tenure problems. Immobilization, soilwashingand phytoremediation are frequently listed amongthe best available technologies for cleaning up heavy metalcontaminated soils but have been mostly demonstratedin developed countries. These technologies are recommendedfor field applicability and commercialization in developing countries where agriculture, urbanizationand industrialization are leaving a legacy of environmentaldegradation.

REFERENCE

Adejumo, S. A., Togun, A. O., Adediran, J. A. andOgundiran, M. B. (2010). Effects of compost application on remediation and the growth of maize planted on lead-contaminated soil. In Conference proceedings of 19th World Congress of Soil Science, Soil Solutions for a Changing World,99-102.

Anonymous (2021). All India Coordinated Research Project on Micro - and Secondary Nutrients and Pollutant Elements in Soils and Plants, Anand Centre, AAU, Anand Gujarat.

Allen, H.E., Perdue, E.M. and Brown, D.S.(1994). Metals in groundwater.CRC-Lewis Publishers,

Bodek, I., Lyman, W.J., Reehl, W.F. and Rosenblatt, D.H. (1988). Environmental Inorganic Chemistry: properties, processes and estimation methods.Pergamon Press,

Chhonkar, P. K. (2004).Phytoremediation: A 'Green Cure' for heavy metal contaminated soils.Journal of the Indian Society of Soil Science, 52(4), 357-373.

Chrotowski, P., Durda, J.L. and Edelman, K.G. (1991). The use of natural processes for the control of chromium migration.Remediation. 2, 341-351.

Dotaniya, M. and Jayanta, S. (2016) Heavy metal polluted soils in India: status and countermeasures.JNKVV Research Journal,49, 320–337.

DPR-EGASPIN (2002). Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN), Department of Petroleum Resources, Lagos, Nigeria

Haq, R, Shakoori, A. R., (2000). Microorganisms resistant to heavy metals and toxic chemicals

as indicators of environmental pollution and their use in bioremediation. Folia Biol 48:143–147

Hima, K. A., Srinivasa, R. R., Vijaya, S. S., Jayakumar, S. B., Suryanarayana, V. and

Venkateshwar, P. (2007). Biosorption: An eco-friendly alternative for heavy metal removal. African Journal of Biotechnology, 6(25), 2924-2931.

Jamwal, N. (ed.). (2015). The selenium scourge in Punjab. Details available at:

https://www.downtoearth.Org.in/news/the-selenium-scourge-in-punjab-10900,last accessed on 30 May, 2019.

Kisielowska, E., Holda, A. and Niedoba, T. (2020). Removal of Heavy metals from coal medium

with application of Biotechnology methods. Gornictwo I Geoinzynieria, 34, 93-104.

LaGrega, M. D., Buckingham, P.L. and Evans, J. C. (1994). Hazardous waste management.

McGraw Hill, New York.

Ministry of Environment, Forest and Climate Change (MOEF & CC). 2015. Inventory and

Mapping of probably contaminated sites in India. Task 1: Existing data and general information on contaminated sites Final report. COWI

Mohan,V. (2018). Across India, high levels of toxins in groundwater. The Times of India.

Details available at across-india/articleshow/65204273.cms, last accessed on 2 June, 2019

NRC (1994). Alternatives for Ground Water Cleanup, National Research Council, National

Academy Press, Washington, D.C.

Pandey, K., R. Sengupta and I Bajpai (2018). Forty two rivers have extremely high concentration of neurotoxic heavy metals. Details available at https://www.downtoearth.org.in/news/water/huge-amounts-oftoxic-heavy-metals-swim-in-indian-rivers-60545, last accessed on 17 June, 2019

Piddock LJ (2006) Multidrug-resistance efux pumps—not just for resistance. Nat Rev Microbiol 4:629–636

Raja, C. E., Anbazhagan, K. and Selvam, G. S. (2006) Isolation and characterization of a metal-resistant Pseudomonas aeruginosa strain. World J Microbiol Biotechnol 22:577–585

Roberts, A. H. C., Longhurst, R. D., Brown, M. W. (1994). NZ J Agric. Res, 37, 119-129.

Smith, L.A., Means, J.L., Chen, A., Alleman, B., Chapman, C.C., Tixier, J.S., Jr., Brauning,

S.E., Gavaskar, A.R. and Royer, M.D. (1995). Remedial options for metals-contaminated sites. Lewis Publishers,

Tchounwou, P. B., Yedjou, C. G.,Patlolla, A. K. and Sutton, D. J.(2012). Heavy metal toxicity and theenvironment. ExperientiaSupplementum Molecular, Clinical and Environmental Toxicology,133-164.

US EPA. (1996).A Citizen's Guide to Soil Washing. EPA 542-F- 96- 002.

WHO (2019). Anonymous India. Retrieved from http://www.searo.who.int

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Horticultural Crops for Management and Utilization of Coastal Degraded Land and Soil

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ABSTRACT

Land degradation is a significant threat to farming communities dependent on agriculture for food and livelihood security in the 7517 km coastline of India. The degradation reduces land's productive capacity due to biophysical causes, unsustainable management practices, and associated problems. Degradation aggravates by salinization, strong coastal storms, heavy rain, strong winds, and associated storm surges and inundation as a consequence of global climate change. Adopting sustainable land management practices for arresting land degradation and enhancing productivity is essential for achieving food security and livelihood security in that ecosystems. The essential measures required for halting land degradation and enhancing productivity in coastal areas are protecting land from tidal inundation with saline water by constructing protective embankments along the rivers and tidal channels;improving drainage through surface and subsurface; maintaining good soil health by alleviation of the problems of salinity/sodicity/acidity, wind and water erosion etc.A complex, paradoxical situation is confronted today in which more production is required from the scarce natural resources for food, fuel, fibre, timber etc.

On the other hand, vast areas are either going out of cultivation or showing declining productivity due to inappropriate usage.Horticultural crops are versatile, as these are annuals, perennials, trees, bushes, herbs, shrubs, creepers, climbers etc resultant bears wide adaptability. Some of the crops have the inherent capability for absorbing noxious and greenhouse gasses, mobilization and utilization of nutrients, arresting of nutrients to check the runoff, bio-drainage etc. Thus, reclaiming these land and soils can also increase terrestrial C pools, which could offset some of the anthropogenic emissions. Some of the horticultural crops suit to the coastal environment are fruit crops like mango, banana, sapota, guava, pineapple, ber, jack fruit, papaya, pummelo, acid lime, roughlemon, aonla, kokum, mangosteenetc; vegetables like brinjal, tomato, potato, onion, okra, chilli, vegetable cowpea, amaranths, sweet potato, yam,colocasia, cucurbits, radish, drumstick, tapioca, curry leaf, beans, bitter gourd, carrotetc; plantation crops like coconut, cashew, arecanut, rubber, palmyra palm, oil palm, cocoa, coffeeetc;spices and condiments likenutmeg, betel vine, black pepper, cinnamon, cardamom, clove, turmeric, ginger, chilli, malabartamarind, vanilla etc. Some of the crops are for a specific purpose of controlling the water and wind erosion, capability to draw the nutrients in poor fertile soil with salinity, sodicity, acid sulfate soil, act as a wind barrier, and stabilization of dikes. Some of the crops act as bio-filter for the purification of polluted water etc. Hence, these crops not only have wider adaptability but also remunerative to the coastal agro-ecosystem as well as to manage and improve those land and soil for general crops which are declining their productivity.

INTRODUCTION

The Indian coastline, which is 7516.6 km long, covers 6100 km of mainland coastline along with the Andaman, Nicobar and Lakshadweep islands. The coastline of India touches 13 states and Union Territories. The western coastal plains are along the Arabian Sea, whereas the eastern coastal plains are located along the Bay of

Bengal.Coastal plains in India are of two types:Eastern Coastal Plains of India and Western Coastal Plains of India. The eastern coastal plains stretch from West Bengal in the north to Tamil Nadu in the south and pass through Andhra Pradesh and Odisha. Deltas of the rivers Mahanadi, Krishna, Godavari and Cauveri are present in the eastern coastal plain. The deltas are very fertile and productive for agriculture. Therefore, the delta of the River Krishna is called the 'Granary of South India'. The Eastern coast is again divided into three categories; the Utkal coast extending between Chilika Lake and Kolleru Lake; they are much wider than the western coastal plains and undergo immense rainfall. Some suitable crops for that area are rice, coconut and banana. Andhra coast, extending between the Kolleru Lake and Pulicat Lake, the Andhra coast forms a basin area for the Krishna and the Godavari rivers.Coromandel coast; extends between Pulicat Lake andKanyakumari in Tamil Nadu. This Indian coastline remains dry in summer and receives rainfall during winter due to the north-east monsoons. In contrast, Western Coastal Plains stretches from Kerala in the south to Gujarat in the north, passing through Karnataka, Goa and Maharashtra. The western coastal plains stretch for 1500 km north to south, and its width ranges from 10 to 25 km. The western coast is narrower than the eastern coast. The most suited crops of the coast are cashew for stony and gravely land. The western coast is further divided into four categories; Kachchh and Kathiawar coast, formerly a gulf formed by the deposition of silt by the Indus. The area of Kachchh is covered with shallow water during the monsoons and is divided into Great Rann in the north and Little Rann in the east. Whereas Kathiawar is situated to the south of Kachchh. It is very good habitat for medicinal plants and dominated by guggul.

Konkan coastextends between Daman in the north to Goa in the south. Rice and cashew are the two important crops of this region.Kanada coast extends between Marmagaon and Mangalore and is rich in iron deposits.Malabar coastextends between Mangalore to Kanyakumari and is relatively broad. This region also consists of lagoons parallel to southern Kerala's coast.In India coastal region covers a considerable area under Lakshadweep in the Arabian Sea and the Andaman and Nicobar group of islands in the Bay of Bengal.Yadavet al. (1983) reported that the coastal saline soils are spread over 3.1 million hacomprising more than 30% of the totalsalt-affected soils in India. This estimate includes0.26 million ha of acid sulphate soils inKerala and the Andaman and Nicobar islands (Singh et al. 1987), and 0.573 millionha under mangrove vegetation.The area generally lags much behind theinland areas in terms of crop productivity,mainly because of unfavourable climate and poor soil and hydrological conditions.Most of the coastal lands are degraded or vulnerable to degradation. Hence, coastal lands need protection against tidal inundation through protective embankments, designed suitably, preferably brick-pitched, with 1 m freeboard above the hightide level.Planting windbreaks prevent wind erosion, particularly in areas with sand dunes. Excessrainwater in monsoon should be channelized through primary and secondary drains and let out througha one-way sluice gate designed to meet the drainage coefficient of the catchment. The existing low croppingintensity with generally only one crop of rain-fed rice should be improved through multi-tier cropping systemsinvolving arable, horticultural, plantation and forest species along with improved soil, fertilizer and watermanagement for greater land use and increased productivity(Chaudhari*et al.,*2015, Aishwath*et al.,* 2010).

Extent of land and soil degradation in the coastal region

A recent report published on world soil day by the Sustainable Food Trust explains why soil degradation is increasing and calls for it to be recognized alongside climate change as one of humanity's most pressing problems during the century. More than 95% of the food we eat depends on the soil, but half (52%) of all farmland soils worldwide are already degraded, mainly due to inappropriate farming methods. Every year, 24 billion tons of soil are irrevocably lost to the world's oceans due to wind and water erosion – equivalent to 3.4 tons for every person on earth (Chaudhari et al., 2015). India has a coastline of 7517 km (SAC, 2012), its peninsular region bounded by the Arabian Sea on the west, the Bay of Bengal on the east and the Indian Ocean to its south. According to Velayuthamet al. (1999) Indian coastal agro-ecosystem occupies 10.78 m ha and extends over the states/ union territories of West Bengal, Odisha, Andhra Pradesh and Pondicherry on the Bay of Bengal in the East, and Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra and Gujarat on the Arabian sea in the West besides, the two island groups viz. the Andaman & Nicobar and Lakshadweep (Chaudhari and Aishwath,2015).

Land resource in the coastal region is vulnerable to degradation due to immediate causes, including biophysical causes and unsustainable land management practices. Biophysical causes include steep slopes, high rainfall, poor natural drainage, hurricane/cyclones/Tsunami, flooding, rising seas, etc. Unsustainable land management practices, such as deforestation, unscientific agricultural practices, overgrazing, overuse of reasonable quality of land, misuse of marginal and easily degraded land, overcommitment of water, constructing dams/canals/roads/buildings, commercial/industrial developments, land pollution including industrial waste, spill outs in the port areas, quarrying of minerals, etc. are also direct contributors to land degradation. Some of the underlying causes of land degradation include population density, poverty, land tenure, access to agricultural extension, infrastructure and markets, policies that promote the use of land degrading practices, etc. Underlying causes of land degradation often have self-perpetuating characteristics. For example, land shortage and poverty, taken together, lead to unsustainable land management practices as a direct source of degradation. The relationship between immediate and underlying causes is complex, and the impact of underlying factors is context specific.

It was estimated that about 8 m ha of land in 3 agroecological regions (AERs), namely AERs 18, 19 and 20, which cover significant parts of the coastal region of the country, are degraded by the different forms of land degradation (Table 1). Water erosion, salt accumulation, acidification and waterlogging are the major processes of land degradation in the coastal region of India.

Table 1: Degraded and wastelands under coastal agro-ecological regions

Sl. No.	Classes	Degraded and wasteland ('000 ha)			
		AER 18*	AER 19*	AER 20*	Total
1	Exclusively water erosion (>10 $tha^{-1}yr^{-1}$); water erosion under open forest	928	2944	0	3872
2	Forest	48	187	0	235
3	Exclusively acid soils (pH<5.5)	43	2029	0	2072
4	Acid soils under water erosion	12	674	0	686
5	Acid soils under open forest	3	76	0	79
6	Exclusively saline soils	574	40	77	691
7	Eroded saline soils	4	1	0	5
8	Acid saline soils	0	20	0	20
9	Waterlogged saine soils	25	0	0	25
10	Exclusively sodic soils	115	0	0	115
11	Eroded sodic soils	6	0	0	6
12	Mining/ industrial waste	10	15	0	25
13	Waterlogged area (Permanent)	83	76	0	159
		Total degraded area			**7990**

*AER 18: Eastern Coastal plain, hot sub-humid to semi-arid eco-region, with coastal alluvium derived soils and growing period (GP) 90–210+ days; AER 19: Western Ghats and Coastal plain, hot humid–per-humid eco-region, with red, lateritic and alluvium derived soils and GP 210+ days; AER 20: Islands of Andaman-Nicobar and Lakshadweep, hot humid and per-humid island eco-region, with red loamy and sandy soils and GP 210+ days. (Source: Maji *et. al.,* 2010).

Salt accumulation is one of the major forms of land degradation in agricultural areas, including the coastal soils. The nature of some of the salt-affected coastal soils in India is briefly described in Table 2. The salinity build up in soil is due to the accumulation of salts in the surface soil on consequent upon upward capillary flow of brackish water from groundwater at shallow depth following evaporation loss of moisture from soil surface and/or submergence of land with brackish water from sea or estuaries. The soil and ground water salinity and depth to ground water table are temporal in nature and vary with the season. Soil salinities developed due to brackish ground water are maximum in dry seasons and minimum in monsoon. Depending on the nature of salts accumulated the salt affected soils may be saline or sodic. Owing to low-lying nature and extremely gentle gradients, the coastal regions are highly vulnerable to storm surges, Tsunamis and inland floods. The occurrences of moderate to heavy cyclones are common almost every alternate year in the coastal states. Such cyclones cause seawater inundation ofland adding further degradation to the already degraded salt-affected land. The super cyclone that struck coastal Odisha in 1999 had made huge tracts of agricultural land unfit for cultivation due to the ingress of sea water. Tsunami waves of December 26, 2004 have destroyed thousands of hectares of arable land in coastal plains and islands. Crop fields were flooded with seawater turning them saline and unproductive/ highly degraded. Aila cyclone struck the coastal areas of West Bengal on May 25, 2009, due to which more than 22,000 homes were ravaged. Saline sea water entered the crop fields and freshwater bodies (ponds, reservoirs, canals, etc.), which snatched away the means of livelihood – agriculture, animal husbandry and pisciculture, from the poor farmers of the area, large area turned highly saline and unproductive (Chaudhari and Aishwath,2015).

Table 2: Geo-climatic distribution and characteristics of coastal salt affected soils in India

Main characteristics	Rainfall (mm annum^{-1})	Distribution
Saline marsh of the Rann of Kutch:Neutral to slightly alkaline pH, high EC, preponderance of chloride and sulphate salts, light textured	< 300	Rann of Kutch in Gujarat
Medium to deep black soils of deltaic and coastal semi-arid region: Neutral to alkaline pH, high EC, preponderance of chloride and sulphate salts, and montmorillonitic clay minerals	700-900	Saurashtra coast in Gujarat and delta of Godavari and Krishna rivers in Andhra Pradesh
Deep black soils (Vertisols): Neutral to highly alkaline pH, high EC, preponderance of chloride and sulphates with or without bicarbonates, and montmorillonitic clay minerals	700-1000	Andhra Pradesh, Gujarat and Karnataka
Saline micaceous deltaic alluvium of the humid region: Neutral, slightly to highly acidic pH, high EC, dominance of chloride and sulphate salts, rich in morntmorillonitic and illitic clay minerals	1400-1600	Sundarbans delta of West Bengal and parts of Mahanadi delta in Odisha
Saline humic and acid sulphate soils of humid tropical region: Highly acidic pH, high EC, presence of humic (organic) horizon, the dominance of sulphate and chloride salts.	2000-3000	Malabar coast in Kerala, Sundarban delta of West Bengal and some parts of Andaman and Nicobar islands

(Source : Bandyopadhyay et. al., 2011)

Management of coastal saline soils

Although coastal regions are quite rich in natural resources and biodiversity for supporting economic development,they are often hit by environmental hazards like storms and cyclones that cause massive destruction of life,infrastructure and natural resources. As far as arable coastal lands are concerned, they suffer from constraintslike excess accumulation of soluble and alkali salts, formation of acid sulphate soils, nutrient toxicities, seawateringress into aquifers, frequent inundation by tidal waves, and a shallow (often saline) groundwater table. A heavysoil texture and water infiltration problems also make them vulnerable to erosion and sedimentation (Sharma, 2021).Sea level rise is a major climate change impact that will have wide-ranging effects on coastal environments (IPCC,2007). During the 21st century, the rate of sea level rise is projected to be several times higher than that measuredover the past century. Recent projections suggest that sea level may be ~0.6 to 1.5 m higher than present by 2100and ~2 m higher under extreme warming scenarios. Because of the large population living along thecoastal lines,even small increases in sea level can have significant societal and economic impacts through increased coastalerosion, susceptibility to storm surges, inundation of low-lying areas, saltwater intrusion into groundwater, loss ofcoastal wetlands, and stresses on ecosystems and community infrastructure. Recently, a digital database of coastalsalt-affected soils was prepared by integrating 31 geo-referenced maps in eight coastal states of India. Of the totalcoastal salt-affected area (2.50 M ha), ~1.83 M ha was saline and the remainder (0.67 M ha) sodic. Among thestates, Gujarat accounts for the largest area (50%) followed by West Bengal (17.6%), Tamil Nadu (12.7%), AndhraPradesh (7.6%), Orissa (5.8%), Andaman and Nicobar Islands (3.0%), Maharashtra (2.0%) and Kerala (0.8%)(Mandal et al. 2018). Coastal salinity prevention and mitigation measures being implemented in various statesof India can broadly be classified into 'salinity control', 'water recharge', 'land reclamation' and 'soil and cropmanagement' interventions. Some of the viable engineering measures for salinityprevention include protective embankments and bunds to reduce seawater inundation, seawater exclusion dams,bunds, bandharas and nalla plugs, surface drainage through field ditches, provision of seawater barriers to preventseawater inflow into fresh aquifers, aquifer storage and recovery (ASR) and the use of skimming wells. In ASR,freshwater is injected into the aquifers during periods of high demand and is pumped back to the surface during thelean seasons. In areas where freshwater is underlain by saltwater, skimming wells can be a good option for keepinggroundwater salinity below the acceptable limit. Similarly, check dams, recharge wells and tanks, and afforestationare considered efficient means to improving the recharge of fresh water aquifers. Land reclamation can be achievedby desiltation of lakes, anti-sea erosion measures, regulation of groundwater extraction, phytoremediation andapplication of soil amendments. A suit of doable agronomic practices and salt tolerant cultivars developed overthe past few decades for the productive management of coastal salt-affected soils are discussed in the followingsections. A number of technologies have been standardized to sustain cropproduction in coastal saline soils of thecountry. 'Dorovu' technology to skim fresh water floating on the saline water has gained immense popularity inmany coastal regions. Other such technologies include *rabi*cropping in mono-cropped coastal saline soils, rainwaterharvesting in dugout farm ponds, salt-tolerant rice varieties, efficient nutrient managementand integrated rice-fish culture (Sharma, 2021).

Nutrient management

Most of the coastal saline soilsare deficient in nitrogen. Besides, lesserutilization of nitrogenous fertilizer, mineralization of organic nitrogen inthe soiland thus the release of native soil nitrogen tothe plant in available form is very slowin the salt-affected soils due to a decrease inmicrobial population and their activities at thehigh salinity level. Bandyopadhyay and Bandyopadhyay(1983) revealed that the rate ofboth mineralization and immobilization ofnitrogen in soil decreased considerably atsalinity of ECe 10 dSm-1 and above. The increasingloss of nitrogen through NH3volatilization from applied nitrogenous fertilizerwith increase in soil salinity was studiedby Sen and Bandyopadhyay (1987). Who furthershowed that this loss could be effectivelyreduced through the placement of fertilizers at 5 cm soil depths. The level of phosphorus in coastal saline soils is highly variable anddepends greatly on the nature and degree ofsalinity (Yadav 1980). The availability of soilphosphorus largely depends on the pHof thesoil developed after hydrolysis of the salt. Theincrease in soil pH on hydrolysis reduces theavailability of soil phosphorus. Very littleworkhas been done on the transformation andavailability ofP to crops in coastal saline soils.The availability of potassiumdepends largely on the parent materials, clayminerals and weathering conditions. It alsodepends on the nature and amount of salts inthe soil. Bandyopadhyay *et al.* (1985) reportedthat the coastal saline soils are rich in watersoluble, exchangeable, non-exchangeable andavailable K. High potassium-bufferingcapacity and Gibb's free energy (AF)also indicate that the coastal saline soils havehigh potassium-supplying capacity.In a long-term experiment conducted for11 years, Bandyopadhyay and Maji (1990)observed that grain yield of crops in ricebarley(*Hordeumvulgare*L.) rotationincreased significantly only due to theapplication ofN. Application ofP did not leadto any significant increase in the yield of cropsin the initial 8 years, after which the yield ofbarley alone increased. Available K contentwas high in the soil. Hence, K application may be omittedwithout any detrimental effect on soil fertilityor crop yield. The coastal soils are generally rich inmicronutrients such as Fe, Mn, Zn, Cu, B andMo, Maji and Bandyopadhyay (1989, 1990)revealed that the application of micronutrientsto crops like safflower *(Carthamustinctorius*L.) and rice either through soil application orfoliar spray may not be beneficial to the crops.The coastal saline soils are subjected to greatchange in the chemical environment of the soilon submergence. Maji and Bandyopadhyay(1992) further found that on submergence the Di-ethylene Tri-amine Penta-acetic Acid (DTPA) extractableFe and Mn contents of the soil increasebut Cu content decreases.

Use of green-manurecrops like prickly sesban (*Sesbaniacannabina*Retz.,*S. aculeate* Pers) proved highly suitable forsaline alkali soils (Keating and Fisher 1985; Evans and *Row,* 1986). In favourable climates with proper management, these crops accumulatemore than 100 kg Nha^{-1}, mainly throughbiological N fixation, in 50-55 days, therebyincreasing the yield of the following rice cropssignificantly (Singh *et al.* 1991). Likewise,application of green leaves of *Madre* tree (*Gliricidiamaculata*) @10 tonesha^{-1} to the puddled soil before ricetransplanting gives yield comparable to thatgiven by inorganic fertilizer N, P and K @100, 50 and 50 kgha^{-1}, respectively. Buresh and De Daua(1991), reported that N fromleguminous green-manure and its residue typicallymeets only partial requirement ofN forthe following high-yielding rice variety. Theyreported high loss of N under the anaerobicaerobicsoil cycles typical oflegume-lowlandrice sequence, as well as higher methane and nitrous oxide production from the lowlandrice field. However, in view of the rising energycost and limited input availability, recyclingof organic wastes and use of renewablesources of bio-fertilizers, viz rhizobium culturesfor pulse or legume and blue-green algaeforwaterlogged rice fields, may play a significantrole in terms of integrated nutrientmanagement forrice field (Kundu and Pillai, 1992) in coastal saline areas.Coastal saline soils generally have medium to high in available P but acid sulphate soils are highly deficient in P. Except acid sulphate soil, in many cases phosphorus may show very poor response or no response of crops, particularly, of rice, but a minimum quantity of basal P application is necessary to maintain the P fertility level.

Management of water logged wetland through Bio-drainage

This method raises salt-tolerant trees with a high transpiration rate to prevent irrigation-induced salinity in canal commands. Being a preventive approach, bio-drainage gives best results when tree plantings coincide with the initiation of irrigation projects. Some tree species that are efficient bio-drainers are eucalyptus, poplar and bamboo. In contrast to the annuals, tree roots extend to the deeper soil depths (>2 m), making them efficient in removing the groundwater rapidly such that water table decreases by 1-2 m in a short span of 3-5 years (Devi *et al.* 2016). *Eucalyptus* (an aromatic tree) have a high bio-drainage capacity removing about 5000 mm of water from the usual and moderately deep (~1.5 m) water tables. However, bio-drainage efficiency declines under shallow (~1 m) and deep (~2 m) water table conditions and with an increase in groundwater salinity. Nonetheless, Eucalyptus trees could transpire about 50% of the water compared to normal conditions at salinities as high as 12 dS m^{-1} (Chhabra and Thakur, 1998). Strip plantations of *Eucalyptus tereticornis*on ridges in north-south direction not only lowered the water table by 0.85 m in 3 years but also sequestered 15.5 t ha^{-1} carbon during the first rotation of 64 months.Kewada (*Pandanus odoratissimus*) is one of the important aromatic plants most suited for mangroves and water-logged areas of coastal region (Aishwath and Nibauria, 2009).

Improved crops, diversified cropping and integrated farming

There is an excellent scope for enhancing productivity of degraded coastal land through crop diversification. The scope to increase the cropping intensity and diversification in the coastal ecosystem depends largely on the soil salinity and irrigation water availability. With proper water management, it is possible to incorporate pulses, oilseeds and vegetables in rice-based cropping system. Among the important winter/summer crops are barley, cotton, chilli, sunflower, and a number of vegetables. Tomato, chilli, brinjal, cabbage, cauliflower, melons, onion, peas, beans, ladies finger and various leafly vegetables are produced in large quantities in coastal areas in the rice based cropping system. Rice-sunflower-cowpea at Navsari (Gujarat) and rice-tomato-okra at Bhubaneswar (Odisha) have been promising. For Andaman and Nicobar Islands, rice-rice-pulse (cowpea) rotation was reported to be most economical and feasible practice(Chaudhari and Aishwath,2015).

Rice is the predominant form of land use in many coastal and deltaic regions of the tropics. No crop other than rice can be grown under these adverse conditions of unstable water levels and highly saline locations. Deepwater rice subjected to devastating floods and cyclones occupies the coastal rice. Because prolonged waterlogging during the monsoon season, continuous mono-cropping of rice with long-duration tall *Indica* varieties is practised in several coastal areas. India, as a whole, has about 55 percent of the total rice area under lowlands, but the proportion is much higher in coastal tracts (Rai, 2004). West Bengal, having the largest share of coastal area, has about 90 percent of the total under 30-90 cm depth of water, and the yield level is comparatively low in the region. Waterlogging, annual occurrence of flash floods and typhoons and salinity result in heavy production losses in rice in the coastal region. The improved submergence and salinity tolerant rice varieties may enhance the productivity of these stress-prone and degraded land in coastal region. Recently developed rice varieties with flood tolerant gene (Sub-1) like swarnaSub-1, IR64 Sub-1, **CR1009-Sub1, Ciherang-Sub1,** etc., with salt tolerant gene (saltol), and with both flood and salt tolerant varieties like **Swarna-Sub1 + Saltol, IR64-Sub1 + Saltol, etc.** should be widely practiced to enhance the productivity of rice in the coastal region(Chaudhari and Aishwath,2015).

The coastal ecosystems offer vast scope for commercial use for a wide variety of fruit and vegetables crops, plantation crops, spices and medicinal plants. Plantation crops, like coconut, arecanut, oil palm, cashew, cocoa, spices ginger, turmeric, and seed spices like cumin, coriander, fennel, and fenugreek are high value commercial crops and coastal region have a great scope to cultivate commercially for all those crops. Both cashew and black pepper are good foreign exchange earners. India has emerged as the largest producer of coconut in the world, and coconut coir industry is a well-established business. Cashew is cultivated mostly in coastal areas. The release of improved varieties in all these crops and improved production technology has brought significant improvements in the production of these crops(Chaudhari and Aishwath,2015).

Medicinal and aromatic plants play an important role in Indian traditional medicines. It is reported that over 2000 native plant species have curative properties, and another 1300 species are known for their aroma and flavour and are native to the coastal ecosystem. Medicinal and aromatic plants, like isabgol (*Plantago ovate*Forsk) and opium poppy, are produced on a commercial scale. Vegetable seed production is also a potential area in this region. Oil palm (*Elaeisguineensis* Jacq.) is the highest edible oil yielding crop, producing 4-6 tons of oil per tree in 25 Years. The total potential area identified for growing oil palm is mainly along the coastal belt.

The integrated farming system combining crop production with sericulture, apiculture, dairy, poultry, duckery, aquaculture, agroforestry, etc have a scope for coastal areas. Vast potential exists for rice-based agrosilvicultural production systems in suitable coastal areas. Based on research, *Acacia auriculiformis*, *Casuarina equisetifolia*, *Acacia nilotica* and *Prosopis chilensis*, *Prosopis juliflora* are some of the promising tree species (Yadav, 2001). Fast growing *Casuarina* plantation as an excellent source of fuel wood and as stabilizer of sand dunes is famous even among the farmers of the coastal areas. *Coixlacryma*jobi has been identified as a suitable fodder species for the salt affected and waterlogged soils. *Stylosantheshamata* is another protein rich leguminous fodder suitable for growing on coastal land(Chaudhari and Aishwath,2015).

Rice-fish culture has assumed prominence in recent years. Fresh water and brackish water aquaculture is one of the most important activities in the coastal areas for employment, income generation and supplementary food item. The promotion of shrimp culture in brackish water has significantly changed the economy, especially in Andhra Pradesh, Odisha, and West Bengal in recent years. Brackish water fish culture can be integrated with rice and coconut cultivation. Rice-fish inside the field and vegetables/fruits on the bunds or rice fields have shown great promise in the coastal area of Odisha and Sundarbans region of West Bengal. Coconut-based system is popular in the Andaman and Nicobar group of Islands and in several parts of west and east coasts. Homestead farming comprising of coconut, arecanut, other trees and species (black pepper, clove and cardamom) in different tiers around the houses is in vogue in Kerala state. However, these complex integrated farming systems need further improvement through most efficient and cost-effective management of soil, water, nutrients and other inputs. However, the location-specific packages, thus developed, should be socially acceptable (Chaudhari and Aishwath,2015).

Crop management

The existing cropping intensity in coastal areas is low (Table 3). The scope to increase the intensity in a rice-oriented cropping system shoulddepend largely on the soil conditions andwater availability. Multi-tier cropping systemsinvolving arable cropping, horticulturaland plantation crops, and agro-forestryshould be given greater attention for betterland use in these areas (Ghosh et al. 1991,Yadav 1994).

Table 3: Major existing crops and cropping systems of coastal districts in different West Coast and the East Coast States of India

Coastal States	Major crops	Major Cropping system
Gujarat	Rice, Arhar, Jowar, Urad, Gram, Sugarcane, Cotton, Groundnut,S oybean, Maize, Wheat, Guar, Castor, Sugarcane, Sesamum, Moong, Tobacco	Rice-Pulses, Rice-Oilseed, Cotton-wheat, Cotton-Gram Soybean-Wheat, Tobacco-Summer Pearl Millet
Maharashtra	Rice, Groundnut, Ragi, Moong, Cowpea, Arhar, Ragi, Gram	Rice-Pulses, Ragi-Gram, Pigeonpea-Millets
Goa	Rice, Sugarcane, Cowpea, Moong	Rice-Cowpea, Rice-Rice Rice-Moong, Rice-Groundnut
Karnataka	Rice, Cowpea, Chilli, Moong, Urad, Maize, Sugarcane	Rice-Pulses, Rice-Groundnut, Maize-Groundnut
Kerala	Rice, Cowpea, Moong, Sugarcane	Rice-Pulses
Tamil Nadu	Rice, Bajra, Cotton, Groundnut, Maize, Jowar,Moong, Urad, Small millets, Sugarcane, Ragi, Arhar	Rice-Pulses, Rice-Groundnut, Cotton-Moong,Ragi-Urad, Pigeonpea-Ragi, Bajra-Jowar, Maize-Groundnut

Andhra Pradesh	Rice, Cotton, Chilli, Groundnut, Maize, Moong, Sugarcane, Urad, Tobacco, Jowar, Small millets, Arhar/Tur, Sunflower, Niger	Rice-Pulses, Maize-Groundnut, Cotton-Jowar,Sorghum-Groundnut/ Pearl Millet/Cotton, Sorghum-Chickpea
Odisha	Rice, Groundnut, Moong, Urad, Sesamum,Rapeseed &Mustard	Rice-Pulses, Rice-Oilseeds
West Bengal	Rice, Jute, Khesari, Urad Rapeseed & Mustard, Groundnut, Sunflower, Wheat, Moong, Potato, Sesamum	Rice-Jute, Rice-Maize, Rice-Mustard, Rice-Wheat, Rice-Groundnut and Rice-pulses, Jute-Wheat, Jute-apeseed&Musatrd

Source: *Hand Book of Agriculture (2019)*

Opportunities for horticultural crops in coastal agro-ecosystem

Horticulture which includes fruits, vegetables, ornamental plants, aromatic and medicinal plants, plantation crops,and spices is one of the most vibrant segments of Indian agriculture. The government of India realized its potentialand role in shaping the Indian economy in the mid-eighties. It accorded high priority for developing thissector, particularly since the VIII plan and beyond. The horticulture sector witnessed a major increase in area andproduction since 1991-92. Indian Horticulture production touched 311.71 million MT during 2017-18 with amajor contribution from vegetables (184.34 million MT) and fruits (97.36 million MT). We are the second-largestproducer of fruits and vegetables in the world. Over the last decade, the area under horticulture has grown by 2.6%per annum and annual production by 4.8%. The horticulture sector contributes around 33% to Agriculture outputfrom 11% of cropped area(Samant*et al.*, 2021). Diversification with Horticulture has brought economic prosperity in many statesof India through increased productivity, employment generation, and enhanced exports. Caught up between thegrowing demand for food, nutrition, and livelihood security on one hand and low agricultural productivity, extremeweather events, and degradation of natural resources, on the other hand, the coastal zones of India are in great needof taking up the horticulture as one of the integral components of the coastal agriculture system on large scale.Following are some points that make horticulture a suitable choice for coastal agriculture.

Suitable fruit crop for coastal climate/rain-fed conditions

There are huge number of fruits crops can be taken well in coastal climate, however minor fruits, such as abiu, atemoya, avocado, breadfruit, carambola, cashew nut, cherimoya, durian, guava, jaboticaba, jackfruit, langsat, litchi, longan, macadamia, mangosteen, papaya, passion fruit, pulusan, rambutan, sapodilla, soursop, and white sapote are the best suited in the area. Some of the fruit crops and their varieties are well adapted to coastal climate, particularly under rainfed conditions are given in table 4. These crop varieties may be grown successfully in the coastal climate with limited moisture and edapho-climatic stresses (Samantet al, 2021).

Table 4. Fruit crop for coastal climate/rain-fed conditions

S No	Crop	Varieties
1	Mango (*Mangifera indica* L.)	Early (Bombai, Bombay Green, Himsagar, Kesar, Suvernarekha), Mid-season (Alphonso, Bangalora, Banganapalli, Dashehari, Langra) and Late (Fazli, Fernandin, Mulgoa, Neelum, Chausa).
2	Guava (*Psidium guajava* L.)	Allahabad safeda, Lucknow 49, Anakapalli,Banarasi, Chittidar, Hafshi, Sardar, SmoothGreen, Safed Jam, ArkaMridula
3	Pomegranate (*Punica granatum* L)	Alandi or Vadki, Dholka, Kandhari, Kabul,Muskati Red, Paper Shelled, Spanish Ruby,Ganesh (GB I), G 137, P 23, P 26, Mridula,Aarakta, Jyoti, Ruby, IIHR Selection, Yercaud1 and Co 1.
4	Custard Apple(*Annunasqumos L.)*	Balanagar, Arkasahan, Barbados seedling, Kakarlapahad, British Guinea, Mahaboobnagar, Saharanpur local and Washington.
5	Jamun *(Syzygiumcumini)*	Goma Priyanka, Ram Jamun, Thai Jamun andOther Variety
6	Ber or Indian jujube *(Ziziphus mauritiana)*	Gola, Umran, BanarasiKarka, Mundia, Kaithli,Umran, Mehrun, Parbani, Elaichi and Sanam 5.
7	Sapota *(Achras zapota)*	Cricket ball, Kalipatti, Calcutta round, Kirthibharathi, Dwarapudi, Pala, PKM-1, Jonnavalasa I & II, Bangalore, VaviValsa
8	Tamarind (*Tamarindus indicus* L.)	Urigam,PKM 1, Yogeshwari, Hasanur, DTS 1, Tumkur Prathisthan,
9	Acid Lime (*Citrus aurantifolia*	Petlur selection, Balaji, PKM1, Vikram, Chakradhar and Local varities.

(Samuel and Pushpanjali 2019)

Suitable vegetable crops for coastal climate

Tropical coastal climate bears humid and hot wind invites insect-past and diseases may be taken be taken care. Some wind breaks/barrier horticultural crops may be grown against the windward side for the successful cultivation of wide variety of vegetable crops are given in table 5. These vegetable crops are more remunerative than the existing traditional crops and their cropping system of the area.

Table 5: Vegetable crops and their varieties suitable for coastal regions

S No	Type of crops	Crops and their varieties
1	Root crops	Carrots, Beets (Cylindra, Forono, Touchstone gold, Boldor, Chioggia, etc) Radishes Turnips and Rutabagas
2.	Brassica Family	Broccoli (Belstar, Arcadia and Marathon), Cabbage (Alcosa, Caraflex, Ruby Perfection, Red Express' and Integro), Cauliflower (Snow Crown, fool proof, Cheddar and Graffiti), Kale (Wild Garden, Red Russian, Redbor and Toscano), Kohlrabi (Kolibri and Gigante) and Brussels Sprouts

3	Lettuce and Greens	Lettuce (Winter Density, Cherokee, Coastal Star, Concept, Little Gem, Bambi, Merlot, Buttercrunch, Red Cross, Continuity, Jester, Celinet, Panisse, Oscarde, Rouxai and Mesclun or baby leaf blends), Spinach, endive friseé and escarole, Chard (Bright Lights, Ruby Red, Neon and Golden Sunrise), Arugula, mustards & micro greens and Asian/Italian/exotic greens
4	Onions, leeks and shallots	Green onions/scallions, Full size onions (Expression, Candy, Sierra Blanca, Red Wing, Exhibition and Ailsa Craig), Shallots (Conservor, Ambition and Camelot), Leeks (Lincoln, Megaton, King Richard and Lancelot)
5	Potatoes	Fingerlings (French Fingerling, Rose Finn Apple, LaRatte and Blossom), Standard yellow flesh (Yukon Gold, Red Gold, German Butterball and Yellow Finn), Blue flesh (Purple Majesty and All Blue), White flesh (Purple Viking, Red LaSoda, Red Norland, Kennebec, Red Pontiac).
6	Peas	Sugar pod ('Oregon Sugar Pod II, Oregon Giant, Sugar Daddy), Snap (Cascadia and Sugar Sprint),Shelling (Oregon Trail).
7	Green Beans	Bush (Jade, Derby, Oregon 54, Maxibel (green), Soleil &Rocdor (yellow) and Jumbo, Pole Beans (Fortex and Helda).
8	Squash	Summer Squash: Sure Thing Hybrid (Paternon, zucchini, Zucchini, Gadzukes, Cocozelle, Fordhook, Cupcake), Gold Rush (Gold Mine). Yellow crookneck (Horn of Plenty and Summerpac), Scallop (Sunburst and Peter Pan) Winter squash and pumpkins:(Honey Bear, Sunshine and Sweet Meat and Butternut squash)
9	Cucumbers	Pickling, lemon, standard slicing and seedless types and their varieties (Sweet Success, Diva, Agnes, Pepinex, Socrates, Iznik and Tasty Jade).
10	Tomatoes	There are thousands of varieties of tomatoes. Cherry and grape types are likely to ripen earlier. Indeterminate like heirlooms.
11	Peppers	Hot peppers generally ripen better than sweet varieties. Choose short season, early maturing sweet varieties or they will not ripen quickly enough.
12	Perennial Vegetables	Artichokes (Imperial Star), Asparagus, Jerusalem Artichoke or 'sunchoke' is actually a tuber that grows underground from roots of a perennial sunflower native to eastern North America.
13	Odds fussy vegetables	Celery (Tango and Ajmer Cel-1), Bulb Fennel (Orion and Orazio), Corn (Luscious), Tomatillos, Eggplant

Abundant of crop choices among the horticultural crops

Horticulture with diverse group of crops offers a range of crop choices to the farmers for crop diversification incoastal agriculture. Availability of moisture throughout the year with excellent soil and climatic conditions facilitatescultivation of horticultural crops. Some important ones under various crop groups are listed in Table 6.Fenugreek variety Hisar mukta is highest salinity tolerant among all the available variety in India. Many seed spices are well adopted under these edapho-climatic stressesie *viz.*, moisture stress and excess, salinity, alkalinity, sodicity and acidity of soil, temperature stress etc. (Aishwath*et al*, 2010, Aishwath*et al.*, 2012a, Yadav *et al.*, 2013).

Table 6: Major horticulture crops of coastal India

S.No	Category	Crops
1	Fruits	Mango, banana, sapota, guava, pineapple, ber, jack fruit, papaya, pummelo, acid lime, rough lemon, aonla, kokum, mangosteen
2	Vegetables	Brinjal, tomato, potato, onion, okra, chilli, vegetable cowpea, amaranthus, sweet potato, yam, colocasia, cucurbits, radish, drumstick, tapioca, curry leaf, beans, bitter gourd, carrot
3	Plantation crops	Coconut, cashew, arecanut, rubber, palmyrah palm, oil palm, cocoa, coffee
4	Spices and condiments	Nutmeg, betelvine, black pepper, cinnamon, cardamom, clove, turmeric, ginger, chilli, Malabar tamarind, vanilla

(Samant*et al.*, 2021)

Wider adaptability of horticultural crops

Many horticultural crops are hardy and well adapted to the adverse edaphic and climatic conditions where cerealsand other crops fail to produce economic yields. Most of the coastal areas have problematic soils, *viz.*, saline,alkaline, acid sulphate, marshy, and waterlogged soils. Soil salinity caused by the presence of saline groundwaterat shallow depth and frequent seawater inundation in the low-lying areas, is the main factor responsible for pooragricultural productivity in coastal regions. About 3.1 Mha area along the coastal tracts of West Bengal, Odisha,Andhra Pradesh, Puducherry, Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat, Goa, and Andaman & NicobarIslands are affected by the problem of salinity. Salt-affected soils of coastal land could be utilized to cultivate coconut, date palm, *ber*, sapota, *aonla*, *karonda*, and custard apple because of moderate to high salt toleranceability (Table 7). Cashew can be cultivated quite successfully in sand dunes which at present are unutilized andoften encroach on adjoining farmlands year after year. Cashew trees once established, stabilize the soil. Coastal areaswith temporary water stagnation issues could be utilized for *jamun*. Vegetables like colocasia, swamp taro, *kalmisag* (*Ipomoea aquatic*), and *thankuni sag* (*Hydrocotyl asiatica*) can be grown in a waterlogged ecosystem (Aishwath*et al.*, 2012b).

Table 7. Relative tolerance of fruit crops to salinity

Tolerance level	ECe (dS m^{-1})	pH	ESP (%)	Fruit crops
High	12-15	9.9-10.5	40-50	Ber, date palm, sapota, khirni
Moderate	09-12	8.5-9.5	30-40	Aonla, ber, karonda, pomegranate, bael, wood apple, jamun, tamarind, custard apple
Low	06-09	7.5-8.5	20-30	Guava, mango
Sensitive	04-06	6.8-7.5	15-20	Banana, pineapple, Jackfruit, cashew

(Samant *et al.*, 2021)

Climate suitability for cultivation of exotic horticultural crops

Climatic conditions of coastal areas are very favourable for expanding the area under exotic horticultural cropswhich are relatively new to India, *viz.*, rambutan, mangosteen, etc. Cultivation of rambutan and mangosteen isbecoming very popular on the west coast, particularly Kerala and Karnataka. Many of the indigenous spices, medicinal and aromatic plants and their varieties are most suited under stressful environment of coastal areas (Aishwath and Lal, 2016 and Aishwath*et al.*, 2012a &b)

Better returns with horticultural crops

Horticultural crops are high-value low volume crops and provide better returns per unit area over other crops.Fruits and vegetables give 4-10 times the return from other crop groups, namely, cereals, pulses, and oilseeds.Diversification towards horticultural crops is the most powerful factor in raising the growth rate of agriculture GDP.A one percent shift in the area from non-horticultural crops to horticultural crops adds 0.46 percentage points to thegrowth rate of the agriculture sector. Vegetables can be grown on small patches of land by the farmers. Vegetablecultivation provides quick returns to the farmers. Perennial horticultural crops have a long productive life andplanting them once provides continuous yield for a long period of time (Aishwath and Anwer, 2010).

Employment generation with horticultural crops

Cultivation of horticultural crop is labour intensive activity, hence, provides assured employment opportunities tothe inhabitants of the coastal region. Fruit production requires on average 860 man-days per hectare per annumas against the employment generation of 143 man-days by cereal crops. Banana and pineapple generate much largeremployment ranging from 1,000 to 2,500 man-days per hectare per annum. Various industries, *viz.*, processing, pharmaceutical, perfumery and cosmetics, chemical, confectionery, oils and paints, coir, etc., run on the rawmaterial provided by horticultural crops. Thus, the Horticulture sector has tremendous potential for employmentgeneration (Samant*et al.*, 2021).

Better foreign exchange with horticultural crops

Horticultural crops fetch more foreign exchange per unit area than cereal crops due to high yields and higher pricesavailable in the international market. Fruits earn 20-30 times more foreign exchange than cereal crops. Some of the spices are low volume and high value crop fetches foreign currencies, which adds to the national economy (Samant*et al.*, 2021).

Better utilization of natural resources with horticultural crops

Diverse features of horticultural crops, *viz.*, growth habit, canopy pattern, root depth, and crop duration allows scopefor multi-tier cropping system, which ensures efficient utilization of natural resources (sunlight, water, land, andnutrient) and gives better returns per unit area, per unit time, and per unit input over the mono-cropping. The multi-tier cropping system is highly successful in plantation crops such as coconut, arecanut, cashew, and coffee.Some examples of multi-tier cropping systems are -coconut/arecanut + black pepper + cocoa + pineapple, coconut/arecanut + black pepper+ banana + ginger+ pineapple, coconut + black pepper + nutmeg + banana + pineapple,areca nut + banana + turmeric, coconut +black pepper + pineapple, coconut + cocoa +coffee + pineapple, mango +pineapple etc. Elephant foot yam, tapioca, greater yam, and sweet potato are common inter-crops in humid tropics.Multi-tier cropping system is a boon to the farming community because of efficient utilization of natural resources,enhancement in productivity of main crop (15-20%), and high revenue realization per unit area (50-90%). Thisnovel approach of "An inch of land with a bunch of crops" is emerging as the sustainable livelihood model for smalland marginal farmers because it ensures ecological stability, enhanced soil buffering ability, continuous income,round the year employment, effective biomass recycling, and less risk of crop failure. Farmers could get a netincome of about 3,75,000/- per hectare per annum by intercropping cocoa with coconut (Samant*et al.*, 2021; Aishwath and Anwer, 2010).

Salt tolerant horticultural crops

Availability of high-yielding cultivars capable of simultaneously tolerating excess salts, waterlogging and similar constraints could enable the farmers to obtain stable yields even in the absence of other salinity management interventions (Sharma, 2021). Genetic improvement programme have led to the development of several STCs in staple crops likerice and wheat that are being cultivated over a large salt-affected area. Several potential genetic stocks have alsobeen developed for use as parents in future selection and hybridization programmes. The importance of high-yieldingSTCs is best illustrated by rice, a salt-sensitive plant inefficient in controlling the influx of Na+ through the roots,where high yielding STCs can provide a yield advantage of 1.5-2 t ha^{-1}. Many promising salt tolerant genotypeshave also been identified in fruits (mango, bael, ber, guava and pomegranate) and vegetables (chilli, capsicum,okra and tomato). A technique for utilizing saline groundwater (ECIW up to 10 dS m^{-1}) in vegetables crops underlow-cost protected structure has been standardized. A germplasm repository consisting of diverse medicinal andaromatic plants has been established in a partially reclaimed sodic land. Success has also been achieved in raisingfruits like guava, bael, Indian jujube and pomegranate under saline shallow water table conditions that are otherwiseconsidered to be unsuitable even for field crops. Taking a cue from less than expected adoption of the STCs released in different crops, efforts are also being made to develop high yielding STCs in a farmer participatory mode toconvince the farmer clientele that their needs and preferences are being taken care of prior to varietal release. Sucha farmer participatory rice varietal evaluation led to the identification and release of salt tolerant rice cv. CSR 43 forcommercial cultivation in sodic areas of central IGP (Singh *et al.,*2014). Similar initiatives have been planned inother crops for expediting large-scale adoption of varieties being developed. Spices and medicinal plants are best suited under those conditions for both high yield and quality (Aishwath and Anwer, 2010, Aishwath*et al.*, 2012a&b)

Horticultural crops for water eroded land and soils

To combat against these problems of erosion, there is vast potential of horticultural crops. Some fruits trees and bushes, creeper and climber type vegetables and ornamental cover crops are the potential to combat erosion and adapt to these conditions. Aromatic grasses on sloppy lands have the wide potential for the extraction of oil. In *Cymbopogon species*, *Cymbopoganmartinii*produced oil yield of 68.3 kg$ha^{-1}year^{-1}$ followed by *C. winterianus*, 41.3kg $ha^{-1}year^{-1}$. Culturing other aromatic plants like *Ocimumkilimandscharicum* and *Anethum sowa* could also be recommended in degraded habitat orchards as inter-crops. At many a places, *Cymbopogons* are utilizing for dual purpose to control the gully erosion and oil extraction in Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat(Verma and Chinnamani, 1998). Similarly, *Eucalyptus globules* and *Eucalyptus robusta* utilized in humid regions for dual purposes to control the soil erosion and stabilization of gully erosion as well as essential oil extraction (Ramamohan Rao, 1998). Lavender (*Lavandula officinale*) and rose (*Rosa domascena*) could also be grown in sloppy and erodes lands or terraces in hill areas (Shiva *et al*., 2002;Aishwath*et al.,* 2010).

Horticultural crops for **wind eroded coastal sands**

In the coastal sand, the suitable fruits are date palm, coconut, ber, pomegranate, etc. Several vegetables like brinjal, chillies, turnip, beet, water melon, pumpkin, long melon,onion, garlic, *Dolichos*, bean, French bean, cluster bean, and drumstick, medicinal plants like senna, periwinkle, vetiver, liquorice and asgand and commercial flowers like marigold, Jasminum, *Nerimodourum, Murraya exotica, etc.*, would be successful **(Chadha and Pareek, 1993;Aishwath, 2019;Aishwath and Anwer, 2010)**.

Horticultural crops for nutritionally eroded soils

Some important horticulture crop/plants have lower requirement of nutrient can be grown as diversified crop (Table 8). The root colonization with VAM fungi have special structures known as vesicles and arbuscules. The arbuscules help transfer nutrients from fungus to the root system and vesicles, which are 'saclike' structures that store P as phospholipids. VAM have also been associated with increased plant growth and with enhanced accumulation of plant nutrients, mainly P, Zn, Cu, and S, through greater soil exploration by mycorrhizal hyphae. It has also been reported that VAM simulate plant growth by physiological effects other than by enhancement of nutrient uptake or by reducing the severity of diseases caused by soil borne pathogens (Dehne, 1982). Hence the untamed potential of horticultural crops with VAM can be harvested in these poor fertile soils. Recently, possibilities have been explored for the cultivation of rose-scented geranium (*Palargoniumsps*) in semi-arid conditions by multiple cuttings/harvesting (Aishwath and Anwer, 2010; Aishwath and Tarafdar, 2007; Prakasha Rao, 1993, Aishwath and Lal, 2016).

Table 8 : Horticulture crops for nutritionally eroded (poor fertile) soils

Common Name	Botanical Name Name	Common Name	Botanical Name Name
Fruits		**Vegetables**	
Ber	*Ziziphus mauritiana*	Aloe	*Aloe babdensis*
Cactus pear	*Opuntia ficus*	Amaranath	*Amaranath spp.*
Karonda	*Carissa carandus*	Cassava	*Manihot esculenta*
Marula nut	*Sclerocaryabirrea*	Cowpea	*Vigna unguiculata*
Phalsa	*Gewiasubinaequalis*	Curry leaf	*Murrayakoenigii*
Wood apple	*Feronia liminia*	Drumstick	*Moringa oleifera*
Ornamental		**Spices**	
Amaranths	*Amaranths sps*	Ajwain	*Tracyspermumammi*
Cornflower	*Centaurea cyanus*	Cinnamom	*Cinnamomum verum*
Garden pea	*Pisum sativum*	Coriander	*Coriandrum sativum*
Heliotropium	*Heliotropium indicum*	Dill	*Anethum graveolens &sowa*
Portulaca	*Portulaca gilliesii*	Fenugreek	*Trigonella foenumgraecum*
Medicinal andaromatic plants			
Ashwagandha	*WithaniaSomnifera*	Mint	*Mentha sps*
Basil	*Ocimumbasilicum*	Musk	*Abelmoschus moschatus*
Kalihari	*Gloriosa superba*	Progostemon	*Pogostemoncablin*
Kalmegh	*Andrographis paniculata*	Pilu	*Salvadorasps*
Khas	*Vetiveriazizanioides*	Senna	*Cassia angustifolia*
Lemon grass	*Cymbopogon sps*	Vanila	*Vanilla planifolia*

(Aishwath, 2019)

Horticultural crops for acid sulfate soil:

Pineapple and sugarcane have shown to grow well on acid sulphate soils. The raised-bed system (i.e., ridge and ditch system) is also an appropriate technology for the use of acid sulphate soils. In some areas, these systems are used successfully for mangoes, citrus, bananas and watermelon. Many perennial crops have been observed to grow in low pH/acid sulfate soils which are unsuitable to corn and soybean. These crops includes banana, guava, cashew, grapefruit, jackfruit, lime, mangoes, orange, pineapple, pomegranate etc are best suited(Cho *et al.*, 2002). Some of the crop suitable low pH and acid sulfate soil are listed in table 9 alongwith their tolerance level.

Table 9 : Soil acidity tolerance in horticultural and other crops

Slightly (pH6.1-6.5)	Medium (pH 5.6-6.0)	Strongly (pH 5.1-5.5)	Very strongly (pH 4.5-5.0)
Alfalfa Sugar beats Beans Asparagus Cabbage Cauliflowers Spinach	Vetch Cowpea Cotton Peanut Soybean Wheat Cantaloupe	Corn Oat Rye Sorghum Millet Tobacco Stawberry Peach Pecan	Rhododendron Blueberry Azalea

(Cho *et al.*, 2002)

Research gap and future lines of work

It is necessary to prepare an inventory onthe soil fertility status and water resource of thecoastal belt with reference to adoptive crops of nontraditional area suits to the coastal climate. Location-specific researches arewarranted to develop integrated nutrient management package, involving inorganic, organic, bio-fertilizer sources for sustainablecrop production. Acid sulfate soils should becharacterized in greater details, to helpdevelop appropriate and location-specificmanagement for improved crop productivityof thesesoils. Research is required fordeveloping appropriate models on salt andwater dynamics in soil and suggest improvedwater management in a given watershed.Study is necessary to improve leaching efficiencyof the heavy textured soils underlimited water availability. It is necessary todevelop *low-cost* irrigation technology withhigher efficiency. Additional water resourcesthrough the harvest of excess rainwater may becreated. Conjunctiveuse of poor-quality water needs emphasis in future. Location-specific drainage designs should bedeveloped on a long-term perspective. It is importantto develop contingency plans with thehelp of advanced telecommunication facilities to avoid cyclones and flood damage in sensitive areas. The feasibility of alternative landuse with multi-tier cropping system has to bedeveloped. Improved high-yielding varieties/lines withhigher tolerance to salinity,sodicity, acidity and moisture stressshould be adopted. The evolution of better varieties undermined ecology, development of genotypeswith higher genetic yield ceilings under irrigatedand shallow lowland conditions, andanticipatory breeding to meet the impact ofchanging global climate scenario are needed.

REFERENCES

Aishwath, O.P. 2019. Horticultural crops for degraded land. In: *Handbook of Horticulture (*Eds Verma *et al* and Tech. Coordinator Dr K.L. Chadha*)*, Pub. ICAR-DKMA, New Delhi, **1**: 205-215.

Aishwath, O.P. and Anwer, M.M. 2010. Natural resource management through seed spices and aromatic plants. In: *Recent Advances in Seed Spices (EdsY.R. babu, R.K. Jaiman, K.D. Patel, N.R. Patel & S.B.S. Tikka).* Pub. Daya Publishing House, New Delhi, India. pp 107-118. ISBN 81-7035-689-X

Aishwath, O.P. and Lal, R.2016. Resilience of spices, medicinal and aromatic plants with climate change induced abiotic stresses. *Annals of Plant and Soil Research*, **18**(2): 91-109.

Aishwath, O.P. and Nibauria, S.V.S. 2009. Problematic soil resource utilization through aromatic plants. *Ecol., Environ. Conserv.,* **15**(4): 32-41.

Aishwath, O.P. and Tarafdar, J.C. 2007. Role of organic farming in medicinal and aromatic plants. In: *"Organic Farming and Sustainable Agriculture"* (Eds. Tarafdar*et al.*, 2007). Publisher - Scientific Publisher, Jodhpur. pp 135- 185.

Aishwath, O.P. Anwer, M.M, Mehta, R.S., Meena, R.L. and Jha, B.K. 2012b. Niche Plasticity of Spices, Medicinal and Aromatic Plants with Abiotic Stresses. Pub. Director, NRCSS, Ajmer. pp 1-42.

Aishwath, O.P., Anwer, M.M., Kant, K., Sharma, Y.K. Meena, R.S., 2012a. Vulnerability and adaptability of seed spices with climate change Pub. Director, National Research Centre on Seed Spices, Ajmer. pp 1-28.

Aishwath, O.P., Meena, S.S., Kant, K., Sharma Y. K. and Anwer, M.M. 2010. Climate Change and Seed Spices. In: *Challenges of Climate Change-Indian Horticulture* (Eds, H.P. Singh, J.P. Singh, and S.S. Lal). Published by Westville Publishing House, New Delhi. pp 85-89.

Aishwath, O.P., Mehta, R.S., Meena, R.S., Anwer, M.M., Dagar, J.C., Yadav, R.K., Lal, K. and Sethi, M. 2010. Seed Germination Study of Fenugreek Cultivars with Extended Exposure to Hyper Saline Conditions. *Journal of Soil Salinity and water quality*, **2**(2): 95-101.

Aishwath. O.P., Mehta, R.S., Lal, G., Anwer, M.M., Dagar, J.C., Yadav, R.K. and Singh, R. 2010. Growing seed spices a boon for problematic areas. *Indian Horticulture*, 55(4):19-21.

Bandyopadhyay, B.K. and Bandyopadhyay, A.K. 1983.Effect of salinity on mineralization and immobilization of nitrogen in the coastal saline soil of WestBengal. *Indian Agriculturists*127: 41-50.

Bandyopadhyay, B.K. and Maji, B. 1990. Long-term experiment to study the effect of missing P and K treatments on yield of crops. *Annual Report, Central Soil Salinity Research Institute. Karnal,* pp 180-18l

Bandyopadhyay, B.K. Bandyopadhyay, A.K. and Bhargava, G.P. 1985. Characterization of soil potassium and quantity/intensity relationship of potassium in some coastal soil. *Journal of Indian Society of Soil Science* **33**: 548-54.

Bandyopadhyay, B.K., Burman, D. and Mandal, S. (2011). Improving Agricultural Productivity in Degraded Coastal Land of India – Experiences gained and Lessons Learned. *Journal of Indian Society of Coastal Agricultural Research***29**(1), 1-9.

Buresh R J and De Daua S K. 1991. Nitrogen dynamics and management in rice-legume cropping systems. *Advances in Agronomy* **45**: 2-59.

Chadha, K.L. and Pareek, S.K. 1993. Horticulture for wasteland development. *J. Environmental Resource*, 1(1-2): 58-64.

Chaudhari, S.K. and Aishwath, O.P. (2015) Management of degraded land in the Indian coastal agro-ecosystems. In: *Compendium of ICAR-winter school on "Utilization of Degraded Land and Soil through Horticultural Crops for Agricultural Productivity and Environmental Quality*(Eds Aishwath*et al.*, 2015) held on December 3-23, 2015 at ICAR-National Research Centre on Seed Spices, Tabiji-305206, Ajmer, Rajasthan. pp 16-27.

Chaudhari, S.K., Singh, B. and Aishwath, O.P. (2015) A Worldview of Land and Soil Degradation: Extent and Eco-technologies. In Compendium of ICAR-winter school on "Utilization of Degraded Land and Soil through Horticultural Crops for Agricultural Productivity and Environmental Quality(Eds Aishwath*et al.*, 2015),held on December 3-23, 2015 at ICAR-National Research Centre on Seed Spices, Tabiji-305206, Ajmer, Rajasthan. pp 1-5.

Chhabra, R. and Thakur, N. P. (1998). Lysimeter study on the use of bio-drainage to control waterlogging and secondary salinization in (canal) irrigated arid/semi-arid environment. *Irrigation and Drainage Systems* **12**, 265-288.

Cho, K.M., Ranamukhaarachchi, S.L. and Zoebisch, M.A. (2002) Cropping system on acid sulfate soils in central plains of thailand: Constraints and remadies. Symposium No 63, 17th WCSS held on 14-21 August, 2002 at Thailand. Pp 812-822.

Dehne, H.W. (1982) Interaction between vesicular arbuscular mycorrhizal fungi and plant pathogens.*Phytopathol.,*726: 1115-1119.

Devi, S., Angrish, R., Madaan, S., Toky, O. P. and Arya S. S. (2016). Sinker root system in trees with emphasis on soil profile. *In:* Plant-Microbe Interaction: An Approach to Sustainable Agriculture (Choudhary D. *et al.* Eds.). Springer, Singapore.

Evans, D.D. and Rotar,P,P. 1986. *Role of SesbanfainAgricultW'e.* West View (Publishers), Boulder, Colorado.

Ghosh, S.P., Gangopadhyay, S. and Varma, A. 1991. Alternate and use for coastal agriculture. *Journal of Indian Society of Coastal Agricultural Research* **9**(1-2): 419-31.

Hand Book of Agriculture. 2019. Indian Council of Agriculture, New Delhi 6th edition.

Keating, B.A. and Fisher, M.I. 1985. Comparative tolerance of tropical grain legumes to salinity. *Australian Journal of Agricultural Research* **36**(3): 373-83.

Knndu, D.K. and Pillai, K.G. 1992. Integrated nutrient supply system ill rice and rice based cropping systems. *Fertilizer News,* **37** (4): 35-41.

Maji, A.K., Obi Reddy, G.P., and Sarkar, D. (2010). Degraded and Wastelands of India: Status and Spatial Distribution. Indian Council of Agricultural Research, New Delhi, India. p. 159.

Maji, B. and Bandyopadhyay, B. K. 1990. Response of rice to soil and foliar application of micro-nutrients in coastal s1lline soil of Sunderbans, West Bengal. *Journal of Indian Society of Coastal Agricultural Research* **8**(1): 47-49,

Maji, B. and Bandyopadhyay, B.K. 1989. Effect of micronutrients on yield and nutrient uptake by safflower on coastal saline soil of Sunderbans, West Bengal. *Journal of Indian Society of Coastal Agricultural* Research**1**: 774-780.

Maji, B. and Bandyopadhyay, B.K. 1992. Effectof submergence on Fe, Mn and Cu contents in some coastal rice soils of West Bengal. *Journalof Indian Society of Soil Science* **40**: 390-2.

Majj. B., Bandyopadhyay, B.K. and Sen, H S. 1990. Characterization of coastal saline soils of West Bengal and Orissa. *Annual Report, Central Soil Salinity Research institute, Karnal,* pp 174-177.

Mandal, A. K., Reddy, G. O., Ravisankar, T. and Yadav, R. K. (2018). Computerized database of salt-affected soils for coastal region of India. *Journal of Soil Salinity & Water Quality* **10:** 1-13.

Prakasha Rao, E.V.S. 1993 Nutrient management in some important tropical aromatic crops present and future. *Indian Perfumer*, 37: 35-39.

Rai, M. (2004). Coastal ecosystem in India- An overview. *Journal of the Indian Society of Coastal Agricultural Research***1&2**: 13-18.

Ramamohan Rao, M.S. 1998. Approaches to management of denudated lands in peninsular, India. In, *Technologies for waste land development* (Eds Abrol, I.P. and Dhurva Narayana, V.V.). Pub. Information Div. ICAR, KAB, New Delhi. pp 232-244.

Samant, D., Chauhan, V.B.S. and Kumari, M. (2021) Horticulture Crops for Nutrition and Livelihood Security: Opportunities and Challenges in Coastal Region. In: Souvenir of ISCA Webinar on *International Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security,* held from 16-19 March 2021 at Indian Society of Coastal Agricultural Research, ICAR-CSSRI, Regional Research, Station, Canning Town - 743 329, West Bengal, India. pp 32-39.

Samuel, J. and Pushpanjali (2019) Rainfed fruit crops -At a glance, *leaflet of ICAR-CRIDA,* Rajendra Nagar,Hyderabad. pp 1-29. DOI: 10.13140/RG.2.2.14318.56648.

Sen H.S. and Bandyopadhyay, B.K. 1987. Volatilization of ammonia from submerged saline soil. *Soil Science* **143**: 34-9.

Sharma, D.K. (2021) Reclamation and Management of Salt-affected Soils for Crop Production with Special Emphasis on Coastal region: Trend and Prospects. In: Souvenir of ISCA Webinar on *International*

Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security, held from 16-19 March 2021 at Indian Society of Coastal Agricultural Research, ICAR-CSSRI, Regional Research, Station, Canning Town - 743 329, West Bengal, India. pp 11-21.

Shiva, M.P. Lehri, A. and Shiva, A. 2002. Introduction, *Calamus, Cardamom, Clove Kewada Mint and Vetiver*. In. *Aromatic and Medicinal Plants*. Publisher, International Book Distributors, Dehra Dun, India. pp 67-307.

Singh, N.T., Mongia, A.D. and Ganeshamunthy, AN. 1987. Coastal successions in relation to soil salinity in soils of Andaman. *Proceedings, International Symposium on Afforestation of Salt Affected Soils.* pp 151-67 held at Central Soil Salinity Research Institute, Kamal.

Singh, N.T., Mongia, A.D. and Ganeshamurthy, A.N. 1988. *Soils of Andaman and Nicobar Islands,* 78 pp. Research Bulletin 1. Central Agricultural Research Institute, Port Blair.

Singh, Y., Khind, C.S. and Singh, Bijay. 1991. Efficient management of leguminous green manures in wetland rice. *Advances in Agronomy,* **45:**135-89.

Singh, Y.P., Nayak, A. K., Sharma, D. K., Gautam, R. K., Singh, R. K., Singh, R., Mishra, V. K., Paris, T. and Ismail, A. M. (2014). Farmers' participatory varietal selection: A sustainable crop improvement approach for the 21st century. *Agroecology and Sustainable Food Systems* **38:** 427-444.

Velayutham, M., Sarkar, D., Reddy, R. S., Natarajan, A., Krishan, P., Shiva Prasad, C.R., Challa, O., Harindranath, C.S., Shyampura, R.L., Sharma, J.P. and Bhattacharyya, T. (1999). Soil resource and their potentialities in coastal areas of India. *Journal of the Indian Society of Coastal Agricultural Research***17**:29-47.

Verma, V. and Chinnamani, S. 1998. Rehabilitation of ravine lands. In, *Technologies for waste land development* (Eds Abrol, I.P. and Dhurva Narayana, V.V.). Pub. Information Div. ICAR, KAB, New Delhi. pp 263-272.

Yadav, J.S.P. (2001). Resource management for higher productivity and ecological security in the coastal ecosystem of India. *Journal of the Indian Society of Coastal Agricultural Research* **1&2**: 10-29.

Yadav, J.S.P. 1980. Efficiency of fertilizers used in saline and alkali soils for crop production. *Fertilizer News* **25** (9): 19-27.

Yadav, J.S.P. 1994. Constraints and potentials of coastal agriculture in India (presidential address). *Proceedings. National Seminar of Indian Society of Coastal Agricultural Research on Strategies for Coastal Agriculture in Twenty First Century,* held during 7-10, November 1992 at Konkan KrishiVidyapeeth, Dapoli.

Yadav, J.S.P., Bandyopadhyay, A.K. and Bandyopadhyay, B.K. 1983. Extent of coastal saline soils in India. .*Journal of Indian Society of Coastal Agricultural Research* **1** (1): 1-6.

Yadav, R.K., Meena, R.L., and Aishwath, O.P. 2013. Salinity tolerance of coriander, fennel and fenugreek seed spices under semi-arid conditions of northern India. *Journal of Soil Salinity and Water Quality,***5**(2): 114-118.

L-9

Nature-based Solutions for Agricultural Sustainability and Climate Resilience in NEH Region, India

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ABSTRACT

Nature-based Solutions (NbS) encompass a variety of practices that, in many cases, have been used for decades, are based on indigenous knowledge or were known under different names like conservation agriculture, smart climate agriculture, organic agriculture, etc. Often, the term `Nature-based Solutions´ is used as an umbrella concept to cover a range of ecosystem related approaches including ecosystem-based adaptation, natural climate solutions, and green infrastructure (Fig. 1). The term itself has received increased attention, with multiple entities working to consolidate definitions, provide principles, educate partners and advance solutions. One of the most common and widely used definitions of NbS comes from the International Union for Conservation of Nature (IUCN)as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2016).

The IUCN has recently released a global standard for properly deploying NbS, which describes eight criteria, including attention to a societal challenge, economic feasibility, biodiversity gain and inclusive governance (IUCN, 2016). These criteria and associated indicators help measure the strength of interventions by ensuring that NbSactivities are properly designed and implemented.

Criteria of Nature-based Solutions

1. NbS embrace nature conservation norms (and principles);
2. NbS can be implemented alone or in an integrated manner with other solutions to societal challenges e.g. technological and engineering solutions;
3. NbS are determined by site-specific natural and cultural contexts that include traditional, local and scientific knowledge;
4. NbS produce societal benefits fairly and equitably, in a manner that promotes transparency and broad participation;
5. NbS maintain biological and cultural diversity and the ability of ecosystems to evolve;
6. NbS are applied at a landscape scale;
7. NbS recognize and address the trade-offs between the production of a few immediate economic benefits for development and future options for the output of the full range of ecosystems services; and
8. NbS are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

Fig. 1:Nature-based Solutions as an umbrella term for ecosystem-related approaches

Source: IUCN(2016)

In recent years, considerable progress has been made in the area of Nature-based Solutions that improve ecosystem functions of environments and landscapes affected by agricultural practices and land degradation while enhancing livelihoods and other social and cultural processes. This has opened up a portfolio of NbS options that offer a pragmatic way forward for simultaneously addressing conservation, climate and socioeconomic objectives while maintaining healthy and productive agricultural systems. NbS can mimic natural processes and build on land restoration and operational water-land management concepts that aim to simultaneously improve vegetation and water availability and quality and raise agricultural productivity (Sonneveldet al., 2018, Sanjay-Swami, 2021a). NbS can involve conserving or rehabilitating natural ecosystems and/or enhancing or creating natural processes in modified or artificial ecosystems (UNWWAP, 2018). In agricultural landscapes, NbS can be applied for soil health, soil moisture, carbon mitigation (through soil and forestry), downstream water quality protections, biodiversity benefits as well as agricultural production and supply chains to achieve net-zero environmental impacts while achieving food and water security, and meet climate goals.

There is a spectrum of nature-based interventions that vary in ecosystem condition – from natural ecosystems to managed or modified ecosystems to novel or artificial ecosystems – as well as in a scale, focal purpose and implementing actors. In the context of the agricultural and allied food production systems, Nature-based Solutions encompass a broad range of practices that can be deployed directly (Miralles-Wilhelm, 2021). These practices can provide triple benefits when appropriately deployed to build agricultural production and resilience, mitigate climate change, and enhance nature and biodiversity. Many sustainable practices and approaches drawing on agroecological principles (Altieri, 1992; FAO, 2018) or collectively referred to as climate-smart agriculture (Rosenstock et al., 2019), would also fall into this category.

The North Eastern Hill (NEH) region of India is culturally rich and socially diversified, being home to around 145 tribal communities with their own cultures, traditions, and livelihood practices. The environment, local conditions, socioeconomic and socio-cultural life of different tribal communities and their rituals associated with agricultural practices have given basis for the development of many indigenous farming systems, which have in-built Nature-based Solutions for conservation, preservation and utilization of natural resources(Sanjay-Swami, 2019a). The rice-fish system of Apatanitribe in Arunachal Pradesh, Zabo farming system and Alder-based farming system in Nagaland, bun cultivation and bamboo drip irrigation system in Meghalaya are good examples of location-specific Nature-based Solutions in agriculture. The following section deals with these critical Nature-based Solutions practised in the NEH region for agricultural sustainability and climate resilience.

Rice-fish system of Apatanitribe in Arunachal Pradesh

It is a multi-purpose water management system that integrates land, water and farming by protecting soil erosion and conserving water for irrigation and paddy-cum-fish culture. It has been practised in a flat land of about 30 km2 located at an altitude of about 1,525 m above m.s.l. in the humid tropic climate of Lower Subansiri district of Arunachal Pradesh. Local tribe 'Apatani', which developed this system, dominates the area; every stream rising from the hill is trapped soon after it emerges from the forest, canalized at the rim of the valley and diverted by the primary, secondary and tertiary channels. The first stream diversion takes off a short distance above the terraces. A central irrigation channel of 0.61 X 0.61 m size and embankment of the same size in each of the paddy plots are constructed (Fig. 2). The water into the plots is drawn from the irrigation channel and has a check gate made of bamboo splits (huburs) at the inlet for regulation of entry and exit of water through the outlet. The farmers draw off the water from the rice fields twice, once during flowering and finally at maturity on an average 10 cm water level is maintained in the plots by adjusting the height of outlet pipes. In fish culture, a vertical pit is dug in the middle of the plot, so that the water remains in these pits even when it drains away from the surrounding fields. To prevent trashes or migration of fish, a semi-circular wooden / bamboo net is installed at the inlet to reduce the beating action of flowing water regulating in soil erosion; wooden strikes or planks are put at the outlet. The huburs are installed about 15 cm to 25 cm above the bed level. They are made of plank, pine tree trunk, or bamboo stem of different diameters. The water from terraces is finally drained into the river, which flows in the middle of valley (Sanjay-Swami et al., 2021).

Fig. 2: Rice-fish system of Apatani plateau

Source: Field trip, 2012

ZABO farming system in Nagaland

"Zabo" is an indigenous farming system of Nagaland. This system originates in Kikruma village of Phek district of Nagaland, located at an altitude of 1270 m above m.s.l. The word "Zabo" means impounding of water. It combines forest, agriculture and animal husbandry with well-founded soil and water conservation base. It has protected forest land towards the top of hill, water harvesting tanks in the middle and cattle yard and paddy fields for storage for crops and irrigation during the crop period (Fig. 3a & b). Special techniques for seepage control in the paddy plots are followed. Paddy husk is used on shoulder bunds and puddling is done thoroughly (Sanjay-Swami et al., 2021).

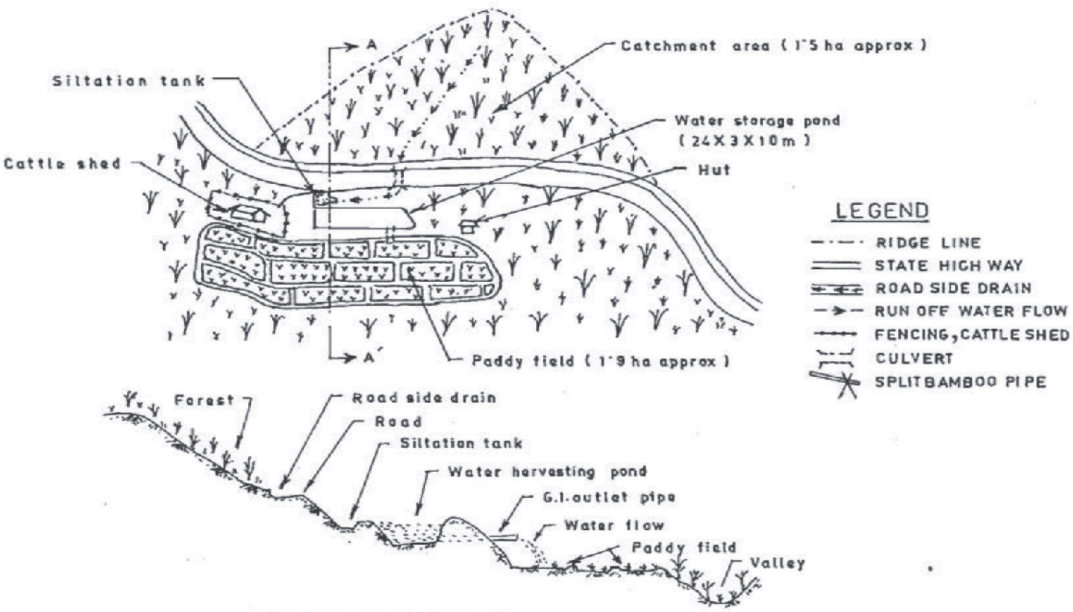

Fig. 3a: Land management under Zabo farming system

Fig. 3b: Land management under Zabo farming system

Source: Field trip, 2022

Alder based farming system in Nagaland

In some pockets of Nagaland, the farmers use Alnus nepalensis (Alder) tree for agriculture. In this system, the Alder seedlings are planted on the sloppy land intended for cultivation and the alder grow fast till attain six to ten years old (Fig. 4). At this stage initially the trees are pollarded, the leaves and twigs are burnt and ash is mixed with soil to prepare it for raising crops (Fig. 5 & 6). Subsequently, pollarding is done once every four to six years. Under this process, coppice are cut except five to six on top of the main trunk and a crop schedule is followed, including the fallow period of two to four years. The bigger branches stripped of leaves are used for five wood, while the root of the tree develops nodules (colonies of Frankia) responsible for soil fertility whereas the spreading nature of the roots helps prevent soil erosion in slopes. Nitrogen fixation in Alnusnepalensis occurs through a symbiotic relationship between Alnus with nitrogen-fixing actinomycetes of the genus Frankia and is, therefore, able to improve degrades jhum lands. The symbiotic micro-organism Frankia (actinomycetes) are located in specialized structures, or nodules, along the root system of the host plants. The root nodules are analogous to those induced by Rhizobium in legumes. They provide an environment where Frankia can grow and prosper while providing the host plant with fixed atmospheric nitrogen. Unlike the Rhizobium-legume symbiosis, where most of the host plants belong to a single large family, Frankia can form root nodules in symbiosis with actinorhizal plants. The ability of the alder trees to develop and retain soil fertility has been fully utilized by farmers in Angami, Chakhesang, Chang, Yimchunger and Konyak areas in Nagaland at varying altitudes.

Fig. 4: Alder based farming in *Jhum* land
Source: Field trip, 2014

Fig. 5: Field after crop harvest
Source: Field trip, 2014

Fig. 6: Pollarding of alder tree**Source:** Field trip, 2014

Bun cultivation in Meghalaya

Bun cultivation is a modification of shifting cultivation and has been followed in the Meghalaya plateau for the last four decades. In this system, the crops are grown on a series of raised beds of 0.15-0.30 m in height and 0.75-1.0 m in width with almost equal width under sunken area made along the slopes, locally referred to as "Bun" (Fig. 7, 8 & 9) While preparing buns, biomass is burnt under the soil. The land is abandoned after two or three years. It provides an improved production system, helps conserve soil moisture, and prevents land degradation and erosion. This system builds bench terraces on the hill slopes running across the slopes. The gap between each bun is levelled using the cut and fill method. The vertical break between each terrace is one meter. Such measures help in preventing erosion and retaining maximum rainwater within the slopes. It also helps safely dispose of the additional runoff from the slopes to the lower areas (Sanjay-Swami et al., 2021).

Fig. 7: Buns ready for sowing
Source: Field trip, 2019

Fig. 8: Vegetable cultivation on buns
Source: Field trip, 2019

Fig. 9: Larger view of bun cultivation
Source: Field trip, 2019

Bamboo drip irrigation system in Meghalaya

Meghalaya is well-known for having the highest rainfall in the world of about 11500 mm recorded annually. This makes Meghalaya the wettest places on earth. Though, the state gets plenty of rainfall during the monsoon season, a well-managed irrigation system is required during the dry spell. Hill farming is subject to a number of serious constraints such as undulating topography, steep-slops, poor and shallow soils (prone to erosion). Majority of the fields in the region are situated across the hilly slopes. Therefore, the water-retention capacity of the terrain is poor and bringing water from distant water sources to the fields is a big challenge for the farmers in the rural areas. Ground channelling is also impractical due to the harsh landscape. Confronted with such adverse conditions for irrigation, the traditional farmers of Meghalaya have come up with an innovative way. The farmers of the Jaintiaand Khasihills have developed unique bamboo drip irrigation system of trapping springs and stream water normally to irrigate the betel leaf or black pepper crops planted in areca nut orchards or in mixed orchards.

The bamboo drip irrigation system is based on gravity and the steep slopes facilitate in implementing it. Water from an uphill source is trapped and brought to the plantation by a main bamboo channel. Usually these water sources are far off from the plantations and the main bamboo channel runs hundreds of meters - in some cases even few kilo meters. The water is then regulated through a complex bamboo network of secondary and tertiary channels to all the parts and corners of a plantation, right up to the bottom of the hill (Fig. 10) (Sanjay-Swami, 2021b).

Fig. 10: Traditional bamboo drip irrigation system

Source: Field trip, 2018

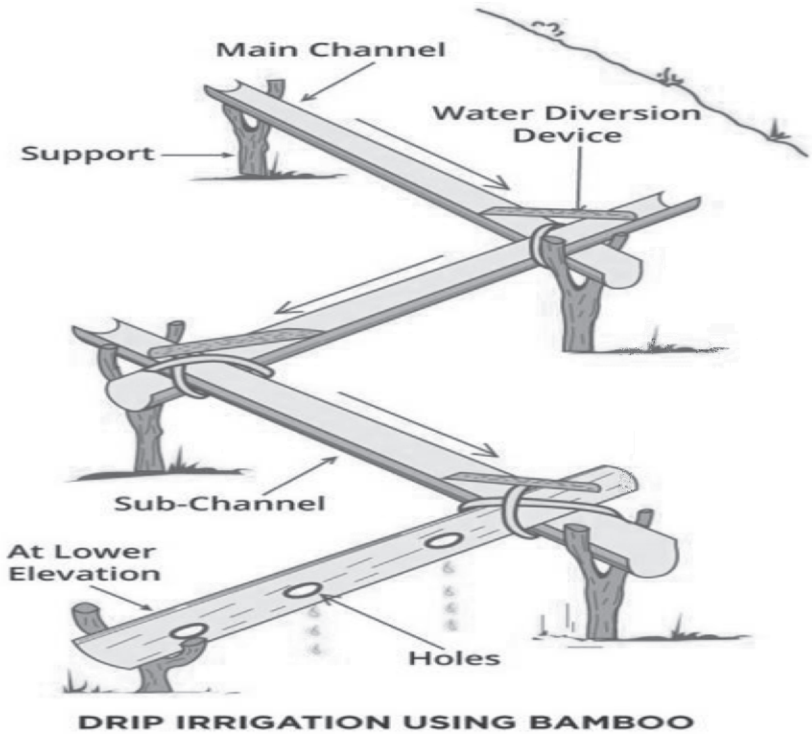

Fig. 11: Different stages of water distribution in bamboo drip irrigation system

Bamboos of varying diameters are used to build the channels, support structures, diversion pipes and strips. Channels are held above the ground by bamboo or wooden Y-shaped sticks (Fig. 11). About a third of the outer casing in length and internodes of bamboo, pieces must be removed while fabricating the system. One stretch of the channel is lashed to another by thin bamboo strips. Indigenous tools like a dao, a type of local axe, and chisels of various shapes and designs are used to build the bamboo network. Two laborers can construct a network covering 1 hectare of land in 15 days. They are built with such skill that water wastage by leakage is minimal. The construction is based on a simple thumb rule that the ratio of the diameter of primary channel to tertiary channel determines the quantity of water which will reach the trees. It is a subtle skill which comes with years of observation and experience. It is so perfected that about 18-20 litres of water entering the bamboo pipe system per minute gets transported over several hundred metres and finally gets reduced to 20-80 drops per minute at the site of the plant (Sanjay-Swami, 2021c).

The cost involved in building the system is minimal. Bamboo is available freely in this region. Usually, the farmer himself sets up the system in his plantation with some help from 1 or 2 labourers. The region gets heavy rain and as a result, each installation lasts for about 2-3 years. After the rainy season, the undergrowth is cleared and reinforcements are provided. Old bamboo is left to rot, which over time, returns to the soil as humus. Cooperatives are formed and each farmer provides his skill and labour to build and maintain the system. Water distribution from one plantation to another is done by diverting water at fixed times. This avoids the occurrence of conflicts between various farmers. By this method, the whole community works harmoniously - sharing the limited resources judiciously (Sanjay-Swami, 2019b).

CONCLUSION

Depending on how the world's ecosystems are managed, they can either contribute to the problem or provide effective Nature-based Solutions for the emerging challenges in agriculture. The above-discussed Nature-based Solutions, adopted and being practised by the farmers of NEH region, conserve, manage and restore natural resources, maintaining agricultural sustainability and climate change issues are just a few of the hundreds. The uniqueness of these Nature-based Solutions is their suitability to the local conditions, their economic feasibility and easy implementation.

REFERENCES

Altieri, M.A. (1992). Agro-ecological foundations of alternative agriculture in California. *Agriculture, Ecosystems and Environment*, 39(1): 23-53. https://doi.org/10.1016/0167-8809(92)90203-N

FAO (2018). The 10 elements of agro-ecology guiding the transition to sustainable food and agricultural systems. http://www.fao.org/3/i9037en/I9037EN.pdf).

IUCN (2016). Nature-based Solutions, International Union for Conservation of Nature. In: IUCN [online].

Miralles-Wilhelm, F. (2021). Nature-based solutions in agriculture: Sustainable management and conservation of land, water, and biodiversity. Virginia. FAO and The Nature Conservancy. https://doi.org/10.4060/cb3140en

Rosenstock, T.S., Rohrbach, D., Nowak, A. and Girvetz, E. (2019). An introduction to the climate-smart agriculture papers. In: T.S. Rosenstock, A. Nowak and E. Girvetz (eds.) *The Climate-Smart Agriculture Papers: Investigating the Business of a Productive, Resilient and Low Emission Future*, pp. 1–12. Cham, Springer International Publishing. https://doi.org/10.1007/978-3-319-92798-5_1)

Sanjay-Swami (2019a). Managing fragile hill ecosystems of North Eastern Region. In: *Soil and Water Conservation Today*, 14(1): 02.

Sanjay-Swami (2019b). Ecosystem approach to make agriculture more efficient, more sustainable in Meghalaya. In: *Souvenir, CAU Regional Agri-Fair 2019-20*, November 11-13, 2019: 52-57.

Sanjay-Swami (2021a). Integrated management of land, water and bioresources for sustainable agriculture in North Eastern Region of India**. *Grassroots Journal of Natural Resources,* 4 (2): 136-150.** https://doi.org/10.33002/nr2581.6853.040210.

Sanjay-Swami (2021b). Bamboo drip irrigation: Coupling tradition and innovation for wider applicability. In: *Soil and Water Conservation Today*, 16 (4): 06-07. ISSN: 0975-4059.

Sanjay-Swami (2021c). Developing agriculturally vibrant and self reliant (AVSR) NEH. In: *Souvenir, CAU Regional Agri-Fair 2020-21*, March 08-10, 2021: 38-43.

Sanjay-Swami, Singh, S., Patgiri, P., Raj, V.A. and Singh, T.D. (2021). Ecological sustainability in agricultural production intensification: NER perspective. In: *Sustainable Agriculture: Recent Advances,* (eds.) Sanjay-Swami and Singh, S., Biotech Books, New Delhi, India. pp. 1-20. ISBN: 978-81-7622-493-2.

Sonneveld, B.G.J.S., Merbis, M.D., Alfarra, A., Ünver, I.H.O., Arnal, M.F., and Food and Agriculture Organization of the United Nations. (2018). Nature-based solutions for agricultural water management and food security.

UNWWAP (2018). *UN World Water Development Report 2018*, the United Nations World Water Assessment Programme, Paris, UNESCO. https://www.unwater.org/publications/world-waterdevelopment-report-2018/).

L-10

Strategies for sustaining soil quality and crop productivity in salt affected soils

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ABSTRACT

Maintaining soil quality is crucial for sustaining crop productivity and product quality under intensive farming systems. The terms soil quality and health are often used interchangeably in scientific literature. Harris and Bezidicek (1991) defined soil health as the continued capacity of soil to function as a vital living system within the ecosystem and land-use boundaries to sustain biological productivity and maintain the quality of air and water environments. On the other hand, soil quality is defined by Doran and Parkin (1994) as the capacity of soil to function within the ecosystem and land-use boundaries, sustain biological productivity, maintain environmental quality and promote plant, animal and human health. Gregorich *et al*. (1994) described soil quality as the degree of fitness of soil for specific use. Soil quality encompasses crop productivity, environmental protection, food safety, and animal/human health.

The sustenance of soil quality depends on the perception of how soils respond to agricultural use and practice over a prescribed period. To develop best management practices, it is necessary to develop a method to assess the soil quality over such time. In this connection, Gregorich *et al*. (1994) have proposed two approaches viz., the descriptive approach and the indicative approach. The illustrative method involves characterizing descriptive properties such as its look, resistance to tillage, smell, etc. The indicative process involves the detection of specific indicators or parameters to enumerate the soil quality. The particular indicator is one that is sensitive to changes in soil management, soil perturbation and inputs into the system. Over time, the indicative approach has become popular and is being used globally by scientists to assess soil quality. Under this approach, the indicators are grouped into three categories: physical, chemical and biological. Further, soils' productivity and its resilient environment capacity depend on interactive effects of these groups of indicators**.** The minimum data set (M.D.S.) of physical, chemical and biological indicators of soil quality is given in **Table 1**. Soil quality can be altered by natural and anthropogenic factors, including land use and farming practices.

Table 1: Proposed minimum data set of physical, chemical and biological indicators for screening the condition quality and soil health

Indicators of soil condition	Relationship to soil condition and function (rationale as a priority measurement)	Ecologically relevant values/units (comparisons for evaluation)
Physical Texture	Retention and transport of water and chemicals; Modeling use, soil erosion and variability estimate	% Sand, silt, and clay; less eroded sited or landscape positions
Depth of soil, top soil and rooting	Estimate of productivity potential and erosion; normalizes landscape and geographic variability	cm or m; non-cultivated sites or varying landscape positions

Infiltration and soil bulk density (SBD)	Potential for leaching, productivity, and erosivity; SBD needed to adjust analyses to volumetric basis.	%(g/cm^3), cm of available H_2O/30 cm; precipitation intensity
Water holding capacity (Water retention characteristic)	Related to water retention, transport and erosivity, available water, calculate from SBD, texture, and O.M.	% (cm^3/cm3), cm of available water/30 cm; precipitation intensity
Chemical		
Soil organic matter (O.M.) (total organic C and N)	Defines soil fertility, stability, and erosion extent; use in process models and for site normalization	kg C or N/ha-30 cm; non-cultivated or native control
pH	Defines biological and chemical activity thresholds; essential to process modeling	Compared with upper and lower limits for plant and microbial activity
Electrical conductivity	Defines plant and microbial nutrients and potential for N loss; productivity and environmental quality indicators	dS/m; compared with upper and lower limits for plant and microbial activity
Extractable N, P, and K	Plant available nutrients and potential for N loss; productivity and environmental quality indicators	kg/ha-30 cm; seasonal sufficiency levels for crop growth
Biological		
Microbial biomass C and N	Microbial catalytic potential and repository for C and N; modeling: Early warning of management, Effect on O.M.	kg N or C/ha-30 cm; relative to total C & N or CO_2 produced
Potentially mineralizable N (anaerobic incubation)	Soil productivity and N supplying potential; process modelling; (a surrogate indicator of biomass)	kg N/ha-30 cm/day; relative to total C or total N contents
Soil respiration, water content, and temperature	Microbial activity measure (in some cases plants); process modelling, estimate of biomass activity	kg C/ha/day; relative microbial biomass activity, C loss vs inputs and total C pool

Source: Doran and Parkin (1994); Larson and Pierce (1994)

The concept of sustainability in agricultural system

All production systems exist today, from nomadic herding to continuous, intensive monocrop systems. Their distribution is determined by soil and climate conditions and social and economic factors. In very general terms, as one moves from drier to wetter areas, pastures and animals become less critical, and trees more so. Population density is most excellent where soils are most fertile and management systems the most intense. Most production systems have evolved to be sustainable in terms of the environmental conditions prevailing at the time-including the level of demographic pressure. Given that demographic pressure has increased dramatically over the past century, and will continue to do so for the next half-century, sustainability in agriculture and soil management must be defined to include the need for increased demand to be met. F.A.O. (1991) has given the following definition: 'A sustainable agricultural system is one which involves the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and animal genetic resources, and is economically viable and socially acceptable. While studying the variation of sugarcane yield under salt-affected soil, Dey *et al.* (1996) observed that step down regression analysis revealed that E.C. and $CaCO_3$ explained 34.7% variation in cane yield; inclusion of available K improved the coefficient of determination significantly (P= 0.05) from 0.387 to 0.712.

Since soil quality is affected by soil genesis and an understanding of soil genesis is essential for sustainable soil management, the genesis of sodic soil and saline soil including salt affected vertisol, is provided below:

Genesis of Sodic Soils

Several types of research carried out on sodic soil genesis in the Indo-Gangetic plain in India indicated that the salt present in these soils resulted from weathering. The primary minerals comprising of quartz, feldspars, muscovite, biotite, chloritised biotite, tourmaline, zircon and hornblende are similar in the sand fraction of sodic and non-sodic soils. The weathering of alumino-silicate minerals through carbonation yield alkaline bicarbonates and carbonates, apart from silica and alumina. The enormous amount of sodium release from the sodic and non-sodic soils was also investigated to ascertain the source of sodium from mineral lattices through hydrolytic dissolution. Studies on the geochemical source of sodium in sodic soils showed periodic release of sodium from the sand fraction in the Indo-Gangetic Plain. On the other hand, relative relief differences between parts of the plain and the outer Himalayas or Siwalik and within the plain facilitate runoff during the monsoon season, carrying amount of the weathering products for deposition in the micro-basin. The process of socialization in these soils, therefore, begins at the surface. It is low at the deeper horizons where illuviation and sodium saturation occurs with deflocculated clay particles and limited leaching of alkali salt solutions. Repeated wetting and drying cycles facilitate maximum salts accumulation on the surface. The most favorable climate is mean annual rainfall between 550-1000 mm with ustic soil moisture regime in Haryana and Punjab and aquic and para-aquic regime in Uttar Pradesh. The soils are characterized by the typical illuviated B horizon enriched with clay and /or sodium, the fine/total clay ratios, and the presence of clay cutans on ped faces are prevalent. A shallow underground water table with seasonal fluctuations prevails below some of the sodic soils. The water having a very low degree of mineralization and being non-sodic is extensively used for irrigation and is an active source of soil sodiumisation. A distinct, regular and thick zone of calcium carbonate accumulation, mainly dolomitic exists below the surface in sodic soils. The smooth boundary of the calcic horizon, irregular shape of individual concretions (Kankar), and regularity of occurrence underneath vast areas highlight their pedogenic origin. It originates in the presence of fluctuating and shallow water table. On drying and the water table recedes, the precipitation of calcium and magnesium occurs irreversibly to develop carbonate concretions. With every passing hydrological cycle, the concretions continue to grow in size and impede the diverse kinds of soil materials. Sodic conditions bring about the degradation of clay minerals leading to the accumulation of amorphous oxides of silica, alumina and iron associated with repeated synthesis of clay minerals. The degradation is judged by the presence of amorphous silica and alumina and an equivalent ratio of $SiO_2/Al_2O_3 > 2$. Characteristics of sodic soil is provided in Table 2.

Genesis of saline soils

Inland saline soils **:** Saline soils occur in the alluvial plain and the shield areas (plains with sand dunes and Aravalli Hills) occupying basins or playas. These soils have commonly cambic and occasionally argillic horizon at a depth below the surface, a calcic horizon at variable depths, coarser soil fabric, high alt content, predominance of chloride and sulfates of sodium, calcium and magnesium, neutral to slightly alkaline pH, usually high S.A.R., rapid to moderately rapid infiltration rates, saline ground water at varying depths and a petrocalcic horizon occasionally within 1 m depth. The occurrence of saline soils in Rajasthan is related to the climate, topography and practice of irrigated farming. Secondary salinization occurred in areas under canal irrigation, waterlogging and presence of hydrological barrier restricting leaching and drainage of salt within the soil profile. Characteristics of saline soil is provided in table 2.

Saline soils of the delta region**:** The process of soil accretion and land subsidence operate in the delta region. The alluvium developed by the rivers in delta region is frequently subjected to inundation during high and low tides with the ingress of sea water through numerous creeks. The problem of soil salinity appeared in the Ganges delta, known as Sunderban, and the country's Godavari, Krishna and Cauvery deltas. The soil in Sunderban are developed from the micaceous rocks and are characterized by an ocric epipedon, grey to light brownish grey color, presence of yellowish brown mottles, signs of gleying, with grey, black or dark grey colors in the substratum, uniformly fine texture varying from clay loam to clay to silty clay loam, neutral to slightly acidic pH, those occurring in the basins contain highest amount of salts in the epipedon and relatively low E.C. values below, lower ECe values at the surface that increases with increasing depth in soils of higher elevation, preponderance of chlorides and sulfates of sodium, magnesium and calcium with minor bicarbonates, S.A.R. and E.S.P. varying between 10 to 30, a shallow saline water table, low infiltration rates, absence of calcium carbonate and organic matter content less than one percent. Because of high rainfall in these areas, high ECe values are not encountered due to salt flushing during monsoon. The local relief and aspect, however, play a major role in facilitating salt accumulation in this region. The soils in the Godavari, Krishna and Cauvery delta regions differ from the Ganges delta primarily due to their origin from basaltic rocks. The climate is semiarid, the soil exhibit completely different mineralogy and salt regime. The soil properties are similar to vertisols of the delta region. The presence of an ocric epipedon, a uniform fine (clay) texture, angular/sub-angular blocky structure grading to massive, absence of concretions and calcium carbonate, neutral to slightly alkaline pH, very high ECe, shallow water table, deep crack and the presence of slickensides in subsurface horizon are typical characteristics of these soils. Owing to low rainfall, these soils are higher in salinity than the soils of the Ganges delta.

Saline soils of the coastal belt**:** The typical ground found in the Guntur and Prakasam districts of Andhra Pradesh shows a close relationship between soil characteristics and physiographic settings. The upland soils are free from salinity. The midland soils characterized by stratified substratum with layers varying in thickness and the texture varying from loamy sand to sandy loam in the surface and sandy clay loam below the surface. In the basin, dark grayish brown to grey with clay textured soils which remain submerged during the monsoon, familiar presence of marine shells in the soil profile, shallow saline water table in the substratum, high E.C. throughout the profile, prevalence of chlorides and sulfates of sodium, calcium and magnesium, neutral pH, slow permeability and low to medium organic matter content.

The problem of soil salinity is severe in the coastal belt of Saurashtra in Gujarat located under the arid and semiarid region. Originating in basaltic rocks, these are commonly vertisols or having vertical characteristics. There are differences concerning the menace of soil salinity due to differences in the relief. These soils are similar to the vertisols of Andhra Pradesh but different in the E.S.P. values ranging from 10 to 60, S.A.R. values from 10 to 25, high hydraulic conductivity but develop sodicity after leaching and poor physical conditions. Almost all the soils are potentially saline with salt reserves in the profile sub-stratum. These are common in the alluvium, and other terraces like a flood plain, mud flats along the tidal inlets and mud flats along the coast, which are more saline than the old flood plain, inter-terraces of flood plains and recent flood plains. The Rann of Kachchh constitutes a vast marshy area in the arid coastal region in Gujarat. It is divided into Great Rann and Little Rann having an area of 18130 and 5180 sq. km. Rann soils are fine textured and contain large quantities of chlorides and sulfates of Na, Mg and Ca. Gypsum layers are encountered at varying depths The Rann receives the huge discharge of flood water from the Luni, Banas, Saraswati, Rupan, Fulka and Brahmani streams during the monsoon. At the same time strong wind from the southwest force seawater into the area, rendering it as saline. The depth of flood water continues to stand up till December. It dries from January till June. These soils showed a high degree of gleying with black matrix in the epipedon and blue-green to bottle green in the substratum. Reddish brown to brown horizons were reported to be the zone of iron pan formation in the substratum. An exciting feature of these soils is the presence of gypsum deposition, iron pan and gleyed horizons within the profile in different sequences. These indicate the operation of similar genetic processes over the past geological period as the process of land accretion continued. Saline acid sulfate soils occur along the Malabar Coast in Kerala, occupying marshy depressions (lagoons). These have developed on the alluvium derived from laterites under humid and tropical climates. The soils undergo freshwater submergence from May to December and seawater inundation under the tidal cycle during the subsequent lean months. The salient features are our epipedon, the humic horizon in the substratum of some soil, a variety of soil matrix colours ranging from pale yellow to very dark grey, grayish brown, and dark yellowish brown, signs of gleying, reduction and bleaching, high E.C. throughout the profile, the prevalence of chlorides and sulfates of sodium, calcium and magnesium, soil pH 3.5 to 7.5, organic matter content varying from 2 to 40%, a shallow saline water table, and in some cases the presence of pyrites clay.

Table 2: Characteristics of sodic and saline soils

Salt affected soils	pH s	EC (dSm^{-1})	Exchangeable Sodium percent (E.S.P.)	Salt in excess
Sodic (Alkali) Soils	> 8.2	Variable	>15	Carbonate and Bicarbonate of sodium salts
Saline	< 8.2	> 4	< 15	Chloride and sulphate calcium, magnesium and sodium salts
Saline-Sodic soils	< 8.2	> 4	> 15	Chloride, sulphate, carbonate and bicarbonate of calcium, magnesium and sodium salts

Saline Vertisols

Among 11 soil orders (Andisols, Alfisols, Aridisols, Entisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, Vertisols), Vertisols form an important soil group. These soils can be defined as clay soils with high shrink-swell potential with wide, deep cracks when dry. Most of these soils have distinct wet and dry periods throughout the year. Deep, wide cracks develop during dry periods in soils with high content of swelling clays. Soils with 30 % or more clay to a depth of 50 cm and shrinking/swelling properties. Vertisols and associated soils are generally very deep (150-200 cm), finely textured with clay content ranging from 45-68 % and montmorillonite as the dominant clay mineral. The soils exhibit high shrink-swell potential and develop wide cracks of 4-6 cm extending up to 100 cm in depth. The water holding capacity is high but permeability is imperfect to poor. These soils are calcareous (2 to 12% $CaCO_3$).

The salinity status in the cultivable land varies widely from EC 0.5 dS/m in monsoon to 50 dS/m in summer. The saline Vertisols in Gujarat occur in Bara tract which experiences a tropical climate. The annual rainfall ranges from 275-1484 mm, averaging 737 mm. The monsoon's onset is erratic, normally affecting crop seeding operations, germinations and seedling establishment. Cotton is the dominant crop in the kharif, followed by sorghum and pearl millet. Pigeon pea is also grown in some areas. Mostly rainfed kharif crops are grown in this area. In the rabi season, the land is either kept fallow, or some fodder sorghum is grown on the residual moisture.

The Vertisols have low permeability; soils having comparable salinity affect the crop growth in a greater magnitude than the light-textured soils. As these soils can sustain the deep-rooted crops and have fine capillary pores, salt concentrations even at a considerable depth affect the crop growth and contribute to surface salinity through the capillary rise. The saltiness of surface soils varies from 0.46-21 dS/m. The salinity of the sub-soil of Bara tract ranges from 0.4-159 dS/m. This transient salinity fluctuates with depth and also changes with season and rainfall. Even in the absence of the contribution of groundwater, the excess use of water may also help the sub-soil salinity to come to the surface layer.

Principles of good soil management

Good soil management always requires that the soil be used in such a way that its productivity is maintained or, preferably, enhanced. This requires that the chemical and physical condition of the earth does not become less suitable for plant growth than when cultivation commences. Cultivation usually means that the soil will deteriorate due both to nutrient removal when harvesting crops and to physical damage to the soil structure. What is essential is that the deterioration is reversible by chemical additions to the soil, mechanical manipulation, or natural processes of fertility restoration under pasture or trees. This implies that the soil must be resilient, i.e. after being subjected to the stresses involved in crop production; it must have the ability to return to its former condition, or an improved condition (Greenland and Szabolcs, 1994). The land must produce on a secure basis, the natural resources must be protected, and the management system must be economically viable and socially acceptable. However it must also be recognized that land cannot be managed sustainably unless the soil, which is a component of the land, is properly managed. This requires maintaining and improving soil productivity, avoiding and rectifying soil degradation, and avoiding environmental damage.

Maintaining and improving soil productivity

If soil is to sustain the production of crops, it must:

1. Provide the nutrient requirements of the crop;
2. Provide a physical medium:
   - In which the plant roots can grow adequately so that water and nutrients can be absorbed;
   - Which stores sufficient water for the crop; and
   - Which allows water to enter and move in the soil to maintain the water supply as it is transpired by the crop and evaporates from the soil;
3. Provide a medium in which soil organisms are able to:
   - Decompose organic materials, releasing nutrients to the plants;
   - Assist the transport of nutrients to plant roots;
   - Compete successfully with pathogens which might otherwise infect roots and damage the plants; and
   - Form the soil organic compounds, which will have a favourable effect on other soil properties.

Nutrient management in alkali soils

About 3.77 million hectares of area is severely affected by sodicity in the Indo-Gangetic plains. Nutrient deficiency and toxicity generally occur in these soils. The fertility of these soils with low nutrient reserves is confounded by the inadequate supply of water and oxygen to roots in profiles with dispersive clays. The main problem is of high pH/E.S.P., high amount of calcium carbonate, meager amount of organic matter and poor physical conditions limiting nutrient availability and plant growth. Crops grown on these soils invariably suffer nutritional disorders (N, Ca and Zn deficiency and Na toxicity), resulting in low yields (Swarup,1998). Nutrient management in sodic soils has been reviewed in details by Yaduvanshi and Dey (2009). Crop production and fertilizer use efficiency in these soils can be increased by following the reclamation technology involving integrated use of amendments preferably gypsum based on gypsum requirement of soil, balanced and integrated use of chemical fertilizers and organic/green manures which help in maximizing and sustaining yields, improving soil health and input use efficiency. Rice based cropping systems like rice-wheat, rice-berseem and rice-mustard are recommended on these soils.

Organic carbon and Nitrogen

Alkali soils are highly deficient in organic matter- a storehouse of essential plant nutrients, especially available N throughout the soil profile. High exchangeable sodium (E.S.P.>15), high pH (>8.5) and low biological activity, commonly found in these soils, are not conducive for the accumulation of organic matter and its mineralization. Therefore, its efficient management and maintenance assumes greater significance. Results have shown that long-term balanced fertilizer use under rice-wheat system helps maintain the soil's organic carbon status compared to the control plots. The results further suggest that alkali soils have great potential for carbon sequestration (Lal and Swarup, 2004). Most crops invariably suffer from inadequate N supply. Moreover, nitrogen transformations are adversely affected by high pH and sodicity, affecting applied N's efficiency.

Numerous experiments have shown that recovery of fertilizer nitrogen normally ranges from 30 to 40 % for rice in alkali soils. Proper management of fertilizer N is thus necessary for better N use efficiency. Because of the adverse physico-chemical conditions, the recovery can be still lower in alkali soils. Under such situations nitrogen use-efficiency can be increased by integrated use of organic and inorganic sources of N.

Phosphorus

Uncultivated barren alkali soils contain high amounts of available (Olsen's extractable) P. This is primarily due to sodium phosphates, which are water-soluble. Water-soluble P increases with soil pH in all the major bench-mark series of alkali soils of the lndo-Gangetic plains, and strongly alkaIine calcareous sodic soils have the bulk of soil P as Ca-P (54%) and residual inorganic fractions (28%). When alkali soils were reclaimed by using amendments and growing rice under submerged conditions, Olsen's extractable P of surface soil decreased due to its movement to lower subsoil layers, uptake by the crop and increased immobilization (Swarup, 2004).

The critical values at which crops responds to applied P vary greatly with the nature of the soil (clay content) and stage of its reclamation, initial soil-test value, crop to be grown and the type of amendment used for reclamation. Results of a long-term fertility experiment conducted on a gypsum-amended alkali soil (texture loam, pH 9.2; E.S.P. 32) with rice-wheat and pearl millet-wheat cropping sequence and N.P.K. fertilizer use showed that phosphorus applied at a rate of 22 kg P ha^{-1} to either or both rice and wheat crop in rotation significantly increased the grain yield of rice when Olsen's extractable P (0-15 cm soil) had decreased from the initial level of 33.6 kg ha^{-1} to 12.7 kg P ha^{-1}, which is very close to the widely used critical soil-test value of 11.2 kg P ha^{-1}. Though wheat responded to applied P when available P level decreased close to 8.7 kg ha^{-1}, pearl millet did not respond to applied P at this level of critical soil-test value. The rice and wheat responded to P application in pyrite-amended alkali clay-loam soil (pH 9.3, ECe 3.42 dS m^{-1}, CEC 20.1 meq 100 g^{-1} and ESP 46.7) testing low in available P (4.63 ppm). These studies indicate that recommendations for P fertilization in alkali soils should be based on a soil test. Single superphosphate (S.S.P.) is a better source of P than other phosphatic fertilizers because of high Na of alkali soils and as it contains appreciable some amount of calcium sulphate. Recent studies on integrated nutrient management showed that continuous use of fertilizer P, green manuring and F.Y.M. to crops significantly enhanced the yield of rice and wheat and improved available P status of the gypsum amended alkali soils.

Potassium

Alkali soils of lndo-Gangetic plains generally contain very high amounts of available K. Studies indicates that the crops do not respond to applied K even after 20 years of rice -wheat and pearl millet-wheat cropping systems in alkali soils . Lack of crop response is attributed to the presence of K-bearing minerals and their dissolution and large contribution of non-exchangeable K (> 90%) towards total K uptake by the crops. Potassium increased the K uptake by plants and reduced the release of K from non-exchangeable reserves from 95 to 70 %. The decrease was about 51 % using K combined with organic manures. After continuous cropping, the quantity: intensity (Q/I) relationship remained virtually unaltered. Due to low leaching, a large portion of applied K remained in the top 30 cm of soil.

Micronutrients

Alkali soils are sufficient in total zinc but generally deficient in available Zn. Only 3.3 % of the total Zn is attributed to the exchangeable, complexed, organically bound and occluded forms, which are considered available during crop growth. Thus zinc deficiency is prevalent in rice, and its deficiency symptoms appear in the early growth stages (21-25 days), which delay maturity and reduce yields. Therefore the significant response to its application is observed. Application of 9 kg Zn ha^{-1} (40 kg zinc sulphate) eliminated Zn deficiency in rice grown on alkali soils treated with gypsum, pyrites, and farmyard manure (F.Y.M.) and rice husk and raised the available Zn status of the soil to an adequate level, to meet the following requirement of 2-3 crops. With the application of F.Y.M. and *Sesbania* green manure, it was possible to prevent Zn deficiency in rice grown on alkali soils. Organic amendments like press mud, poultry manure and farmyard manure could effectively supply zinc from the native and applied sources to rice crop in saline-sodic soil.

The alkali soils are rich in total Fe and Mn but are generally poor in water-soluble plus exchangeable and reducible forms of Fe and Mn. There exists a negative relationship between pH and Fe-Mn availability. When applied to alkali soils, soluble Fe and Mn salts are unavailable because of rapid oxidation and precipitation, and their recovery by soil-test methods is shallow. Thus higher addition of Fe and Mn salts is needed to correct the deficiencies or to have a beneficial effect on crop growth. The transformation of Fe and Mn in alkali soils is very strongly influenced by organic matter under submerged conditions, pH per se being relatively less important. This is primarily because of intensely reduced conditions (drop in redox potential) and enhanced PCO_2 created by organic matter under submerged conditions in rice culture Addition of F.Y.M., rice husk and green manures had a marked effect in increasing the extractable Fe and Mn by 10 to 15 times, with the corresponding decrease in reducible forms . Available Fe and Mn and rice yield increased significantly when alkali soils were flooded for 15 and 30 days before transplanting rice; the effects being more pronounced at higher levels of E.S.P. However, benefit of iron application to rice could be realized in sodic soils only when it was applied along with Zn.

Adoption of the rice-wheat system for more than two decades on gypsum-amended alkali soils resulted in the decline of the DTPA- extractable Mn to a level of 2.7 mg kg^{-1}, where wheat responded to manganese sulphate application at a rate of 50 to 100 kg ha^{-1}. Substantial leaching losses of Mn occur following gypsum application in alkali soils. Foliar application of Mn is better than soil application. Nutrients such as B and Mo are not likely to be limiting factors for plant nutrition in alkali soils, though they could prove toxic at higher concentrations however, once the alkali soils are amended with gypsum/pyrites and leached, concentrations of these elements in solution drop to within safe limits and remain no longer toxic to plants.

Nutrient management in saline soils

In India, about 2.96 million hectares are lying barren due to waterlogging problems and soil salinity. Out of these 1.146 million ha lie in the various canal commands. Saline soils are those which have excessive amounts of soluble salts, (ECe>4 dSm^{-1}, pHs< 8.5 and E.S.P. <15). These soils predominantly have a high concentration of chloride and sulphate of sodium, calcium and magnesium. Often these soils have shallow water table representing brackish groundwater, which may be the major cause of salinity due to capillary rise under arid and semiarid climatic conditions. The provision of adequate subsurface drainage to lower the water table's depth and to facilitate salts' leaching has long been recognized as fundamental to the reclamation and management of saline soils. During leaching of these soils release of soil nutrients, especially N, P, K, Ca, Mg and Mn and their loss to the groundwater have been reported. Moreover, the choice of crops to be grown in saline soils under reclamation is also of paramount importance since different crops differ widely in their tolerance to salinity.

Nitrogen

Nitrogen is the most limiting nutrient for crop production in saline soils as they are poor in N status and organic matter. Volatilization is a significant N loss mechanism that reduces the efficiency of applied N. Volatilization losses increases with an increase in salinity. Volatilization losses of N from rice field increased by about 100% when soil salinity (ECe) increased from 4 to 8 dSm^{-1}. Ammonium sulphate showed highest amount of loss being 37.4 per cent at a soil salinity of 8 dSm^{-1}, while fertilizer placed in soil (UPP-urea in paper packet and U.B. –urea briquette) reduced losses to about 5-6 %. Results also showed that sulphur coated urea followed by urea briquette were more efficient than prilled urea for rice. Poor nitrification rates of NH_4^+ - N at high soil salinity was chiefly responsible for higher volatilization of N from saline soil. Apart from antagonistic effects of high amounts of Cl^- and SO_4^{2-} on the absorption of NO_3 in waterlogged saline soils; poor aeration and anaerobic condition may restrict the availability to and absorption of N by plants leading to low efficiency of applied ammonical fertilizers. Further, high salts inhibit nitrification and result in ammonical nitrogen accumulation. Due to these reasons, it is better to use NO_3-N fertilizer than NH_4-N in saline soils. Increased water stress faced by the plants in saline environments further restricts the proper metabolization of the absorbed nitrogen. These factors along with higher leaching losses of NO_3^- during reclamation of the saline soils result in low availability of N to the plants. Therefore, nitrogen requirement of crops is higher in saline soils than in normal soils.

Phosphorus

The available P status of saline soils is highly variable. It showed no regular trend in relation to soil salinity, probably because of the varied concentration of neutral soluble salts of Ca, Mg and Na in the experimental soil. These may have displaced exchangeable Ca and changed the ionic composition of the soil solution, thus influencing the extraction of soil phosphorus. The availability of P increases to a moderate level of salinity but decreases after that.

Application of P significantly enhanced the yield of mustard, wheat and pearl millet, the effects of being more pronounced at high soil salinity. An increase in salinity decreased P concentration and uptake by the crops. Absence of P in the drain water effluent and available P status of the soil profile after crop harvest indicated very slow movement of P, the large portions being retained by the top soil (30 cm) thereby drastically reducing the chances of ground water pollution through phosphorus fertilization. The availability of fertilizer phosphorus in the soil may be modified by soil salinity due to higher precipitation of added soluble P.

Potassium

Available K status of saline soils is high initially but after continuous leaching and cropping it declines to a level where crops respond to its application. Application of K fertilizer in saline soil increases crop yields in several ways: (i) by directly supplying K, (ii) by improving tolerance of plants to Na uptake (iii) by improving water use efficiency, (iv) by improving N use efficiency. Plants grown under high salinity may show K deficiency due to antagonistic effect of Na and Ca on K absorption and /or disturbed Na/K or Ca/K ratio. Under such condition application of K fertilizer may increase yields. Studies showed that the application of K enhanced the yield of pearl millet and wheat and also reduced the contribution of non-exchangeable K towards K uptake by plants. The gift of non – exchangeable K towards total K uptake was 97 per cent in plots receiving no fertilizer K. In contrast, K application at 21 and 42 kg ha-1 reduced it to 83 and 71 per cent, respectively. Pearl millet was more exhaustive of K than wheat. This implies that continuous cropping with higher levels of K along with N and P would result in rapid depletion of K reserves, thereby rendering the soil poor in K fertility.

This suggests that unless K fertility is maintained, yield will remain at low levels and will decline. Presence of K in the drain water effluent (3.2 to 8.2 mg K L-1) and a higher level of available K into the lower soil depths indicated the continuous release of native and applied K from saline soils, thereby contributing to higher K content of groundwater in the vicinity of saline areas. K concentration and salinity of drainage effluent were lower during rainy season (July-September) than in winter (November–March) and summer season (April–June). Leaching losses of native and applied K was also confirmed in a laboratory column experiment when a high saline soil (ECe 43 dS m-1) was leached with good quality water (E.C. 0.3dS m-1) maintaining a constant water head in the column.

Micronutrients

In a microplot field study (Swarup,1995) effect of micronutrients namely, Fe, Mn and Zn and their combinations was studied on yields of wheat and availability of micronutrients in a reclaimed saline soil with sub-surface drainage system (ECe 5.5 dSm-1, organic carbon 0.36 per cent, DTPA extractable Zn 0.56 mg kg-1, Fe 4.3 mg kg-1, and Mn 2.65 mg kg-1. Results showed a significant increase in grain yield following Zn and Mn fertilization. The highest yield was obtained when both Zn and Mn were applied. Application of Fe did not affect yield (Table 3). After crop harvest recovery of added Fe, Mn and Zn were 25.1, 23.7 and 17.1 per cent, respectively.

Nutrient interactions and balanced fertilization

Nutrient interactions play an important role for sustaining crop production in saline soils. Studies on nutrient interactions showed that N and K interacted significantly on wheat yield, N concentration, uptake and recovery. High dose of N alone had a depressing effect on yield. Application of K had a significant effect on yield at all levels of applied N. Increasing rates of N and K enhanced significantly N and K concentration and uptake. The much higher N and K uptake with the higher K rate indicated that there might be a complementary uptake effect between N and K. It was concluded that K+ enhanced NH4+ assimilation in the plant and that K+ did not complete with NH4+ in the absorption process of the plants. The recovery of N and N-use efficiency increased with K application at all levels of applied N and more so at the highest K rate. These results thus suggest the importance of adequate K for efficient N use. Interactions between nitrogen and phosphorus, and between phosphorus and potassium were significant. However, increasing rates of P and K enhanced significantly N concentration in grain and straw and uptake by pearl millet and wheat, the effect being more pronounced when both P and K were applied together. The highest uptake of N by pearl millet (122 kg ha-1) and wheat 159 kg ha-1) was attained at the highest P and K rate. In fact, the much higher N uptake with the highest P and K rate indicated that there might be a complementary uptake effect between N and P and N and K. This is possible because of a more balanced use of soil nutrients in the presence of adequate phosphorus and potassium for efficient N use by crops in saline soils. Drain water effluent had no NH4+ and NO3- - N thereby indicating little danger of groundwater pollution as a result of leaching of nitrates.

Table 3: Effect of micronutrients on yield of wheat and micronutrients availability in soil

Treatments	Yield (t ha^{-1})		DTPA extractable micronutrients (mg kg^{-1})		
	Grain	Straw	Fe	Mn	Zn
Control	5.42	5.85	4.34	2.62	0.58
Fe_{50}	5.45	6.10	9.95	3.65	0.56
Mn_{50}	5.81	6.25	4.40	7.98	0.58
Zn_{11}	5.76	6.18	4.38	2.65	1.42
Fe_{50} + Mn_{50}	5.88	6.30	8.90	9.56	0.57
Fe_{50} + Zn_{11}	5.78	6.21	8.95	4.10	1.32
Mn_{50} + Zn_{11}	6.12	6.43	4.50	8.10	1.45
Fe_{50} + Mn_{50} + Zn_{11}	6.20	6.50	8.56	9.86	1.40
LSD at P=0.05	0.34	0.45	1.18	1.25	0.32

Changes in Soil quality due to the adoption of agroforestry in sodic soils

Carbon sequestration and its mechanism in sodic soil (Dey, 2009) and organic matter as well as nutrient dynamics (Dey and Singh, 2008) under agroforestry systems in Saraswati forest range Haryana have been studied in detail. The soil originally was highly sodic throughout the profile. pH and E.C. values were highest on the surface (10.7 and 3.3 dS/m) and decreased with depth (Mongia *et al.* 1998). Organic C was very low (0.5 g/kg). A sharp decrease in surface soil pH, E.C. and ionic concentrations of water extract was observed within three years of growth under all the plantations, the decrease being more under *Prosopis juliflora* followed by *Acacia nilotica, Dalbergia sissoo* and *Casuarina equisetifolia*(Dey *et al.* 2004a). However, pH and soluble salts increased in the lower depths. The increase in the salts may be due to their translocation through leaching and the lowering of pH can be related to the organic matter accumulation because of litter fall and their subsequent decomposition. The lowest pH under *Prosopis jllliflora* may be related to the highest amount of organic matter accumulation as evident by organic C content.

Ionic composition of the water extract shows that CO3=, HCO3- and Na+ were the dominant ions in the sodic soils. The ionic concentration as a whole decreased considerably on the surface following tree plantation. The decrease was highest in the case of *Prosopis juliflora* while all the other species were almost at par to each other. A general increase in organic C content *was* observed throughout the profile under all the plantations, the increase being more in the surface layer and the rate of increase decreased with depth (Dey et al. 1999). The increase in organic C was maximum *Prosopis juliflora* (3.2 g/kg) and the least in *Casuarina equisetijolia* (1.7 g/kg). As regards the available nutrients, available P declined while an increase in available K was observed under all the plantations. The highest value of available K was noticed under *Prosopis juliflora (*Mongia *et al.* 1998). The higher content of K may be due to the release of K from the K-bearing minerals following reclamation and partly due to the recycling of K on account of litter decomposition. Calcium carbonate content in the surface and subsurface soil decreased with the growing of tree plantations, but it remained more or less constant in the lower horizons of the soil profiles. Tree roots increase the CO_2 level in the soil which helps to mobilize and dissolving in $CaCO_3$ and it results in an exchange of Ca^{++} with Na^+ on the soil exchange complex, thus resulting in decreased calcium carbonate content on the surface and subsurface (Dey *et al.* 2004b). High variations of Olsen-P in sodic soil can be described by water-soluble silicon (Dey *et al.* 2004c). The Fe and Mn concentrations in the profile increased following plantations. The highest concentrations of these elements were observed in *Casuarina equiselifolia* and the least in *Prosopis juliflora.* Zn and Cu content rather registered a decrease following tree plantations. The variation in the concentrations of these micronutrients in the soil may be due to their differential uptake by the trees and subsequent recycling in the soil through litter decomposition. The afforestation of sodic soil by tree plantations helps in the reclamation of sodic soil by lowering pH and soluble salts of the soil, creating a favourable root environment and building organic matter and fertility status of the soil.

Recommendations for sustaining soil health and crop productivity

The following package of practices is recommended for reclamation of salt-affected lands and for sustaining soil health as well as crop productivity:

(i) Land levelling and bunding of fields and providing 35-40 cm high bunds to check outflow and entry of outside water from unreclaimed fields. Strong bunding is essential to preserve and utilize rainwater for leaching salts and growing rice crops.

(ii) Suitable surface drains are also required to regulate the excessive surface flow of water during heavy rainfall.

(iii) Installation of tubewells to ensure timely irrigation. It is also essential to lower the water table for attaining permanent reclamation. The shallow cavity tubewells serve as vertical drains.

(iv) Soil sampling and testing to determine gypsum requirement, the quantity of gypsum is decided on the basis of soil pH and texture of the soil and varies from 10 to 15 t/ha.

(v) Apply gypsum powder in the well-ploughed and leveled fields in the month of June or July. It should be mixed in the upper 8-10 cm soils. Gypsum is applied only once in the 1st year of soil reclamation.

(vi) After gypsum application, water is kept standing in the field for 10-15 days before transplanting rice as a first crop.

(vii) Rice is recommended to grow as the 1st crop during soil reclamation. Mainly rice-wheat crop rotation is followed during the reclamation period. In the initial stage CSR10 variety of rice is recommended to grow on newly reclaimed sodic soils. Later on, CSR13, CSR30, PR106, PR107, Basmati (B-370), Pb No.1, Pusa150, Pusa169 etc. can also be grown for economic returns.

(viii) For rice crops, 35-40 days old seedlings grown on the normal soil should be transplanted at a distance of 15 cm keeping 3-4 plants per hill. The seed rate needs to be kept more (40-50 kg/ha) for transplanting one hectare of reclaimed sodic land.

(ix) Apply 25% more nitrogen in rice crops as compared to those applied in the normal soil. Nitrogenous fertilizers and zinc sulphate are recommended to apply @ 150 kg and 25 kg/ha, respectively. By adopting these practices bumper rice crops can be harvested right from the first year of reclamation.

(x) Phosphorus and potash need not apply during the initial years of the reclamation (5-6 years).

(xi) Wheat crops should be grown during winters. The wheat varieties K.R.L. 1-4 and K.R.L. 19 are the recommended salt tolerant cultivars to grow during the initial stage of the reclamation. Barseem (*Trifolium alexandrinum*) or shaftal (*Trifolium resupinatum*) can also be grown for fodder in subsequent years as per the requirement of animals.

(xii) Five to six light irrigations are recommended for the cultivation of wheat crops.

(xiii) Sesbania should be grown for green manuring during summers.

(xiv) The field should not allow being fallow during the reclamation period. After a few years of continuous cropping, other crops may be introduced to diversify the cropping system.

REFERENCES

Dey, P. 2009. Transformation and availability of primary nutrients in submerged sodic soils. *In: Improving Sodic Soil Quality, Input Use Efficiency and Crop Productivity through Integrated Nutrient Management* (Eds. Yaduvanshi, N.P.S., Dey, P. and Singh, Gurbachan),Central Soil Salinity Research Institute, Karnal, India, pp. 43-47.

Dey, P. 2009. Carbon sequestration and its mechanism in sodic soils. *In: Improving Sodic Soil Quality, Input Use Efficiency and Crop Productivity through Integrated Nutrient Management* (Eds. Yaduvanshi, N.P.S., Dey, P. and Singh, Gurbachan),Central Soil Salinity Research Institute, Karnal, India, pp. 93-95.

Dey, P., Mongia, A.D. and Singh, Gurbachan 1999. Spatial variation of soil properties and tree growth parameters in agroforestry under sodic soil condition. In: *Wasteland Development: Challenges & Opportunities* (A.K. Singh, K.S. Bhatia and J.P. Yadav eds.), C.S.A. University of Agri. Technology, Kanpur and State Land Use Board, Dept. of Planning, Yojana Bhawan, Lucknow, pp. 168-172.

Dey, P., Mongia, A.D. and Singh, Gurbachan 2004a. Bio-amelioration of sodic soil. In: *Extended Summaries: International Conference on Susrtainable Management of Sodic Lands*, Lucknow, India, pp. 387388.

Dey, P., Mongia, A.D. and Singh, Gurbachan 2004b. Performance of woody perennials in highly sodic soil of semiarid climatic region under land use pattern of agro-forestry. In: *Proc. 91st Indian Science Congress*, Chandigarh, January 3 to 7, 2004, pp. 49-50.

Dey, P., Mongia, A.D. and Singh, Gurbachan 2004c. Distribution and variation of water soluble silicon in agro-forestry under sodic soil condition. In: *Proc. 91st Indian Science Congress*, Chandigarh, January 3 to 7, 2004, pp. 48-49.

Dey, P. and Singh, Gurbachan 2008. Organic matter and nutrient dynamics in agroforestry system under salt affected soils. *In: Chemical Changes and Nutrient Transformation in Sodic/Poor Quality Water Irrigated soils* (Eds. Yaduvanshi, N.P.S., Yadav, R.K., Bundela, D.S., Kulshreshtha and Singh, Gurbachan),Central Soil Salinity Research Institute, Karnal, India, pp. 224-226.

Dey, P., Yadav, D.V. and Singh, P.N. (1996). Soil factors affecting growth parameters and juice quality in sugarcane grown on salt affected soils. *Indian J. Sugarcane Technol*. 10 (2): 139-140.

Doran, J.W. and Parkin, T.B. (1994) Defining and assessing soil quality. In: Defining soil quality for a sustainable environment (JW Doran, DC Colemann, DF Bezdicek and BA Stewart Eds.), pp. 3-21. Soil Sci. Soc. Am. Publ. No. 35, Madison, WI.

F.A.O. 1991. *F.A.O./Netherlands Conference on Agriculture and Environment*. S-Hertogenbosch, The Netherlands, 15-19 April 1991.

Greenland, D. J. and Szabolcs, I. (eds) 1994., *Soil Resilience and Sustainable Land Use*. C.A.B. International. Wallingford, U.K.

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M. and Ellert, B.H. (1994) *Can. J. Soil Sci.* 74:367-385.

Harris, R. F. and Bezdick, D. F. (1991) Defining soil quality for a sustainable environment. SSSA Special Publication 35, SSSA, Madison, WI.

Lal, K. and Swarup, A. 2004. Effect of afforestation and fertilizer use on functional pools of carbon in alkali soil. In Extended summaries: International Conference on Sustainable Management of Sodic Lands, Lucknow, Feb. 9-14. pp.212-214.

Larson, W. E. and Pierce, F.J. (1994) The dynamics of soil quality as a measure of sustainable management. In:

Defining soil quality for a sustainable environment (JW Doran, DC Colemann, DF Bezdicek and BA Stewart Eds.), pp. 3-21. Soil Sci. Soc. Am. Publ. No. 35, Madison, WI.

Mongia, A.D., Dey, P. and Singh, Gurbachan 1998. Ameliorating effect of forest trees on a highly sodic soil in Haryana. *J. Indian Soc. Soil Sci.* 46 (4): 664-668.

Swarup,A.1995. Management and Balanced Use of Inputs in Achieving Maximum Yield in Salt Affected Soils. Fertiliser News 40(11):39-47

Swarup, A. 1998. Emerging soil fertility management issues for sustainable crop productivity in irrigated systems. In: Long-Term Soil Fertility Management through Integrated Plant Nutrient Supply. Eds. Swarup et.al pp. 54-68. IISS, Bhopal.

Swarup, A. 2004. Chemistry of sodic soils and fertility management. In Advances in Sodic Land Reclamation. International Conference on Sustainable Management of Sodic Lands, Lucknow, Feb. 9-14. pp. 27- 52.

Yaduvanshi, N.P.S. and Dey, P. (2009).Nutrient Management in Sodic Soils.In: *Enhancing Nutrient Use Efficiency in Problem Soils*. (Eds. Singh, Gurbachan, Qadar, Ali, Yaduvanshi, N.P.S. and Dey, P.), Central Soil Salinity Research Institute, Karnal, India.

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Variability, properties and management of saline soils of coastal ecosystem for sustained production

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ABSTRACT

A coastal ecosystem is a land ecosystem adjacent to a marine ecosystem. Unlike inland soils, salinity in coastal soils is caused during the process of their formation under the marine influence and subsequently due to the periodical influence of saline water either through inundation or capillary rise from shallow underground water or saline water irrigation. The primary causes of salinity in coastal soils are ingression of sea water in coastal plain, deposition of salts in deltaic plain, linkage of drainage channels with saline sea water and salty parent materials, presence of poor-quality/brackish groundwater, periodic inundation of seawater.Soil salinization is a continuous and repetitive process occurring in complex physiographic regions in coastal areas *viz*, alluvial, aeofluvial, coastal, deltaic and mud flats/mangrove swamps. There exists variability in soil properties like salinity spatially as well as temporarily. The variability in properties of coastal soils is due to various factors like climate, topography/physiography, texture of soils and groundwater dynamic. Seasonal changes during one annual cycle strongly influence degree of spatial and temporal variation. Two dimensional salt distribution patterns, i.e. horizontal and vertical is attributed to landscape position/ soil texture and groundwater salinity, respectively. Secondary salinization is a problem of irrigated agriculture whereas *dryland* salinity is the problem of *rainfed* area and tackling these problems is crucial for achieving food security. Developing and refining appropriate technologies for managing coastal saline soils seems a promising option to achieve future food and nutritional security as well as adoption and mitigation strategies to cope with future climate change scenarios. The two approaches to manage salinity are one to combat salinity and another to live with salinity. Combating salinity refers to reclaiming or installing drainage systems that allow salts to be washed out of the soil with better irrigation water management, creating salinity levels acceptable to productive crops. Living with salinity is a more pragmatic approach which refers to adapting crops to more saline conditions. Soil application of organic manure and amendments, compost, and crop residue management could be possible solutions to reclaim saline soils and develop a sustainable agro-ecosystem. Suitable water and crop management practices like conjunctive use of saline water with canal water, cultivation of low water requiring crops, and use of pressurized irrigation system are to be adopted while practising canal water irrigation to crops on coastal saline *Vertisolsfor achieving land degradation neutrality*. Crops with higher water productivity were the best in the developed integrated farming system model. Bio-saline agriculture, including salt tolerant horticultural species, forage grasses, is also an option for its management. Creating a bio-shield along the coast helps in many fold like reducing salinity ingress, reducing soil erosion, creation of "carbon sink" with increased access to food, fodder and fuel and enhanced livelihoods in primary and renewable energy sectors. Integrated nutrient management has been imperative for sustainable crop production from coastal saline soils. The productivity of these soils can be restored by reclamation and management using different technologies like drainage, leaching, cultivation of salt tolerant varieties/ halophytic plants, bio-saline agriculture, plantation of bio-shield including mangroves in the coastal area, etc.

Keywords: *coast, sea ingress, variability, salinity, leaching, soil properties, production*

L-12

Drip Irrigation and Mulching in Relation to ClimateChange

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INTRODUCTION

Presently, climate change is being talked about by politicians, policy makers, industrialists, traders, academicians, farmers, fishermen etc., at each forum.This is because of the reason that with the progress of time, global warming and related climate changes are resulting in the erratic weather pattern. Less or more rainfall, erratic distribution of rain, drought, flooding, and other unprecedented changes have all taken a toll on day to day life of every living creature on the earth and more so of those actively involved in agriculture. Food is a universal need that demands endless supply. In the wake of these unfortunate happenings, food security would be seriously threatened unless timely, appropriate remedial measures are implemented. This is where drip/trickle irrigation and mulching technologies are going to play a vital role in sustaining crop productivity under changing climatic conditions in the time to come.

Water resources of India

Considering the total geographical area (329 m ha), mean annual rainfall of 1170 mm, glacial snow melt and net cross-border river inflow, the total water resources available are 4000 BCM.Of these water resources, 2047 BCM is unaccounted, including evaporation, non-crop ET, percolation to very deep strata and sub-surface flow to ocean.So the total accountable water resources are 1953 BCM. Accountable water resources constitute 690 and 396 BCM utilizable surface and ground water resources, respectively(Table 1).The limited water availability on the one hand and the ever increasing population on the other are jointly leading to a gradual decrease in per capita availability of water from 6008 MCM/year during the pre-independence period to 1250 MCM/ year during 2004 and projected to be reduced to only 760 MCM/ year in the year 2050. This is a grim situation by any standard of per capita water availability.

Water requirements of various sectors

As discussed earlier, the decrease in per capita availability of water coupled with the increase in water demand by different sectors further complicates the situation. Water requirements for various sectors of India given in table 2suggest that irrespective of sources and sectors, the water requirement is increasing with time. As per the standing subcommittee, the total water requirement in 2010 was 813 BCM which will be increased by 78 % during 2050, while as per the assessment of NCIWRD, this increase during the same period is on the lower side (66%).Though the total volume of water required for irrigation is increasing from 688 BCM in 2010 to 1072 BCM in 2050, yet in terms of per cent share of total water for irrigation is decreasing from 85 %in 2010 to 74 %in 2050. Such *paper readat National Conference on* ***Innovative Resource Management Approaches for Coastal and Inland Ecosystems to Sustain Productivity and Climate Resilience****, Navsari Agricultural University, Navsari - 396 450, Gujarat (October 2022).*

The decrease in the share of irrigation water as per another source is from 78 % to 68 %. In contrast, the requirement both in terms of volume of water as well as per cent share of total water for rest of the sectors is showing an increasing trend over a while.

Source-wise irrigated area

Irrespective of sources, the net irrigated area has increased from 55205 thousand ha during 2000-01 to68120 thousand ha in 2014-15 (24 %). Though there were not many variationsinthe area irrigated by canal during this period, the area irrigated by groundwater increased by 27 % (Table 3).Due to the continuous increase in groundwater contribution towards the irrigated area, the over-exploited blocks in India are also rising steadily.

Not only is this, but the quality of groundwater is also becoming a significant concern in arid and semi-arid tracts of India.

Irrigation water losses

It is well-known fact that agriculture is the major consumer of available water resources. Similarly, agriculture is the primary sector where maximum water losses occur. At a global level, the crops use only 55 % of irrigation water, and the remaining 45 % of water is lost during distribution and application. While the scenario is worst in India as 61.5 % of water is wasted through seepage and evaporation, and only 39.5 % of water is utilized by the crops (Table4).The values further revealed that the seepage losses are four times more than evaporation losses.Though seepage losses are controllable through suitable remedial measures, not much effort has been made in this direction. Overall, the irrigation efficiency under canal command was hampered considerably. In the upper Ganga canal command (Uttar Pradesh) the conveyance losses are to the tune of 45 % coupled with application losses of 23 %, which indicate the irrigation efficiency is only 32 %. The corresponding values for Karjan Project (Gujarat) are 40, 27 and 33 %. Apart from these losses, irrigation water losses are also governed by the farmers' methods and schedule of irrigation. The conventional flood method of irrigation, presently being mainly followed by the farmers, has as low as 30 % efficiency as against 60 to 75 % with sprinklers and 80 to 90 % efficiency with drip irrigation. This implies a good scope for saving irrigation water, which will ultimately help sustain crop productivity and safeguard the environment.

Area under micro irrigation methods

In India, the area under micro irrigation (drip and sprinkler) is slowly but steadily increasing due to concerted and consistent efforts being made by centre and state governments. The total area under micro irrigation is 102.54 lakh ha, of which the drip method accounts for 47.80 lakh ha, and the remaining 54.75 lakh ha is occupied by the sprinkler method (Table 5).At the national level not much difference between the area under drip and sprinkler irrigation methods is observed. However, farmers of Rajasthan and Karnataka prefer sprinklers over the drip method and in Maharashtra and Andhra Pradesh, the adoption of the drip method is more than the sprinkler method. Of the total area under micro irrigation, the states viz. Rajasthan, Andhra Pradesh, Maharashtra, Karnataka and Gujarat occupy around 75 % area.

Drip irrigation(Anon., 2011)

The drip irrigation method is becoming popular among farmers due to its following advantages.

- Water saving ranges from 30 to 60 %
- Fertilizer saving to the tune of 25 to 40 %
- Saving in labour charges by 20 to 40 %
- Induces early maturity in crops (85 % farmers)
- Improves quality of produce in crops (90% farmers)
- The premium price of the produce (46 % farmers)
- Reduces pest and disease problems
- Minimizes receding groundwater table problem
- Though the drip method has proven advantages, it has certain limitations as experienced by the farmers.
- High initial investment
- Damage to drip system by rat/animal (56-59 %)
- Poor after sell service (59-61 %)
- Non-availability of power supply during daytime (20 %)
- Poor technical knowledge about drip system of the farmers (56- 59 %)

- Poor quality of drip system material like valves, GI-PVC fittings, pressure gauge *etc.* (56-68 %)
- The threat of burning the system, particularly in sugarcane (28 %)
- In spite of the better quality of produce, drip owners (89-95 %) are not getting a premium price

Mulching

Like drip irrigation, mulching is another technology which has vast potential in India and can increase crop yield under diversified climatic conditions and across crops (Solia et al., 2013).Mulching is an age-old agricultural practice primarily used for moisture conservation under rain-fed farming conditions. Earlier, the materials used for covering the soil surface (mulching) were crop residue, leaf litter, pebbles, loose soil (interculturing) etc. However, with the advent of synthetic materials suitable for mulching, its applicability has become more versatile than ever before. This is because of the following advantages

- Moisture conservation
- Control weed effectively
- Restricts upward movement of soluble salts in the soil
- Moderates soil temperature
- Minimizes compaction and erosion hazards caused due to raindrops
- Increases soil air CO_2 content
- Induces early maturity in crop
- Improves nutrient availability in soil
- Repels certain insects
- Improves quality of produce
- The increases interval period between two irrigation of course, mulching has some manageable limitations.
- High cost
- High labour requirement for laying and removal
- Non-biodegradable
- Inadequate availability of LLDPE film in the local market
- Limited knowledge about mulching among the farmers *etc*

All these advantages, in a cumulative way increase the crop yield. So, synthetic mulch can also be used effectively under irrigated agriculture. Not only this, but it is best suited to drip irrigation. Among the different synthetic materials like LDPE, HDPE, flexible PVC, woven and non-woven fabrics etc., LLDPE film (Linear low density polyethylene) is widely used for mulching in different crops and seasons. As far as color of the LLDPE film used for mulching is concerned, black color film (black plastic) was found to be the best in most the crops and seasons. Though this film has added advantages over natural ororganic mulch materials and the research and extension efforts being done by different institutes, Universities, Govt. organizations, NGOs etc., yet the farmers have not adopted mulching technology up to the desired level.

Drip irrigation and mulching in relation to climate change

Any type of irrigation in a commercial agriculture system can significantly reduce the climate-related yield risks resulting from water stress (Harwood et al., 1999). Because of improved efficiencies and reduced pest pressure, micro irrigation can provide some added measures of reduced risk compared to conventional and overhead irrigation systems. This can be summarized as follows.

- Because of its high efficiency (less non-beneficial soil-water evaporation, wind drift, evaporation of canopy-intercepted water*etc.*), micro irrigation reduces the irrigation water volume required to grow crops, which can lower the risk of water supply shortages for irrigation.
- Micro irrigation allows for flexibility in the timing and amounts of water to be applied according to the evapotranspiration/plant demand.
- Because less water is applied, nutrient leaching is reduced.
- Enable to synchronize the time of nutrient application with the nutrient demand of crop plants directly in the root zone.
- Micro irrigationis also suitable for using polyethene mulch, which helps insoil-water conservation.
- Micro irrigation can be used to protect small horticultural crops from freezes.

High water use efficiency: As stated earlier, drip irrigation is so versatile that it can save irrigation water in any crop grown under agro-climatic conditions. This has been proved empathetically through systematic research carried out by ICAR institutes, SAUs, research organizations, companies, PFDCs, NGOs *etc.* Irrespective of crop and agroclimatic conditions, the water saving with drip method over the conventional method of irrigation ranges from as low as 20 % to as high as 60 % (Table 6).As a result, WUE also increases across the crops and agroclimatic conditions. This benefit is further enhanced if the drip system is placed below the soil surface. As the subsurface drip irrigation (SDI) system prevents evaporation loss, it is more efficient than surface placed drip system.Lamm*et al.* (2010) and Colaizzi*et al.* (2004) used cotton and sorghum as a test crop to compare performance evaluation between the overhead sprinkler and drip irrigation method. They reported a significant increase in yield with less water in the case of SDI compared to over head sprinkler(Tables7 and 8). They explained the results because a greater proportion of irrigation water contributes to transpiration (less soil evaporation) and a warmer environment results from the absence of soil wetting with SDI. In India also some studies have been and also being conducted isshowing similar results particularly in sugarcane.

High nutrient use efficiency: Like water, nutrient use efficiency is also improved considerably with drip irrigation, which further enhances in combination with mulching. Voluminous work related to fertigation in different crops has been done under varying agroclimatic conditions in India. The results have indicated that fertilizer dose can be reduced by 20 to 60 % without any reduction in yield. On the contrary, there is an increase in yield, which varies with the crop. This advantage is further enhanced in the presence of mulching (Table 9). This is mainly due to fertilizer application at a higher frequency and directly in the root zone. The combined use of drip and mulch also improves the availability of nutrients in soil due to an increase in the concentration of CO_2 in soil air(Table 10).This increase in soil air CO_2 facilitates solubilization of insoluble nutrients to soluble form which becomes available to the plants. In other words its C sequestration in soil.

Environmental benefits : The drip and mulching technologies utilize water and nutrients most efficiently and exert less pressure on precious water resources. The saved water can be used either to bring more area under irrigation or diverted to the domestic/industrial/environment sector. The studies conducted by Sanchez-Martin *et al.* (2008) have shown that subsurface drip irrigation systems result in substantial decreases in N_2O emissions compared to furrow irrigation emissions. Further, the fuel costs of SDI compared to center pivot irrigation is lower for corn irrigation (Lamm*et al.* 2012), suggesting reductions in energy-related CO_2 emissions can be observed with SDI.

A field study was conducted to compare soil CO2 concentrations and soil surface CO2 fluxes between TC (traditional cultivation - no mulching and flood irrigation) and MC (plastic mulching anddrip irrigation) systems during a cotton growing season. CO2 concentrations in the soil profile were higher in the MC system (3107-9212 ì L L? 1) than in the TC system (1275-8994 ì L L? 1) but the rate of CO2 flux was lower in the MC system. Possible reasons for this included decreased gas diffusion and higher soil moisture due to the mulching cover in the MC system and the consumption of soil CO2 by weathering reactions. Over the whole cotton growing season, accumulated rates of CO2 flux were 300 and 394 g C m- 2 for the MC and TC systems, respectively. When agricultural practices were converted from traditional cultivation to a plastic film mulching system, soil CO2 emissions could be reduced by approximately 100 g C m- 2 year- 1 in agricultural lands in arid and/or semi-arid areas of northern and northwestern China (https://doi.org).

Generally, the dry biomass-based CWP of paddy was higher than chilli. That is due to paddy's higher crop water requirement than chilli (Table11). Soil mulching also resulted in higher biomass that is because mulching helps drip irrigation to provide efficiency and maintain the quality of water given. In chili, the straw mulching resulted in higher CWP (29.9 and 35.1 kg ha-1 l -1) than silver-black plastic mulch (24.6 and 33.2 kg ha-1 l^{-1}) at both conventional and dripped irrigation, respectively. On the other hand, plastic mulch resulted from higher biomass (62.3 and 78.2 kg ha-1 l^{-1}) than straw mulch (52.5 and 72.5 kg ha-1 l^{-1}) in paddy under conventional and drip irrigation, respectively. Higher biomass with straw mulch in chili is probably because the root of chili needs oxygen by good soil respiration than just the availability of soil moisture.But soil moisture contributes more to paddy's growth.Sodrip irrigation under soil mulch is appropriate to use in this climate change situation. Because it provides higher productivity by optimizing the usage of minimum water availability to minimize exaggerate of water wasted (Anon., 2021).

The field experiment results showed that biomass was significantly higher in the ridges- furrow irrigation with full plastic mulching (PM) than cultivation without mulching (CK), and their four-year average biomass values were 4996 ± 967 and 2850 ± 817 kg C ha^{-1}, respectively. SOC did not significantly differ between the two treatments within the four years of the experiment. The model simulation with various rainfall and temperature change scenarios indicated that SOC (0–30 cm) and biomass were more affected by climate change in CK than PM. Themodelling results showed that the PM cultivation system maintained high productivity and increasing trends of SOC under the high and medium greenhouse gas emission scenarios derived from climate change projections before 2060. The PM is currently an effective way to increase productivity and is a possible measure for dry land agriculture to adapt to near-future climate change (https://doi.org).

Apart from arable crops, transplanted paddy, the primary contributor to methane emission, can be reduced considerably if this crop is brought under drip irrigation or even SRI or direct seeding method of sowing (Table 12). Numbers of trials on the introduction of drip or sprinkler methods of irrigation in paddy are in progress in different parts of India. The results obtained so far indicate the feasibility of drip irrigation in paddy. Of course, the results vary with the locations, cultural practices and paddy varieties.

The work reported by Kumar *et al.* (2016) revealed that with a decrease in irrigation water application from 1200 mm to 608 mm, the greenhouse gas (GHG) and paddy yield showed a declining trend. The decline was more pronounced after 673 mm level of irrigation. This means that we have to strike appropriate balance between a reduction of yield and GHG(Table 13).

Agronomic benefits : The reduced wetting of soil surface drip irrigation results in lower weed and disease pressure. Along with yield increase, drip alone, drip + mulch and drip + fertigation + mulch also reduce soil crusting problems. These systems enable to adopt automation which economizes the labour use as well. The agronomic benefits can further be enhanced through soil – site suitability based selection of crop. This approach enables to reduce input cost without reduction in crop yield. Presently, the farmers are selecting crop by neglecting the soil-site suitability criteria. This is because of the reason that the crop selection by the farmer is market driven rather than suitability based.

From the above discussion, it is imperative to improve Input Use Efficiency by expanding the area undermicro irrigation and mulching to the maximum possible extent in the suitable crops for these technologies. These steps would not only help in sustaining crop productivity but would also mitigate the ill effects of GHG on global warming. Otherwise, we have to be ready to face the following crises

- There is hardly any city which receives 24 hrs supply of drinking water

- Many rural habitations covered under the drinking water program arenow being reported as having slipped back with target dates for completion continuously pushed back. There are pockets where drinking water's arsenic, nitrate and fluoride pose serious health hazards.
- In many parts, the groundwater table is receding due to over-exploitation, imposing an increasing financial burden on farmers who need to deepen their wells and replace pump sets and on state Govt. whose subsidy burden for electricity supplies rises.
- Many major and medium irrigation projects remain under execution forever as they slip from one plan to another with enormous cost and time overruns.
- Due to the lack of maintenance, the older systems' capacity seems to be decreasing.
- The gross irrigated area does not seem to be rising as it should be, given the investment in irrigation. The difference between potential created and area irrigated remains large. Unless we bridge the gap, significant increase in agricultural production will be difficult to realize.
- Floods are recurring problems in many parts of the country. Degradation of catchment area and loss of flood plains to urban development and agriculture have accentuated the intensity of flood.
- Water quality in our rivers and lake is far from satisfactory. Water in most parts of the river is not fit for bathing or drinking. Untreated or partially treated sewage from towns and cities is being dumped into the rivers.
- Untreated or inadequately treated industrial effluents pollute water bodies and also contaminate groundwater.
- At the same time, water conflicts are increasing. Apart from traditional conflicts about water rights between upper and lower riparian in river, conflicts about water quality, people's right for rain water harvesting in watershed against downstream users, industrial use of ground water and its impact on the water table and between urban and rural users have emerged.

REFERENCES

Anonymous (2011) 7th AGRESCO Report, NRM subcommittee, SWMRU, NAU, Navsari.

Anonymous (2015)11th AGRESCO Report, NRM subcommittee, Dept. of NRM, ACHF, NAU, Navsari

Anonymous (2021) 6th International Conference on Climate Change 2021 IOP Conf. Series:

Earth and Environmental Science 824 (2021) 012014 IOP Publishing doi:10.1088/1755-1315/824/1/0120144

Colaizzi, P. D.., A. D. Schneider, S. R. Evett and T. A. Howell (2004) Comparison of SDI,

LEPA and spray irrigation performance for grain sorghum. Trans. ASAE, 47 (5) : 1477- 1492.

Department of Agriculture, Cooperation's and Farmers Welfare, Micro irrigatin area in India ason 31-03-2018)

Harwood, J., R. G. Heifner, K. Coble, P. Janet and A. Somwaru (1999) Managing Risk in

Farming – Concept, Research and Analysis. Washington DC: Economic Research Services, USDA. https://doi.org/10.1016/j.agsy.2016.10.011

Kumar et al. (2016) Green house gas emission from direct seeded paddy field under different water potential in Eastern India. Agri. Ecosyst. Environ.2016, 228: 111-123

Lamm, F. R., P. D. Colaizzi, J. P. Bordovsky, T. P. Trooien, J. Enciso-Medina, D. O. Porter, D. H. Rogers and Lamm, F. R., D. M. O'Brien, D. H. Rogers and T. J. Dumbler (2012) Using the K-State centre pivot sprinkler and SDI economic comparison spread sheet. Proc. 24 th Ann. Central Plains Irrigation Conf., Colby, Kansas (Feb. 21-22)Lus.dacnet.nic.in PDF file – of:planningcommission.nic.in/plans/planrel/fiveyr/11th/ 11…/11v3_ch2.pdf

Raman, S. (2012) Potential of Micro Irrigation in India – A State wise Assessment. In: Micro

Irrigation- Economics and Out Reach, (Eds. Dr. Palanisami, Dr. Raman. S. & Dr. Kadiri Mohan), Pub. Mac Milan Pub. House, New Delhi.

Sanchez-Martin,L., A. Benito, L. Garcia-Torres and A. Vallejo (2008) Influence of drip and furrow irrigation system on nitrogen oxide emission from a horticultural crop. Soil Biol. and Biochem. 40 (7):1698 – 1706.

Savani ,N. G., R. B. Patel, B. M. Solia, V. R. Naik, K. K. Patel, J. M. Patel and R. G. Patil (2012) Water Management Technologies – A Compilation (1980 – 2012). Pub. 24, SWMRU, NAU, Navsari.

Singh, H. P. (2001) Emerging scenario of micro irrigation in India. In: Micro Irrigation (Ed. H. P. Singhet al.) Central Board of Irrigation and Power, Proc. Intl. Conf. on Micro Irrigation and Sprinkler Irrigation System, 8 – 10 Feb. 2000, Jalgaon(MS). Pp.18 – 30.

Solia, B. M., R. B. Patel, J. M. Patel, N. G. Savani, S. S. Sonvane and R. G. Patil (2013). Mulching Technologies for Enhancing Crop Yield. In: Water Management Research in Gujarat (Ed. R. G. Patil et al.), SWMP Pub. 27, SWMRU, NAU, Navsari Gujarat, pp : 125.

Verma, Shilp and Snajiv J. Phansalkar (2007) India's water future 2050: Potential deviations from business - as-usual. Intl. J. Rural Management, 3 (1): 149 – 179.

Table 1 : Total accountable water resources of India (BCM)

SN	Particulars	Value
1	Annual precipitation	4000
2	Unaccounted water resources	2047
3	Accounted water resources	1953
4	Total surface water resources	**1521**
	Utilizable surface water resources	690
	Unutilizable surface water resources	831
5	Total ground water resources	**432**
	Utilizable ground water resources	396
	Unutilizable ground water resources	36

Source:Verma and Phansalkar (2007)

Table 2: Water requirement for various sectors of India (BCM)

Sector	Standing subcommittee of MoWR			NCIWRD		
	2010	2025	2050	2010	2025	2050
Irrigation	688	910	1072	557	611	807
Drinking	56	73	102	43	62	111
Industry	12	23	63	37	67	81
Energy	05	15	130	19	33	70
Others	52	72	80	54	70	111
Total	**813**	**1093**	**1447**	**710**	**843**	**1180**

Source :PDF file (XI FYP)

Table 3: Year and sources wise net irrigated areas in India ('000 ha)

Year	Canal	Tanks	Tube wells &wells	Others	Total
2000-01	16012	2466	33818	2909	55205
2001-02	15200	2186	35183	4350	56920
2002-03	14071	1803	34348	3662	53884
2003-04	14455	1916	36383	4292	57046
2004-05	14763	1734	35189	7531	59218
2005-06	16716	2083	36070	5962	60831
2006-07	17026	2078	37641	5998	62744
2007-08	16812	1978	38400	6103	63291
2008-09	16945	1985	38795	6015	63740
2009-10	16697	1638	39042	5880	63256
2012-13	15680	1750	41300	7550	66280
2013-14	16280	1840	42440	7560	68120
2014-15	16182	1723	42960	7519	68384

Source: lus.dacnet.nic.in

Table4 : Ways of irrigation water losses (%) in India

SN	Source	Seepage	Evaporation	Total
1	**Main canal & branches**	13.6	3.4	17
2	**Distributaries**	6.4	1.6	8
3	**Field water course**	16.0	4.0	20
4	**Field application**	13.2	3.3	16.5
	Total	**49.2**	**12.3**	**61.5**

Source: Raman (2012)

Table 5 : Area (lakh ha) under micro irrigation in some states of India

SN	State	Drip	Sprinkler	Total area
1	**Rajasthan**	2.29	16.08	18.37
2	**Andhra Pradesh**	11.51	4.34	15.85
3	**Maharashtra**	10.90	4.56	15.45
4	**Karnataka**	5.81	7.03	12.84
5	**Gujarat**	6.37	6.44	12.81
	India	47.80	54.75	102.54

Source: Department of Agriculture, Cooperation's and Farmers Welfare(As on 31-03-2018)

Table 6: Benefits of drip irrigation over control in different crops

SN	Location	Crop	Yield increase (%)	Water saving (%)
1	**Navsari/Gujarat**	Sugarcane	22	40
2	**Surat/Gujarat**	Cotton	11	20
3	**Navsari/Gujarat**	Banana	13 - 21	40
4	**Junagadh/ Gujarat**	Papaya	20	27
5	**Delhi**	Kinnow	31	22
6	**Dharwad/Karnataka**	Grape	17	47
7	**Allahabad /UP**	Guava	27	17
8	**Navsari/Gujarat**	Onion	35	39

Source: Singh (2001) and Savani et.al. (2012)

Table 7 : Water foot print(l/kg) of grain sorghum

SN	Method of irrigation	l/kg of grain
1	LESA	806
2	LEPA	752
3	MESA	725
4	SDI	662

Source: Colaizziet al.(2004)

Table 8 : Per cent yield increase of cotton lint under SDI at different locations

SN	Location/year	% increase
1	Halfway/1995-97	12
2	Halfway/1999-2001	23
3	Bushland/03,04,06,07	24

Source: Lamm et.al.(2010)

Table 9: Drip + mulching technologies for some fruit crops in India

SN	Crop	Location/State	Yield increase (%)	Water saving (%)	Remarks
1	**Banana**	Navsari/Guj.	21	40	40% N & K saving, induces early maturity
2	**Papaya**	Navsari/Guj.	32	40	90 % weed control
3	**Ber**	Danti/ Guj.	25	Rain fed	Restrict upward movement of salts
4	**Cashew**	Bhubaneshwar/Odissa	80	20	-
5	**Apple**	Rajaura/Kullu	31	-	Less fruit drop
6	**Pomegranate**	Kalyani/ WB	69	-	
7	**Mango**	Lucknow/UP	85	-	Less fruit drop

Source: Singh (2001) and Savani et.al. (2012)

Table 10 : Mulching improves soil health

SN	Crop	Mulch material	Yield increase (%)	Soil air CO_2 (vpm)
1	**Banana**	BP + Drip	21	683
		ST + Drip	16	608
		Control	-	371
2	**Papaya**	Drip	28	378
		Drip + BP	40	868
		Control	-	269

Source: Anon. (2011)

Table 11: Irrigation method and soil mulching on biomass CWP of chilli and paddy

Mulch	Chilli		Paddy	
	Conven.	Drip	Conven.	Drip
Control	22.8	25.6	53.3	61.5
Silver-black	24.6	33.2	62.3	78.2
Straw	29.9	35.1	52.5	72.5

Source: Anon. (2021)

Table 12: Methane emission ($mg/m^2/hr$) as influenced by method of planting and nutrient management in paddy (Mean of 7 samplings)

Method of planting	Nutrient management				
	Inorganic(S_1)	INM(S_2)	Organic(S_3)	Control(S_4)	Mean
M_1: SRI	0.42	0.83	1.20	0.28	0.68
M_2 :DS	0.95	1.43	1.62	0.68	1.15
M_3 :NTP	0.97	1.67	2.07	0.88	1.40
Mean	0.78	1.28	1.63	0.61	
CD @ 5%	M = 0.24	S = 0.10	MxS = 0.18	CV (%) = M 17	CV (%) = S 10

Source: Anon. (2015)

Table 13:Effect of water regimes on emission of GHG and yield of paddy

SN	Irrig. water (mm)	N2O (kg/ha)	CH4 (kg/ha)	CO2 e (kg/ha)	Paddy yield (kg/ha)
1	1200	1.04	35	1488	4940
2	840	1.25	24	1194	4850
3	726	1.27	20	1043	4810
4	673	0.98	17	863	3780
5	643	0.89	15	777	3220
6	608	0.84	14	722	2560

Source: Kumar et al. (2016)

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Precision Agriculture for Sustainable Natural Resource Utilization

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INTRODUCTION

Precision agriculture, also known as "site-specific crop management," is an information and technologybased agricultural management system used to identify, analyze, and manage variability within fields for optimum profitability, sustainability, and environmental protection. Fields often vary in soil types, elevations, soil chemistry, fertility, and productivity. Producers can specify the farm input needs (including nutrient and pesticide application, tillage, and irrigation) throughout an individual field by applying precision agriculture practices.Precision agriculture (PA) is "an approach to farm management that uses information technology (IT) to ensure that the crops and soil receive exactly what they need for optimum health and productivity". The goal of PA is to ensure profitability, sustainability and protection of the environment. PA is also known as satellite agriculture, as-needed farming and site-specific crop management (SSCM).

How Precision Agriculture is working?

PA is "a technology-enabled approach to farming management that observes, measures, and analyzes the needs of individual fields and crops". Precision agriculture relies upon specialized equipment, software and IT services. The approach includes accessing real-time information about the conditions of the crops, soil and ambient air, along with other relevant information such as hyper-local weather predictions, labour costs and equipment availability. Predictive analytics software uses the information to guide farmers about crop rotation, optimal planting times, sowing, fertilizer rates, irrigation management, harvesting times, and soil management. Intensive soil samples, along with longitude and latitude coordinates, are taken from different parts of the field showing variations in yield and are analyzed for soil parameters like nutrient status, pH, EC etc. This information is stored in the controllers, which variably determine the rate of application of nutrients and soil amendments in the field.

Similarly, field sensors measure the moisture content and temperature of the soil and surrounding air. Satellites and robotic drones provide farmers with real-time images of individual plants. Information from these images can be processed and integrated with sensor and other data to guide immediate and future decisions, such as precisely what fields to water and when or where to plant a particular crop. Agricultural control centers integrate sensor data and imaging input with other data, allowing farmers to identify different parts of the fields that require treatment and determine the optimum amount of water, fertilizers and pesticides to apply. This helps the farmer avoid wasting resources and prevent run-off, ensuring that the soil has just the right amount of additives for optimum health, while also reducing costs and controlling the farm's environmental impact. In the past, precision agriculture was limited to larger farms, which could support the IT infrastructure and other technology resources required to fully implement and benefit from precision agriculture. Today, however, mobile apps, smart sensors, drones, and cloud computing make precision agriculture possible for farming cooperatives and small family farms.

Advantages of Precision Agriculture

The fundamental idea behind this new technology is to provide economic returns by optimizing crop yield and minimizing environmental impact. The different advantages are:

- Improves productivity and quality
- Reduces cost of production
- Improves input and resource use efficiency
- Eco-friendly- reduces environmental pollution
- Leads to sustainable agriculture

Application of Advanced Technology for Precision Farming

Drone Application:

Precision Agriculture is the future of an advanced farming system far ahead of conventional farming practices. The word precision here stands for site-specific, and thus it is confined to the specific area of land rather than the large fields.Precision Farming uses drone technology(Fig.1). Agriculture Drones allow farmers to monitor crop and livestock conditions to quickly find problems that would not become apparent in ground-level spot checks. For example, a farmer might find that part of their crop is not being properly irrigated through time-lapse drone photography.

Satellite Application:

Precision Agriculture is a new concept of farming, also known as satellite?farming?or site-specific crop management (SSCM). It is a?farming?management concept based on observing, measuring and responding to inter and intra-field variability in crops.Precision farming is farming that uses satellite data to make soil?work?better by informing about the condition of soil, its moisture level and other aspects. They use research about weather patterns, soil temperature and humidity, growth, and other factors. They rotate crops to improve diversity and monitor irrigation rates so salts?do?not accumulate.

GPS Application:

Some of the large agricultural equipment are now furnished with GPS systems. The GPS aids in planting accurate rows of crops, as well as applying fertilizers. One example of a precision agriculture practice is evaluating a field's natural soil variability. If the soil in one area holds water better, crops can be planted more densely, and irrigation can be spared. Or, if the plot is used for grazing, more cattle can graze than a similar area of poorer quality soil. By studying these factors and using precision agriculture, farmers are able to produce more food at a fraction of the cost. Farmers also conserve soil for sustainable food production. Precision agriculture results in a stable food supply and a strong community.

Precision Agriculture can involve any of the following elements:

Variable rate technology (VRT)- VRT refers to any technology that enables the variable application of inputs and allows farmers to control the number of inputs they apply in a specific location. The basic components of this technology include a computer, software, a controller and a differential global positioning system (DGPS). There are three basic approaches to using VRT- map-based, sensor-based and manual. The adoption of variable rate technology is estimated at 15% in North America and is expected to grow rapidly over the next five years.

GPS soil sampling- Testing a field's soil reveals available nutrients, pH levels, and other important data for making informed and profitable decisions. In essence, soil sampling allows growers to consider productivity differences within a field and formulate a plan that considers these differences. Collection and sampling services that are worththe effort will allow the data to be used for input for variable rate applications for optimizing seeding and fertilizer.

Computer-based applications-Computer applications can be used to create precise farm plans, field maps, crop scouting and yield maps. This, in turn, allows for the more precise application of inputs such as pesticides, herbicides, and fertilizers, thus helping to reduce expenses, produce higher yields and create a more environmentally friendly operation. The challenge with these software systems is they sometimes deliver a narrow value that does not allow data to be used for making bigger farm decisions, especially with the support of an expert. Another concern with many software applications is poor user interfaces and the inability to integrate the information they provide with other data sources to enrich and show significant value to farmers.

Remote sensing technology- Remote sensing technology has been used in agriculture since the late 1960s. It can be invaluable for monitoring and managing land, water, and other resources. It can help determine everything from what factors may be stressing a crop at a specific time to estimating the amount of moisture in the soil. This data enriches decision-making on the farm and can come from several sources, including drones and satellites. At its most basic level, precision agriculture takes the role of an agronomist and helps makethe method they use more accurate andscalable. The primary aim of precision agriculture and precision agronomics is to ensure profitability, efficiency, and sustainability while protecting the environment. This is achieved by using the big data gathered by this technology to guide both immediate and future decisions on everything from where in the fieldonly beenover the past decade that they have become mainstream due to technological advancements and the adoption of other, broader technologies. The adoption of mobile devices, access to high-speed internet, low-cost and reliable satellites - for positioning and imagery and farm equipment that's optimized for precision agriculture by the manufacturer are some of the key technologies characterizing the trend for precision agriculture.

Common barriers to widespread use of precision agriculture:

- Cost of equipment (VRT, sensors, controllers, GPS) and services (remote sensing, soil analysis)
- Lack of experience and knowledge
- Not suitable for small holdings

Precision Irrigation Water Management in India

The productivity of irrigated agriculture is more than 2-3 times the productivity of rainfed agriculture; there is a need to bring more area under irrigation to meet the food demands of the constantly increasing population. However, due to technical, environmental, economic and social reasons, there is a limit to creating additional water resources. Under these circumstances, the only alternative is to use the available water efficiently for irrigation so that more area can be brought under irrigation. Also, the requisite quantity of water can be made available for the domestic and industry sectors, which are also the backbone of the Indian economy.There are several means to use the water available for irrigation efficiently. These means are complementary to each other. One such means is to follow the appropriate irrigation scheduling. While modern irrigation systems such as sprinklers and drip are being promoted and increasingly used by the farmers for efficiently applying water, there is no proper attention on how much to apply and when to apply. Application of the right quantity of water at the right time is important for enhancing agricultural productivity and precisely and efficiently using the available water resources. This is very important as "under-watering" will cause loss of productivity, and "over watering" will lead to wastage.

Internet of Things (IoT) is one such advanced technology that enables us to connect things, people and decision support; and perform tasks automatically and precisely by using real time data and information. By adopting of IoT technologies, the farmers can optimize the use of water. IoT is the network of smart devices such as sensors that interconnects with each other with decision support on time.

ICAR-Indian Institute of Water Management (IIWM), Bhubaneswar had undertaken studies on performances of automatic irrigation systems (sensor based and timer based) on crop evapotranspiration (ETc), variable rate fertigation, and different plant densities with different soil wetted volume (SWV) under drip irrigation for banana (cv. *Grand Naine*) at its research farm. Under automated irrigation, different time based irrigation (1 hour interval 3 times daily at 80% ETc, 2 hour interval 2 times daily at 80% ETc, 1 hour interval 3 times daily at 60% ETc, 2 hour interval 2 times daily at 60% ETc) were compared with soil water sensor-based irrigation and manually operated irrigation (at 100% ETc, 80% ETc and 60% ETc) under drip system in the crop. The second experiment studied crop growth stage (pre-flowering, PF; flowering and fruit set, F & FS; fruit development, FD) based on irrigation and fertigation. Different irrigation treatments imposed based on crop evapotranspiration (ETc) were I1 : 60% ETc at PF+ 80% ETc at F & FS +60% ET at FD; I2 : 80% ET at PF+100% ET at F & FS + 80% ET at FD and I3 : 100% ET : 100% ET throughout the season, whereas fertigation doses applied based on recommended dose of fertilizer (RDF) were F : 60% RDF 1 at PF + 80% RDF at F&FS + 60% RDF at FD; F : 80% RDF at 2 PF + 100% RDF at F&FS + 80% RDF at FD and F : 100% 3 RDF throughout the season. In the third experiment, the response of a different number of plants (1 plant, 2 plants and 3 plants) per pit with different plant to plant and row to spacing (2.0 m × 1.5 m; 2.0 m × 2.0 m; 2.0 m × 2.5 m) and different wetted soil volume (WSV: 20%, 40%, 60% and 80%) were studied under drip-fertigation. The hydraulic performance of the drip irrigation system installed for the study was found satisfactory with emitter flowrate variation (Q) of 5%, coefficient of variation (CV) of 6% and distribution uniformity (DU) of 95%. The water applied in various automatic irrigation treatments varied from 363 mm to 580 mm compared with 744 mm under manual irrigation. The soil water content under manual irrigation at 100% ETc (21.2–24.1%, v/v) was marginally higher than that under sensor-based irrigation (20.8–23.7%, v/v) and time-based irrigation (19.8%–21.27%, v/v). The available N, P and K content in soil was highest under sensor-based irrigation, followed by time-based and manual irrigation. However, manual irrigation resulted in higher light interception (60–72%) and SPAD values (45–60) than sensor-based and time-based irrigation schedules. The vegetative growth of plants increased with an increase in irrigation level from 60% ETc to 100% ETc, whereas irrigation at 80% ETc resulted in yield at par with 100%ETc under manual irrigation. The plant height, canopy diameter, number of leaves, stem girth, and leaf area index of the plants under manual irrigation was 9-16% higher than sensor-based irrigation. The sensor-based irrigation produced 18% higher yield with better quality fruits (higher TSS and lower acidity), resulting in 51% improved water productivity compared with manual irrigation. The studies indicated the suitability of the sensor and time-based irrigation systems.

MPKV, Rahuri has developed mobile and web-based applications and IoT-enabled technologies for precision irrigation management as detailed below.

Phule Jal (PJ)

The innovative 'Phule Jal' mobile and web-based application enable users to determine the important parameters required for estimating irrigation water requirement, i.e., evapotranspiration by different methods offline, online and in real-time modes for the specified location; and also for different talukas of India. This application is popular amongst students, researchers and practitioners and is available at Playstore:https://play.google.com/ store/apps/details?id=net.parthinfotech.phulejal&hl=en_IN&gl=USand also available at:https://www.rkvyiwras.ac.in/PhuleJal/Login

The mobile and web applications *'Phule Jal'* have been developed to estimate reference evapotranspiration using weather data.'*Phule Jal'* mobile application estimates the reference evapotranspiration (*ETr)* by the different standard methods for the specific location by fetching the required input weather data (maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, wind speed, sunshine hours, etc.) from the 'Open weather', weather service provider for the current and 3 days ahead.In addition to online estimation of reference evapotranspiration based on information on weather fetched from the weather data provider, there is also arrangement to input the own weather data for estimation of evapotranspiration in offline mode. This is particularly important if farmers have their own data/AWS.

Modified Phule Irrigation Scheduler (Mod-PIS)

The 'Modified Phule Irrigation scheduler' mobile and web applications is the upgraded version of Phule Irrigation Scheduler (PIS) that estimates the irrigation date in addition to the amount of water to be applied and time of operation of pump. The irrigation date is calculated based on irrigation scheduling approaches such as depletion of water and irrigation water, divided by cumulative pan evaporation approach (IW/CPE).

IoT enabled Phule Irrigation Scheduler-based Automatic Pump Controller (AutoPIS) mobile application for a single plot

The innovative 'Auto Phule Irrigation Scheduler'mobile-based application is the seamless integration of three mobile apps namely "Phule Jal" to estimate crop evapotranspiration in real time, "Phule Irrigation Scheduler (PIS)" to estimate the precise quantity of water to be applied based on real-time weather, crop, soil, farm and irrigation system information and corresponding time of operation of the pump and "mod PIS" to communicate with the cloud-based communication system; and Pump Controller. Auto-PIS enables the farmers to start the pump automatically from anywhere for the specified time duration, and after the specified time has elapsed, the pump automatically stops. Additionally, through Auto PIS, farmers can provide irrigation time to automatic pump controllers from anywhere as per their own knowledge. When pump stops before operating for the desired time in case of power failure, there is a provision to start the pump automatically once the power restores for the remaining time.

IoT enabled soil moisture sensor(capacitance)-based irrigation scheduling system.

The innovative 'Internet of Things (IoT) enabled soil moisture sensor-based irrigation scheduling system (mobile application) measures the available soil moisture content at various depths in the soil root zone. The soil moisture measurement can be recorded at different intervals, such as daily and hourly, as per the requirement. The soil moisture measured periodically by the sensors is collected at the server side through a wireless sensor network. The action regarding whether to irrigate or when to irrigate is decided based on already defined depletion criteria for a specified crop and irrigation method. The water to be applied at the time of irrigation is then determined based on the moisture to be added in the soil root zone to take the moisture content in the soil from the actual observed level to the field capacity or other desired level. Then according to system/pump discharge, the time of irrigation application is estimated.

Krish-e (https://krishe.co.in/digital-services) by Mahindra & Mahindra group is a popular agriculture app that provides a personalized crop calendar for your farm and valuable agriculture information like land preparation, crop sowing, crop planning, fertilizer management, seed treatment, pest and disease management, diagnosis and treatment of crop issues, weed treatment and irrigation. Available in 8 popular Indian languages, this farm app is the preferred technology solution to boost your farm yields. The app and the advisory services are available in English, Hindi, Marathi, Telugu, Kannada, Tamil, Gujarati and Punjabi.

Conclusion

Based on the research studies conducted in India and abroad, it appears that the need of developing the appropriate technologies for the precision irrigation water management has already been realized and many of the researchers developed the sensor-based applications involving wireless communication for the data transfer from the sensors to processing unit and then to controller to operate the pump. However, it is also observed that a comprehensive tool consisting of the real-time weather and crop parameters that influence precision irrigation water management needs to be developed for precision irrigation water management. These applications, however, need to be made smarter and also with precision by including the measurement of moisture content at different depths of soils as per root growth variation; and tested and validated for the major crops for their adoption at a large scale.Through this technology, farmers can decide how much water needs to be irrigated and what pesticides are required for the particular crop. Precision agriculture can help farmers know how much and when to apply these inputs. They also use precision agriculture practices to apply nutrients, water, seed, and other agricultural inputs to grow more crops in a wide range of soil. These type of research activities are also undertaken in a consortia research mode under Agri-Consortia Research Platform on Water which ICAR-IIWM, Bhubaneswar, is coordinating.

Reading materials

https://krishe.co.in/digital-services

https://play.google.com/ store/apps/details?id=net.parthinfotech.phulejal&hl=en_IN&gl=US

https://www.aem.org/news/the-environmental-benefits-of-precision-agriculture-quantified

https://www.rkvyiwras.ac.in/PhuleJal/Login

Mondal, P. and Basu, M., 2009. Adoption of precision agriculture technologies in India and in

some developing countries: Scope, present status and strategies. Progress in Natural Science (Elsevier), 19(6), pp.659-666.

Nowak, B., 2021. Precision agriculture: where do we stand? A review of the adoption of

precision agriculture technologies on field crops farms in developed countries. Agricultural Research, 10(4), pp.515-522.

Paustian, M. and Theuvsen, L., 2017. Adoption of precision agriculture technologies by German crop farmers. Precision agriculture, 18(5), pp.701-716.

Vrchota, J., Pech, M. and Švepešová, I., 2022. Precision Agriculture Technologies for Crop andLivestock Production in the Czech Republic. Agriculture, 12(8), p.1080.

Yang, C., 2020. Remote sensing and precision agriculture technologies for crop disease detectionand management with a practical application example. Engineering, 6(5), pp.528-532.

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Soil and water conservation technologies for sustainable agriculture in coastal region

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INTRODUCTION

India has a coastline of about 7,516 km, of which about 5,400km belong to peninsular India and the remaining to the Andaman, Nicobar and Lakshadweep Island which is less than 0.25% of the world's coastline. India houses approximately 11% of the global population in low-elevation coastal areas. The coastal districts (73 out of 593 districts) have a share of 17% of the national population, and nearly 250 million people live within 50km of the coastline. Accelerated soil erosion in coastal land severely threatens agriculture in coastal regions. Climate change further aggravates the risks to coastal communities and infrastructure. An assessment with satellite data revealed that around 45.5% of the coastal length is observed to be under erosion (Rajawat*et al.,*2014). The Goa state experiences varying rainfall from 2700 mm to over 3800 mm per annum. The soils are predominantly lateritic (73.4%), followed by alluvial and marshy soils (11.1%), sandy soils (10.1) and saline (4.79%). Most of the soil series are coarse to medium textured with well-drained and poor water holding capacity. Plantation crops predominantly occupy the steep slopes of lower coastal Ghats. High rainfall with higher intensity and erosivity coupled with steeper and longer lengths of slopes and horticultural crop cultivation without proper soil and water conservation measures are causing severe erosion and land degradation problems in the area. This leads to the washing away of topsoil and nutrients, loss of productivity, siltation of drainage channels, reservoirs and ponds, floods and droughts. Though the coastal lower Ghats receive higher rainfall, many places still experience severe water scarcity during the summer months as the maximum amount of rain is received during the monsoon period (June to September). As a result, moisture stress and drought adversely affect the productivity of horticultural crops like cashew, mango, arecanut, coconut, etc. Apart from this, on the other hand, higher runoff amounts are causing frequent floods in the coastal ecosystem and greater dependence on groundwater exploitation in the absence of surface water leading to declining groundwater tables at an alarming rate. All these problems are warning signals and suggest laying greater emphasis on sustainable agricultural development through the integration of soil, water and vegetation resources in harmony with the human resources.

Soil and water conservation measures

Though the coastal regions receive higher rainfall, many places still experience severe water scarcity during the summer month as the maximum amount of rainfall is received during the Monsoon period (June to September). As a result of this, moisture stress and drought have adversely affected the productivity of horticultural crops like cashew, mango, arecanut, coconut etc. Apart from this, on the other hand higher runoff amounts are causing frequent floods in the coastal ecosystem and greater dependence on groundwater exploitation in the absence of surface water leading to declining ground water tables at alarming rate. All these problems are warning signals and do suggest laying greater emphasis on sustainable agricultural development through the integration of soil, water and vegetation resources in harmony with human resources. Runoff and soil loss behaviours under different land use with varying conservation measures are prerequisites to suggest suitable conservation measures for any type of land use system. Hence, a field study was conducted in the lower coastal region of Goa state to understand the runoff and soil loss pattern of different conservation measures under different land uses. In-situ rainwater retention in the field is the most efficient method to recharge and store moisture in the root zone for better plant growth. This can be achieved by suitable agronomic measures such as crop geometry, crop combinations, mulching etc. and also by promoting moisture retention by mechanical actions such as trenching, bunding, terracing, basins or micro catchment, contour furrow *etc*.,

Mechanical and bioengineering measures

A continuous contour trench (CST) is a trench made for the entire field length continuously along the contour at certain vertical intervals. A graded trench (GT) is a trench made for the entire field length constantly in different grades. Staggered contour trench (SCT) to be excavated for the length of 2m, top width 0.45 m, bottom width 0.30 m and depth of 0.45 in a staggered manner of an aligned contour. The trench with the length of 2m, top width 0.45 m, bottom width 0.30 m and depth of 0.45 m were prepared in respect to each plant in a semi elliptical manner on the upstream side of the plant is called semi elliptical trench (SET). The trench that will be taken up in crescent shape is called as a crescent-shaped trench (CST). The trenches or terraces supported with live barriers are called bio - engineering measures. Vegetaive barriers such as Vetivariazizanoides, Stylosanthesscabra and Glyricidiamaculatacan be planted as hedge crop on the bunds of trenches.

Effect of conservation measures

Experiments were conducted on the hydrological effect of different conservation measures under different crop spacing. Based on the studies, the quantitative impacts of different soil and water conservation measures on runoff, soil and nutrient loss, soil moisture content, major nutrient status and growth parameters, yield and economic feasibility of different conservation measures were assessed. Two sets of experiments were conducted in different high density planting methods. One set of soil and water conservation measures evaluated under 4 m X 4 m spacing and other set with 6 m X 6 m spacing. Field data on runoff, soil loss, nutrient loss, and soil moisture content, growth of cashew and yield parameters were recorded for six years period. Thus, collected data were pooled, analyzed and reported.

Continuous contour trenches with *Stylosanthesscabraand Vetiveriazizanioides*and staggered contour trenches with *Stylosanthesscabraand Vetiveriazizanioides*reduced the runoff by 44.5 and 34.6 per cent, respectively under spacing of 4 m X 4 m cashew plantations. Similarly, continuous contour trenches with vegetative barrier of *Stylosanthesscabra* + *Glyricideamaculata,* staggered contour trenches with *Stylosanthesscabra* and *Glyricideamaculata*andcrescent shape trenches with *Stylosanthesscabra* and *Glyricideamaculata* recorded runoff reduction of 46.3, 35 and 29.0 per cent, respectively in the field where cashew was planted at 6 m x 6m spacing.

Continuous contour trenches with *Stylosanthesscabraand Vetiveriazizanioides* and staggered contour trenches with *StylosanthesscabraandVetiveriazizanioides* reduced the soil loss by 11.3 and 8.1 t ha^{-1} yr^{-1} in 4 m x 4 m cashew field. Similarly, continuous contour trenches with vegetative barrier of *Stylosanthesscabra* + *Glyricideamaculata*significantly reduced average soil loss (6.5 t ha^{-1}) followed by staggered contour trenches with *Stylosanthesscabra* and *Glyricideamaculate* (5.6 t ha^{-1})andcrescent shape trenches +*Stylosanthesscabra* and *Glyricideamaculata* (5.7 t ha^{-1}) in the plot where the cashew was planted at 6 m x 6 m spacing.

Continuous and staggered contour trenches with vegetative barriers recorded the maximum plant growth and yield. Total cashew nut yield of 7.72, 14.21 and 18.1 q ha^{-1} were recorded in treatment comprising of continuous contour trenches with *Stylosanthesscabraand Vetiveriazizanioides* during fourth, fifth and sixth years, respectively, under 4 m X 4 m cashew plantations. The total cashew nut yield of 6.80, 3.50 and 5.20 q ha^{-1} were recorded in treatment comprising of continuous contour trenches with *Stylosanthesscabra* + *Glyricideamaculata* during fourth, fifth and sixth years, respectively under 6 m X 6 m plantations. Maximum NPW of Rs. 4, 61, 820 per ha was obtained under cashew cultivation with continuous contour trenches with

Stylosanthesscabraand Vetiveriazizanioides followed by Rs. 4,08, 090 per ha under cashew cultivation with staggered contour trenches *StylosanthesscabraandVetiveriazizanioides*. Maximum NPW of Rs. 1, 64, 900 per ha was obtained under cashew cultivation with continuous contour trenches with *Stylosanthesscabra* + *Glyricideamaculata* followed by Rs. 1,27,190 per ha under cashew cultivation with staggered contour trenches *Stylosanthesscabra* + *Glyricideamaculata*. Higher benefit cost ratio and Internal rate of return were obtained under the continuous contour trenches with *Stylosanthesscabra and Vetiveriazizanioides* (6.87 and 20 per cent, respectively) followed by staggered contour trenches with *Stylosanthesscabra and Vetiveriazizanioides*(6.82 and 18 per cent, respectively) under 4 x 4 m cashew plantation. Similarly, BCR and IRR were higher under the continuous contour trenches with *Stylosanthesscabra and Glyricidiamaculata* (5.07 and 13 per cent, respectively) followed by the staggered contour trenches with *Stylosanthesscabra and Glyricidiamaculata* (4.64 and 12.5 per cent, respectively) under 6 m X 6 m cashew plantations and these measures can be adopted for cultivating cashew in lateritic soils of hilly slopes.

Rainwater harvesting

In many parts of the world, the collected rainwater from natural precipitation is the only source of water supply, and it is considered an economical and useful method. Proper water harvesting techniques will mitigate the problems of soil erosion and flooding to a large extent. It will also enhance agricultural productivity in the region. The water harvesting can be done through the following techniques

- Harvesting the surface runoff from the land surface
- Diversion of surface/subsurface water sources
- Direct rainwater harvesting in undulating topography and hilly region
- Subsurface water harvesting

Surface Water Harvesting

Surface water harvesting includes harvesting the water from catchments and storing in tanks, ponds, lakes etc. The total number of tanks, ponds and lakes of the Goa state is 3928 contributed by 2744 and 1184 in North Goa and South Goa district, respectively. Tank is generally a small storage reservoir formed across a stream in a valley. Sometimes these tanks could have independent catchments, drawing their supplies from the run off from the catchment areas. Tanks fully dependent on the rainfall in their catchments are called as non-system tanks. In addition, some tanks may have a supply channel from a neighbouring stream or river, which has a dependable flow, are known as system tanks. The following tanks are constructed after liberation of Goa. Farm pond may be constructed where the largest storage volume of water can be obtained with the least amount of earth filled within or close to the point of use. In general the farm ponds are constructed in a rectangular or trapezoidal shape. Depending on the soil conditions, these ponds may be constructed with or without lining. Polythene sheets may also be used for lining to minimize percolation losses. Pollution of farm pond water should be avoided from drainage, farmsteads, sewage lines and mine dumps. Where this cannot be done successfully, it is recommended that water from such areas should be diverted from farm pond.

Dugout ponds

Where the topography does not lead to embankment construction, dugout or sunken ponds can be constructed in relatively flat terrain. Since dugout ponds can be built to expose a minimum water surface area in proportion to volume, they are advantageous where evaporation losses are high, and water is scarce. Some important physical features that must be considered in locating dugout sites are the watershed characteristics, silting possibilities and topography and soil types. The watershed must be capable of furnishing the annual runoff sufficient to fill the dugout ponds. The lowest point of a natural depression is often a good location for a dugout pond. The soil type at the site should be thoroughly investigated to determine the soil's permeability and avoid cutting in very hard stuff. A dugout pond can be constructed where the water table rises within a few meters of the ground surface to intercept the water adjusting the depth to the expected fluctuations. Location of this type may supply water all around the year. These dugout ponds are found in valleys in the Western Ghats regions of Goa.

Larger Farm Ponds

Larger farm pond in the dimensions of 40 X 20 m has to be excavated in a trapezoidal manner and fine sand has to be placed to a depth of 30 cm followed by spraying of weed control chemicals. The sides of the farm pond have to be prepared in step by step enable to withhold the plastic sheet. The silpaulin sheets having 250-300 GSM thick must be placed and completely covered.

Diversion of Surface / Subsurface Water

The surface water from stream and drainage lines is being stored and diverted to irrigate the nearby fields. The source of water is excess runoff and subsurface flow during summer seasons *Bandharas* are the small diversion structures constructed across the streams and drainage lines and the stored water is irrigated to the nearby fields by gravity flow. There are two types of bandhas based on the materials used for construction: earthen dam and concrete masonry dam. The height of such structures varies from 1m to 1.5 m. A sluice gate is provided in the centre of the structure to facilitate the draining of water entirely during the heavy rains and consequent floods which avoids damage to the crops during peak flow of water. These *bandharas* serve the purpose of storage and cater to water supply and irrigation needs. These structures have existed since the Portuguese regime. These structures are quite cost-effective and yield quick benefits to the farmers. Large bandharas have been constructed by Water Resources Department under minor irrigation scheme. The bandharas of Sanquelim, Bicholim, Maulinguem, Assonora and Koperdem were erected many years ago and need modernization.

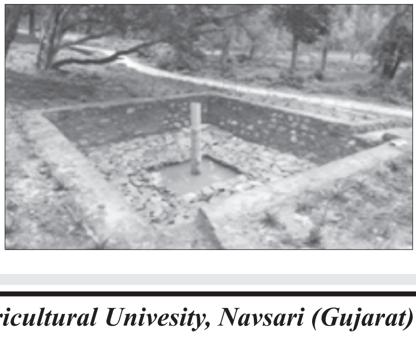
Direct Rain Water Harvesting

Goa receives 2800 mm to 3800 mm annual precipitation and possibly stores water for the depth of 2 m to 3.5 m from the self-catchment of pond area.To harvest the water during the rainy season for recycling during the summer season, small ponds are dug up with the dimension of 2m x 2m x 1m or 4m x 1m x 1m depending upon the soil depth. If the soil depth is more than one meter, farmers can go for 2m x 2m x 1m dimensions pond and evaporation losses also will be less in 2 m deep ponds. These smaller ponds must be lined with silpaulin or HDPE, 200 GSM thick plastic poly films. Before lining of the ponds, paddy straw or any other materials as a cushion has to be placed adequately. These water harvesting systems store water to the tune of about 4 m3 and will serve the irrigation purpose to 8-10 perennial crops for seven months. Accordingly, the farmer can increase the number of ponds depending upon the number of trees or other crop components. To reduce the evaporation losses neem oil may be applied on the water surface.

Subsurface water harvesting

Springs constitute the major source of water supply in the hilly regions, especially in valleys. Springs are the manifestations of the groundwater hydrology of hilly regions. These springs are frequently found on the hill slopes and in the valleys of Western Ghats. Small and large springs depend on the degree of concentration and seasonal or perennial springs. Most of the springs in Western Ghats valley are perennial and will supply water for small land holdings throughout the year.

ARTIFICIAL RECHARGE STRUCTURES



The artificial recharge structures are helpful in groundwater reservoir augmentation by modifying surface water's natural movement. Artificial recharge techniques enhance the yield in areas where over-development has depleted the aquifer, conserve and store excess surface water for future requirements, and improve groundwater quality. The primary purpose of artificial groundwater recharge is to restore supplies from aquifers depleted due to excessive groundwater development.

Percolation ponds

Percolation ponds are small storage structures constructed across natural streams and nalas to collect, spread and impound surface runoff to facilitate infiltration and percolation of water into the sub-soil for augmenting ground water recharge. The site should have highly porous soil and sites with heavy soils or impervious strata should be avoided. There should be a number of irrigation wells in the zone of influence upto about 1 km from the pond to benefit from the groundwater recharge. The ponds may be designed to store about one-third of the annual water yield from the catchments and 1 ½ to 2 fillings during the monsoon are assumed.

Sunken ponds

These are small water harvesting pits sunk in gully bottoms. These pits are made to capture rainwater for recharging groundwater. These are usually created in small gullies where sediment discharge is less. It can also be created upstream side of the wells in either common or private land. But, side of the drainage lines on the bunds should be avoided. The depth of pits is limited to 2.00 m, in most cases only 1.00m. The width of pit depends upon gully bottom may vary from 1 m to 3 m. The length of pit may be 4.00 m or 2 m diameter in case of circular shape. The excavated soil is deposited in thin layers at down stream leaving provision of surplus arrangements. Suitable vegetation is planted around the pit. Silt trap is provided at upstream. Revetment is provided an inlet side. These are usually made in series.

Percolation trenches

A percolation trench/ infiltration trench is a recharge structure that is used to harvest runoffwater, prevent flooding and downstream erosion,

and improve water quality in an regions. Medium size of trenches with a length of 4 to 6 m, width of 0.5 to 1 m and depth of up to 1 m can excavate upstream in common and community lands. These trenches will recharge the groundwater at down streamside.

SUMMARY

In view of achieving sustainable agricultural development in coastal regions,*in-situ* moisture conservation should be taken up for the cultivation of all crops. Continuous contour trenches with vegetative barriers were the best compared to all other treatments for runoff, soil loss and nutrient loss reduction. Staggered contour trenches with *Stylosanthesscabra and Vetiveriazizanioides* were the alternative measure for the reduction of runoff and soil loss for cashew land use. Additional income could be generated from the vegetative barriers, which can be used as either fodder or biomass during the initial periods of cashew plantation by adapting the bioengineering measures. Continuous contour trenches with *vegetative barriers*and staggered contour trenches with*vegetative barriers* were found economically viable, and these technologies are recommended for cashew plantations in hilly terrain. Water should be harvested either in the surface or subsurface by various technologies. The possible sub-surface water harvesting technologies are wells and sunken ponds. Artificial recharge of ground water should be entertained by constructing percolation ponds and check dams in watercourses, and it should be promoted in all watershed development programmes in the region. Direct rainwater harvesting in smaller ponds and recycling is the solution for providing protective irrigation to plantation crops in the hilly areas. The lining of ponds is recommended where the percolation losses are very high.

REFERENCE

Geddes, H.J. 1963, Water harvesting. In Proceeding of National Symposium on Water Resources, Australia Academy Of Science, Canberra, Australia

Juyal, G.P., Katiyar, V.S., Sastry, G., Singh, Gurmel, Joshi, P. and Arya, R.K. (1991). Geojute for rehabilitation of steep minespoil areas, CSWCRTI, Dehradun. Bulletin No.T-26/D-19.

Manivannan. S, V. KasthuriThilagam and O.P.S. Khola (2017). Soil and water conservation in India: Strategies and Research Challenges. Journal of Soil and Water Conservation 16 (4): 312-319.

Manivannan.S., O. P. S. Khola (2013) Soil and water Conservation in the Nilgiris : issues and Strategies. In An anthology of Nilgiri Biosphere Reserve (Ed.) B.Ramakrishnan and A Veeramani.Government Arts College, Udhagamandalam, Tamil Nadu. PP 528-535. (ISBN: 978-93-5165-099-9)

Ministry of Water Resources, Central Ground Water Board (2007). Manual on artificial recharge of groundwater.

Rajawata, A.S., H.B. Chauhana , R. Ratheesha , S. Rhodea , R.J. Bhanderia , M. Mahapatraa , Mohit Kumara , R. Yadavb , S.P. Abrahamc , S.S. Singhb , K.N. Keshrib and Ajaia (2014). Assessment of coastal erosion along Indian coast on 1:25, 000 scale using satellite data. In The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-8, 2014 ISPRS Technical Commission VIII Symposium, 09 – 12 December 2014, Hyderabad, India

Samra, J.S., Sharda, V.N. and Sikka, A.K. 2002. Water harvesting and recycling – Indian experiences. CSWCR & TI, Dehradun.

Sharda, V.N. and G.P.Jual, 2002 Water harvesting and recycling in Himalayas. In Proceedings Of National Symposium On Soil and Water Conservation Measures And Sustainable Land Use systems With Special Reference To The Western Ghats Region, Invited and Contributed Papers, 16-17th November 2002, ICAR Research Complex for Goa, Old Goa – 403 402, Goa

Tideman, E.M. (1996). Watershed Management. Guidelines for Indian conditions. Omega Scientific Publishers, New Delhi-110 024.

Manivannan.S and A.K.Sikka (2013) Hydrological impact of bioengineering measures on Cashew plantations in Lateritic soils of Konkan region, Journal of Agricultural Engineering, Vol. 50(3):57-65.

Manivannan,S., (2010) Impact of bioengineering measures on soil moisture retention and major nutrients under cashew land use in lateritic soils of Goa, Journal of the Soil and Water Conservation, 9(1): 9-12.

Manivannan, S, A.K.Sikka, B.L.Manjunath, S.Priyadevi and J.Ashokkumar. 2007. Effect of bioengineering measures on runoff, soil and nutrient losses under Cashew plantations in Western Ghat region, Journal of Agricultural Engineering, 44(4):16-22.

L-15

Resources Conservation through Climate Smart Watershed Management in Eco-Sensitive Sahyadri Ranges - A Case Study of Ratnagiri District, Maharashtra

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Carbon sequestration from soil and vegetation (forest and agriculture) is a cost-effective option to mitigate global climate change. Therefore, mapping and quantifying economic values of soil and vegetation carbon stock are essential for carbon trading and offset projects. There is an urgent need to demarcate terrestrial carbon stocks in the ecosystem to plan climate change mitigation and adaptation strategies.Remote Sensing (RS) and Geographical Information systems (GIS) can play a vital role as they offer the advantage of large area coverage. It will provide a foundation for stakeholders and managers for land management decisions with an additional parameter of carbon sequestration.So, the resource-rich Ratnagiri district, with an area of 8,461 km2located inthe Konkan region of Maharashtra, India, is selected for the study. It represents India's eco-sensitive Sahyadri mountain ranges with rainfall of 3000 to 4500 mm. The carbon stock was estimated from the terrestrial ecosystem, which collected soil and vegetation samples from the grid of 5 km2. The biomass and carbon stock ofvegetation was estimated using a regression equation developed by the FAO, 1997 for the moist region and soil carbon stock was estimated using the Wet oxidation method of Walkley and Black. The vegetation and soil carbon stock were added together to get total carbon storagein the terrestrial ecosystem of the Ratnagiri district.

The total carbon stock of the Ratnagiri district was found to be 89.99 million tonnes of carbon (soil 25.79 + vegetation 64.19). Total amount of CO2 sequestered by Ratnagiri District was 330.35 million tonnes of CO2 (vegetation was 235.43 + soil was 94.92). It was found that CO2 sequestration was highest in forest (56%) followed by soil (29%), horticultural plantation (15%) and agricultural crop of paddy (0.19%). It was found that forest cover, horticulture plantationsand soils can store more significant atmospheric CO2 and play a vital role in mitigating climate change impacts. It was recommended that afforestation practices can be implemented on barren land to increase the study area's carbon sequestration rate.

Keywords: Global warming, climate change, carbon trading,Sahyadri mountain, carbon sequestration.

INTRODUCTION

Land and water resources are limited with their extensive vital exploitation, especially for countries like India where the population pressure is increasing continuously. However, in recent years, increased frequency of extreme events such as droughts and floods due to climate change leads to accelerated rates of degradation of soil and water resources (Kanime, *et al*., 2013). It includes deforestation, burning of biomass, burning of fossil fuels for energy, overexploitation of natural resources, change in land use and wetlands (Srinivasarao*et al.,* 2013). The agriculture accounts about 17% of the total global emission of greenhouse gases (IPCC, 2007).

Carbon sequestration implies transferring atmospheric CO_2 into long-lived pools and storing it securely, so it is not immediately reemitted. The global carbon cycle comprises five carbon (C) pools, of which the largest is the oceanic pool, the second is a geological pool, the third is soil, and the fourth is the atmospheric pool. The forest ecosystem plays vital role in the global carbon cycle. Carbon sequestration by growing forests is the cost-effective option for mitigating global climatic changes (Andrasko, 1990; Brown *et al*., 1996).

According to Forest Survey of India (FSI), carbon stock in Indian forest land are 6663 million tonnes (98.40 t/ha). The forest in Maharashtra contains total carbon stock of 479 million tonnes (100.80 t/ha) of carbon which is 7.18 per cent of country's entire forest carbon stock (FSI, 2004). Thus, it shows that forests in Maharashtra have low potential of storing carbon compared to the world's forests. Globally, about 80% of carbon exchange between terrestrial systems and atmosphere in which forests contain more than half of all the terrestrial carbon (Venkatesh and Newaj, 2012).

Soil is also of global importance because of its part in the global carbon cycle and therefore, it plays an important role the mitigation of atmospheric levels of greenhouse gases (GHGs), with special reference to CO_2. Agriculture is currently the most cost-effective, way to remove carbon dioxide from the atmosphere. There are many ways for improve of carbon stock in soil. Therefore, soil and water management in forest and agriculture land is highly critical for adaptation to climate change. Increasing soil carbon content can increase soil organic matter and improve soil water-holding capacity. It also improves soil and water quality, decreases nutrient loss, reduces soil erosion, increases soil's water storage capacity and ultimately increases crop production.

Ratnagiri is a coastal district of Maharashtra state, situated in the mountain range of Western Ghats, also known as Sahyadri hills. Western Ghats are major biodiversity hotspot that contains a large proportion of the country's flora and fauna, many of which are only found here and nowhere else in the world. Forest in Ratnagiri contains semi-evergreen with moist and dry deciduous vegetation cover. These forests have a high potential to sequester carbon dioxide from the atmosphere and can play an important role in mitigating climate change effects. The soils found in Ratnagiri district mostly belong to laterite and lateritic types, derived from basaltic and granite (Mahajan, 2001). Therefore, there is needs and total carbon stock from vegetation cover and soil are needed to understand the effect of climate change on forests and agricultural lands of Ratnagiri district to mitigate climate change.

METHODOLOGY

The total geographical area of Ratnagiri district is 8,461 sq. km. Average annual rainfall of Ratnagiri district is 3,591 mm. Total of 242 villages were selected for data collection from agriculture, forest and horticultural lands by manual method.

Carbon Stock in Biomass

There are various biomass measurement methods such as in situ destructive direct biomass measurement and in situ non-destructive biomass estimations (using regression equations or conversion factors). In present study in situ non-destructive biomass method used to estimate the biomass of tree. In this method, tree height and diameter are measured using field gears like range finder, clinometer, tape, etc.

Estimation of above-ground biomass using regression equations

Regression equations were used in this study to estimate the above-ground biomass from forest and horticultural trees. Each tree's girth was measured 1.3 m above the ground surface using a measuring tape. Depending upon the diameter at breast height and considering climatic conditions, regression equations developed by Food and Agricultural Organization (FAO, 1997) were used to estimate the above-ground biomass of individual trees in kg.

$$Y = 42.69 - 12.800 \times D + 1.242 \times D^2$$

Where, Y is above ground biomass (Kg), D is diameter at breast height (cm),

Estimation of below ground biomass

The below ground biomass for forest was calculated by multiplying above ground biomass taking 0.26 as the root to shoot ratio (Cairns, *et al*., 1997; Ravindranath and Ostwald, 2008). Below ground biomass was calculated for each sample of forest area Ratnagiri district.

Generation of carbon stock of forest

The total carbon stock in the forest of Ratnagiri district was calculated by multiplying the total biomass of the forest by a conversion factor representing the average carbon content in biomass. This coefficient is widely used internationally. Thus it may be applied on a project basis. Therefore, the coefficient of 0.5 for the conversion of biomass to carbon was used (Dixon, *et al*., 1994; Ravindranath, *et al*., 1997).

Estimation of biomass of crops

The biomass (dry weight) of crops is calculated by applying the moisture loss of the samples (Losi, *et al*., 2003). This method was applicable for crops such as Wheat, Soybean, Sorghum and Paddy for which the plant samples were harvested and collected for analysis of biomass content (Kushwah, *et al*., 2014). In Ratnagiri district, the major crop grown is paddy; therefore at every sampling location paddy crop sample from 1m × 1m area were harvested and collected in bags. Plant samples were collected from different locations in the study area. The initial weight of crops was measured and then these samples were further left to air dry for 2–3 days and then placed in a hot air oven at 60°C for 24 h. The final dry weight of dried crops after oven drying was taken. Carbon stock present in crops was calculated by multiplying 0.5 to the biomass content of the crop.

Amount of CO_2 sequestered by vegetation.

Estimated carbon stock values from vegetation were converted into CO_2 equivalents (quantity × 44/12) for calculating CO_2 assimilation by vegetation (Guleria, *etal*., 2014).

Carbon Stock in Soil

Soil carbon sequestration

The top 0-30 cm soil profile is more dynamic due to organic matter input and associated surface fine root dynamics, which is susceptible to anthropogenic pressure and other natural processes (Gandhi and Sundarapandian, 2017). Land use patterns and soil management methods can significantly influence soil organic carbon from the soil (Batjes, 1996; Post and Kwon, 2000).

Determination of SOC stock

Organic carbon (%) and bulk density (g/cm^3) values were used to estimate the SOC density of soil samples from Ratnagiri district. The SOC density was calculated for two depths viz. soil surface depth of 0-15 cm and 15-30 cm. Soil carbon stocks were considered up to 30 cm soil depth only per IPCC guidelines (Guleria, *et al*., 2014). SOC storage values were calculated using following equations given by Ramachandran *et al*. (2007):

$$SOCdensity = \frac{SOC}{100} \times Correctedbulkdensity \times layerdepth \times 10^4$$

$$Correctedbulkdensity = Bulkdensity \times \frac{(100 - \text{coarse fraction})}{100}$$

$$TotalSOCdensity = SOCdensity \times Area$$

Where, soil organic carbon in %, corrected bulk density in Mg/m^3, layer depth in m, bulk density in Mg/m^3, soil organic carbon density in Mg/ha, area in ha.

Total Carbon Stock (biomass + soil) of Ratnagiri district

Carbon stock values from the biomass and soil were added together to get total carbon stock values of Ratnagiri district.

RESULT AND DISCUSSION

Land Use/Land Cover

The land use/land cover characteristics were described using land use/land cover (LU/LC) map of the Ratnagiri district and the statistical data of land use/land cover obtained from the attribute table in ArcGIS 10.2 software Spatial coverage of land use land cover classes of Ratnagiri district are shown in Table 1 and Fig. 1.

Table 1: Spatial coverage of LU/LC classes in Ratnagiri district

Sr. No.	Land use/land cover	Area covered (ha)	Area (%)
1.	Agriculture	125481	14.83
2.	Water body	13406	1.58
3.	Forest	228779	27.04
4.	Barren	206398	24.39
5.	Built up	85490	10.10
6.	Horticulture	186589	22.05
	Total	**846143**	**100**

Carbon Stock in Forest

Above ground biomass of forest

Values of above-ground biomass indicate that tree diameter increases the value of above ground biomass increases. The potential of forests to sequester carbon depends on the forest type, age of forest and diameter of trees. Tehsil-wise values of above ground biomass in the forest of Ratnagiri district were shown in Table 2. The above ground biomass values in Ratnagiri district ranged from 16.21 to 1611.54 tonnes/ha. Above-ground biomass accumulated in each tree was 80 % of the total biomass of the tree.

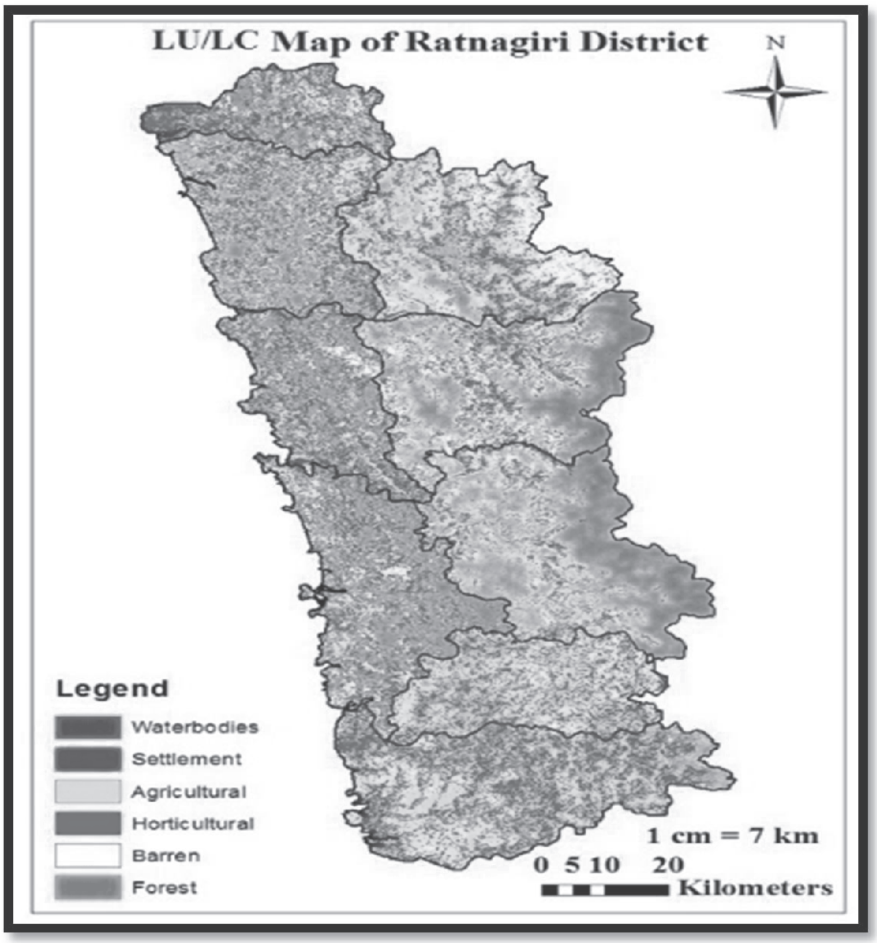

Fig. 1: LU/LC map of Ratnagiri district

Table 2: Tehsil wise values of above-ground biomass in forest from Ratnagiri district

Sr. No.	Tehsil	Above-ground biomass range (t/ha)	Average above ground biomass (t/ha)	Below ground biomass range (t/ha)	Average below-ground biomass (t/ha)
1	Mandangad	97.61 – 1278.56	365	25.37 - 332.42	95
2	Dapoli	16.21 – 591.20	253	4.21 – 153.71	65
3	Khed	31.38 – 1611.54	369	8.15 – 418.99	96
4	Guhaghar	57.20 – 956.44	345	14.87 – 251.01	89
5	Chiplun	138.67 – 1170.04	402	36.05 – 304.20	104
6	Ratnagiri	98.89 – 941.98	271	25.71 – 244.91	70
7	Sangameshwar	145.41 – 719.31	438	37.800 – 187.022	114
8	Lanja	15.09 – 787.4	388	3.92 – 204.72	101
9	Rajapur	94.72 – 730.51	298	24.62 – 189.93	77

Below ground biomass of forest

Tehsil wise values of below ground biomass in forest of Ratnagiri district are shown in Table 2. Values of below ground biomass in Ratnagiri district were ranged from 4.21 to 418.99 t/ha.

Total biomass of forest

The total biomass of a forest is the addition of above-ground and below-ground biomass. Values of total biomass in the woods of Ratnagiri district are shown in Table 3. The total biomass from Ratnagiri district was 99.74million tonnes, with an average biomass rate of 435.22t/ha. Total biomass map of forest is shown in Fig. 2.

Table 3: Tehsil wise values of total biomass in forests of Ratnagiri district

Sr. No.	Tehsil	Total biomass range (t/ha)	Average total biomass (t/ha)	Forest Area (ha)	Total Biomass (tonnes)
1	Mandangad	122.99 – 1610.99	460	13741	6320860
2	Dapoli	20.43 – 744.91	319	29861	9525659
3	Khed	39.53 – 2030.54	465	27702	12881430
4	Guhaghar	72.08 – 1216.46	435	21621	9405135
5	Chiplun	174.73 – 1474.25	507	33818	17145726
6	Ratnagiri	124.60 – 1186.90	342	34260	11716920
7	Sangameshwar	183.22 – 906.33	523	48034	25121782
8	Lanja	19.01 – 992.12	490	1787	875630
9	Rajapur	119.35 – 920.45	376	17955	6751080
	Total		**435.22**	**228779**	**99744222**

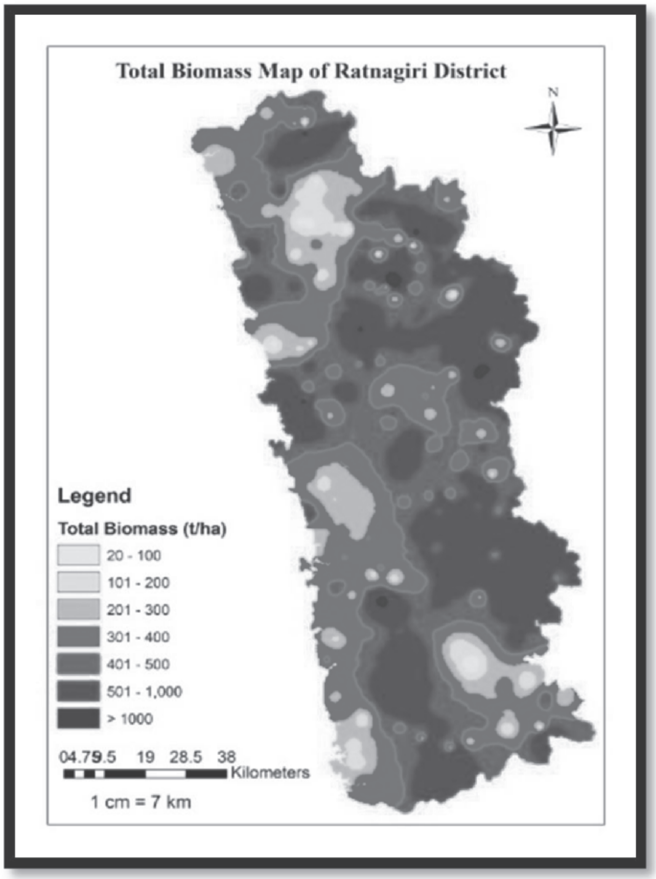

Fig 2: Total biomass map of Ratnagiri district

Carbon stock of forest

Carbon stock values in forest of Ratnagiri district are shown in Table 4. Carbon stock values in forest for Ratnagiri district were ranging from 9.5 to 1015.27 t C/ha. Total carbon stock in Ratnagiri district was found to be 50.59 million tonnes with an average carbon stock rate of 219.31 t C/ha.

Table 4: Tehsil wise values of carbon stock in forests of Ratnagiri district

Sr. No.	Tehsil	Carbon stock range (t/ha)	Average carbon stock (t C/ha)	Forest Area (ha)	Carbon stock (tonnes)
1	Mandangad	61.49 – 805.49	230.41	13741	3166064
2	Dapoli	10.21 – 372.46	159.60	29861	4765816
3	Khed	19.77 – 1015.27	232.63	27702	6444316
4	Guhaghar	36.04 – 608.23	217.83	21621	4709702
5	Chiplun	87.36 – 737.12	253.32	33818	8566776
6	Ratnagiri	62.30 – 593.45	170.94	34260	5856404
7	Sangameshwar	91.61 – 453.16	276.36	48034	13274676
8	Lanja	9.5 – 496.06	244.94	1787	437708
9	Rajapur	59.67 – 460.22	187.76	17955	3371231
	Total		**219.31**	**228779**	**50592693**

Carbon stock of agricultural crops

Carbon stock values of paddy crop from the study area are given in Table 5. The carbon stock values for Ratnagiri district were ranges from 0.45 to 8.00 tonnes of C/ha. The total carbon stock from paddy in Ratnagiri district was found 169458.02 tonnes with an average carbon stock of 2.36 t C/ha.

Table 5 : Tehsil wise carbon stock values from paddy crops in Ratnagiri district

Sr. No.	Tehsil	Biomass range (t/ha)	Avg. biomass rate (t/ha)	C stock range (t C/ha)	Avg. C stock rate (t C/ha)	Paddy area (ha)	Cstock (tonnes)
1	Mandangad	2.09 – 10.06	4.52	1.04 – 5.03	2.26	4121	9313.46
2	Dapoli	3.59 – 20.55	6.16	1.79 – 7.11	3.08	8041	24766.28
3	Khed	1.13 – 16.00	6.74	0.56 – 8.00	3.37	10321	34781.77
4	Guhaghar	0.90 - 11.10	5.62	0.45 – 5.55	2.81	4261	11973.41
5	Chiplun	1.41 – 11.34	4.68	0.70 – 5.67	2.34	10745	25143.3
6	Ratnagiri	1.80 – 6.10	3.59	0.90 – 3.05	1.79	7321	13144.52
7	Sangmeshwar	1.20 – 6.20	3.85	0.60 – 3.10	1.82	11061	20131.02
8	Lanja	1.50 – 6.40	3.38	0.75 – 3.20	1.69	7219	12226.82
9	Rajapur	1.40 – 11.10	4.15	0.70 – 5.55	2.08	8643	17977.44
	Total		**4.74**		**2.36**	**71733**	**169458.02**

Carbon stock of horticulture plantation

Horticultural crops like Arecanut, Mango, Coconut and Cashew are dominant crops in Ratnagiri district. Horticulture crop wise carbon stock values of Ratnagiri district were given in Table 6. The carbon stock rate for Arecanut in Ratnagiri district was ranging between 6.30 to 26.83 t C/ha with an average carbon stock rate of 17.93 t C/ha.

Table 6: Horticultural crop wise carbon stock in Ratnagiri district

Sr. No.	Crop	Biomass range (t/ha)	Avg. biomass (t/ha)	C. stock range (t C/ha)	Avg. C. stock rate (t C/ha)
1	Arecanut	12.61-53.67	35.86	6.30 – 26.83	17.93
2	Mango	75.63-1576.878	261.17	37.81 – 788.43	130.58
3	Coconut	56.28-237.23	164.05	28.14 – 118.61	82.02
4	Cashew	35.65-168.58	105.51	17.82 – 84.29	52.75

Carbon stock of vegetation

Carbon stock values of forest, horticulture and cropland were added to get the carbon stock values from the vegetation for Ratnagiri district. Tehsil-wise average carbon stock rate from different vegetal cover in Ratnagiri district were shown in Table 7. Vegetation carbon stock map of Ratnagiri district is shown in Fig. 3.

Table 7: Tehsil wise average carbon stock rate from vegetation in Ratnagiri district

Sr. No.	Tehsils	Forest (t C/ha)	Horticulture				Paddy (t C/ha)	Shrub (t C/ha)	Grasses (t C/ha)
			Arecanut (t C/ha)	Mango (t C/ha)	Coconut (t C/ha)	Cashew (t C/ha)			
1	Mandangad	230.41	18.20	114.75	75.82	61.92	timic0.2	0.29	0.13
2	Dapoli	159.60	17.20	131.43	86.00	52.59	3.08	0.43	0.15
3	Khed	232.63	17.95	100.05	65.29	52.06	3.37	0.16	0.11
4	Guhaghar	217.83	20.28	125.5	85.10	55.59	2.81	0.28	0.17
5	Chiplun	253.32	19.20	132.89	82.17	36.38	2.34	0.37	0.18
6	Ratnagiri	170.94	19.29	188.62	77.78	37.30	1.79	0.38	0.19
7	Sangameshwar	276.36	9.68	116.78	93.09	55.25	1.82	0.35	0.18
8	Lanja	244.94	23.17	137.27	92.90	61.54	1.69	0.4	0.18
9	Rajapur	187.76	16.38	127.96	80.05	62.13	2.08	0.44	0.17
	Average	**219.31**	**17.93**	**130.58**	**82.02**	**52.75**	**2.36**	**0.34**	**0.16**

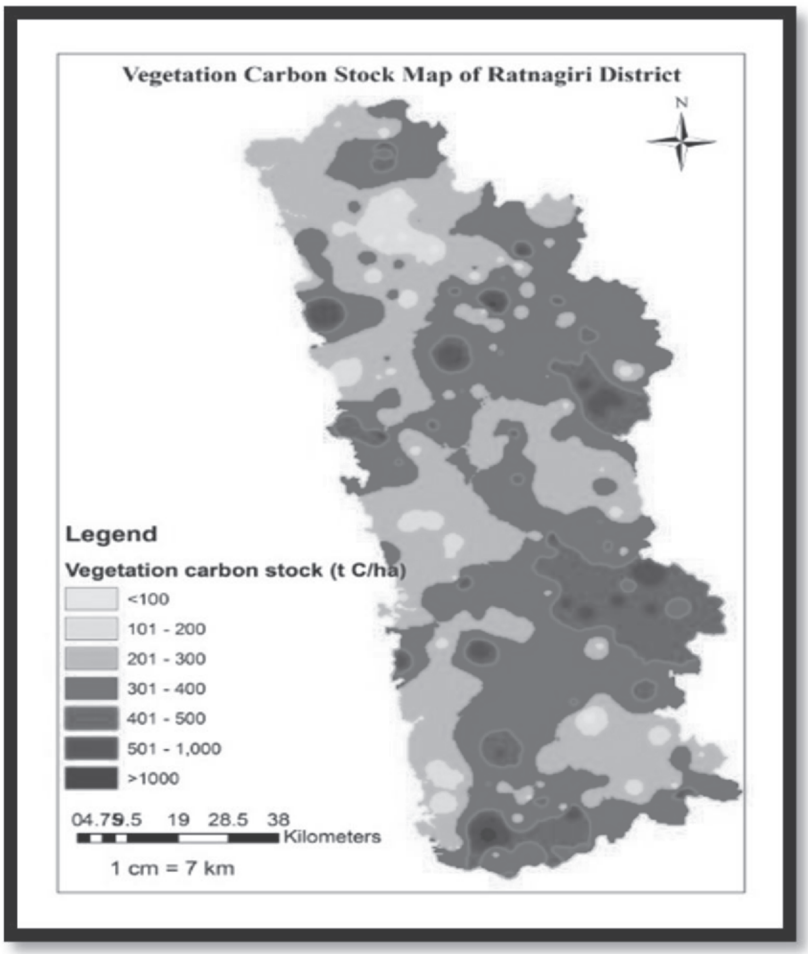

Fig. 3: Vegetation Carbon stock map of Ratnagiri district

CO2 sequestered by vegetation

Tehsil wise average carbon sequestration rate from vegetation in Ratnagiri district is given in Table 8 The vegetation is an important sink of carbon and plays vital role in the global carbon cycle by sequestering a substantial amount of CO_2 from the atmosphere (Vashum and Jaykumar, 2012).

Table 8 : Tehsil wise average C sequestration rate from vegetation in Ratnagiri district

Sr. No.	Tehsils	Forest (t C/ha)	Horticulture				Paddy (t C/ha)	Shrub (t C/ha)	Grasses (t C/ha)
			Arecanut (t C/ha)	Mango (t C/ha)	Coconut (t C/ha)	Cashew (t C/ha)			
1	Mandangad	844.94	66.74	420.86	278.03	227.06	8.29	1.07	0.49
2	Dapoli	585.25	63.07	481.96	315.36	192.86	11.29	1.58	0.56
3	Khed	853.08	65.82	366.88	239.42	190.92	12.36	0.58	0.42
4	Guhaghar	798.78	74.37	460.21	312.06	205.35	10.30	1.03	0.62
5	Chiplun	928.91	70.41	487.32	301.32	133.42	8.58	1.37	0.65
6	Ratnagiri	626.84	70.74	691.68	285.25	136.79	6.58	1.41	0.69
7	Sangameshwar	1013.41	35.52	428.26	341.36	202.63	6.67	1.29	0.67
8	Lanja	898.19	84.96	503.38	340.68	225.69	6.21	1.49	0.66
9	Rajapur	688.54	60.09	469.24	293.57	227.85	7.62	1.49	0.62
	Average	**804.22**	**65.75**	**478.87**	**300.78**	**193.62**	**8.66**	**1.26**	**0.60**

Carbon Stock in Soil

Organic carbon

Organic carbon (%) data was computed using wet oxidation method of Walkley and Black. Values of soil organic carbon in Ratnagiri district were ranging from 0.08 to 5.56 % with an average value of 2.13 % at 0-15 cm depth (Fig. 4). While soil organic carbon value at 15-30 cm depth were ranging from 0.12 to 4.45 % with an average value of 1.95 % fromRatnagiri district (Fig. 5). Tehsil wise average soil organic carbon values for Ratnagiri district are given in Table 9.

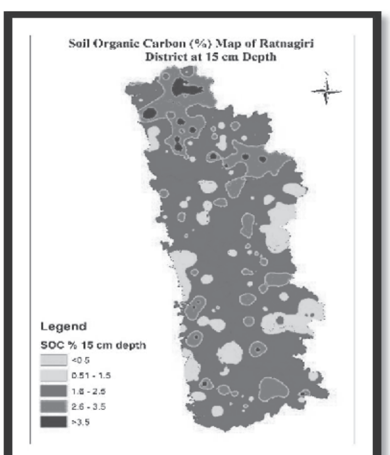

Fig. 4. Soil organic carbon (%) map at 0-15cm depth of Ratnagiri district

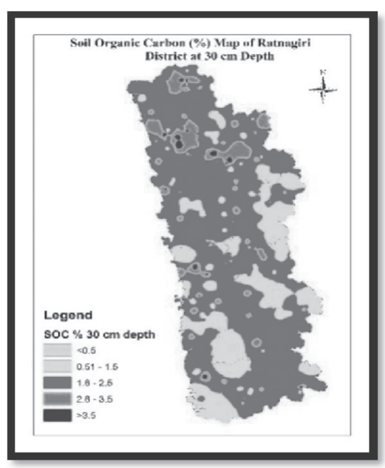

Fig. 5. Soil organic carbon (%) map at 15-30cm depth of Ratnagiri district

Table 9: Tehsil wise average soil organic carbon at two depths from Ratnagiri district

Sr. No.	Tehsils	0-15 cm depth		15-30 cm depth	
		Soil organic carbon range (%)	Average soil organic carbon (%)	Soil organic carbon range (%)	Average soil organic carbon (%)
1	Mandangad	0.82 - 4.41	**2.38**	0.51 - 4.45	**1.83**
2	Dapoli	0.59 - 4.78	**2.35**	0.78 - 4.37	**2.29**
3	Khed	0.59 - 5.56	**2.30**	0.59 - 4.31	**2.08**
4	Guhaghar	0.66 - 4.37	**2.38**	0.78 - 4.29	**2.48**
5	Chiplun	0.20 - 3.24	**1.93**	0.39 - 3.12	**1.72**
6	Ratnagiri	0.12 - 3.98	**1.82**	0.35 - 4.06	**1.80**
7	Sangameshwar	0.08 - 4.47	**2.07**	0.39 - 3.16	**1.83**
8	Lanja	0.51 - 4.29	**1.89**	0.70 - 3.90	**1.69**
9	Rajapur	0.16 - 5.03	**2.01**	0.12 - 4.10	**1.82**

Bulk density

The bulk density values from all tehsils of Ratnagiri district were ranging from 0.93 to 2.42 gm/cc at 0-15 cm depth with an average value of 1.23%. Similarly bulk density values at 15-30 cm depth were ranging from 1.01 to 2.89 gm/cc with an average value of 1.26 % in Ratnagiri district. Tehsil wise bulk density values for Ratnagiri district are given in Table 10.

Table 10: Tehsil wise average bulk density at two depths from Ratnagiri district

Sr. No.	Tehsils	0-15 cm depth		16-30 cm depth	
		Bulk density range (gm/cc)	Average bulk density (gm/cc)	Bulk density range (gm/cc)	Average bulk density (gm/cc)
1	Mandangad	1.01 - 1.38	**1.20**	1.01 - 1.44	**1.26**
2	Khed	0.93 - 1.42	**1.21**	1.02 - 1.42	**1.23**
3	Dapoli	0.99 - 1.42	**1.20**	1.02 - 1.39	**1.20**
4	Guhaghar	1.02 - 1.41	**1.20**	1.02 - 1.39	**1.19**
5	Chiplun	1.11 - 1.52	**1.24**	1.12 - 1.47	**1.27**
6	Ratnagiri	1.05 - 2.42	**1.35**	1.04 - 2.89	**1.37**
7	Sangmeshwar	1.08 - 1.57	**1.24**	1.11 - 1.42	**1.27**
8	Lanja	1.02 - 1.40	**1.23**	1.05 - 1.44	**1.26**
9	Rajapur	0.97 - 1.54	**1.24**	1.04 - 2.89	**1.28**

Soil carbon stock

Organic carbon (%), bulk density (g/cm3) values were computed for samples collected from each selected villages in Ratnagiri district and carbon stock values were estimated for soils at depths of 0-15 cm and 15-30 cm. Total soil organic carbon stock in Ratnagiri district was 13.44 M tonnes at 0-15 cm depth and 12.35 M tonnes at 15-30 cm depth. The average carbon stock rate was 16.15 t/ha and 14.71 t/ha at 0-15 cm and 15-30 cm depths, respectively in the Ratnagiri district. Tehsil-wise SOC density of Ratnagiri district is given in Table 11.

Table 11: Tehsil wise average SOC density at two depths from Ratnagiri district

Sr. No.	Tehsils	0-15 cm depth			15-30 cm depth		
		SOC density range (t C/ha)	Average SOC density (t C/ha)	Average C sequestrated (t C/ha)	SOC density range (tC/ha)	Average SOC density (t C/ha)	Average C sequestrated (t C/ha)
1	Mandangad	2.02 - 30.76	**19.41**	**71.16**	1.49 - 23.84	**13.55**	**49.69**
2	Khed	1.94 - 56.06	**20.46**	**75.02**	3.72 - 44.39	**18.43**	**67.57**
3	Dapoli	4.15 - 29.44	**15.31**	**56.13**	3.94 - 24.11	**14.38**	**52.74**
4	Guhaghar	6.46 - 34.94	**17.69**	**64.85**	6.51 - 33.63	**19.21**	**70.73**
5	Chiplun	1.82 - 29.80	**15.34**	**56.25**	3.02 - 30.70	**14.91**	**54.66**
6	Ratnagiri	1.10 - 40.23	**16.09**	**59.00**	2.22 - 41.24	**15.00**	**58.33**
7	Sangmeshwar	0.73 - 37.41	**15.79**	**57.90**	4.72 - 34.95	**14.27**	**52.32**
8	Lanja	1.43 - 20.00	**12.35**	**45.28**	1.95 - 18.14	**11.83**	**43.39**
9	Rajapur	1.33 - 35.09	**12.90**	**47.29**	0.26 - 31.93	**10.84**	**39.78**
	Average		**16.15**	**59.21**		**14.71**	**54.36**

CO_2 sequestered by soil

Amount of CO2 sequestered by soil from each tehsil of Ratnagiri district were ranging from 3.18 M tonnes to 7.70 M tonnes of CO2 upto 0-15 cm depth and 2.22 M tonnes to 6.93 M tonnes of CO2 for 15-30 cm depth. Total soil carbon sequestration value for whole Ratnagiri district was 49.29 M tonnes of CO2 upto 0-15 cm depth and 45.65 M tonnes of CO2 at 15-30 cm depth. Tehsil wise soil carbon sequestration rate and soil carbon sequestration values for Ratnagiri district are given in Table No 11.

Total carbon stock from vegetation and soil

Values of total carbon stock ranged from 4.06 to 18.27 M tonnes of carbon with an average carbon stock rate of 105.96 tonnes of carbon/ha for Ratnagiri district. Total carbon stock value of Ratnagiri district was 89.99 M tonnes of carbon out of that soil carbon stock were 25.79 M million tonnes of carbon and vegetation carbon stock was 64.20 M tonnes of carbon. Tehsil wise total carbon stock values from Ratnagiri district were given in Table 12.

Table 12: Tehsil wise carbon stock in Ratnagiri district

Sr. No.	Tehsils	Carbon stock from vegetation (tonnes)	Carbon stock from soil (tonnes)	Total carbon stock from vegetation and soil (tonnes)	Average carbon stock rate from vegetation and soil (t C/ha)
1	Mandangad	3888306.3	1472245	5360551.30	120.01
2	Khed	7472815.31	3989414	11462229.31	111.74
3	Dapoli	6260171.77	2702992	8963163.77	98.45
4	Guhaghar	5845048.69	2564196	8409244.69	121.01
5	Chiplun	9690299.35	3387858	13078157.35	116.77

6	Ratnagiri	9320074.6	3037493	12357567.6	126.48
7	Sangameshwar	14322551.21	3811608	18134159.21	143.01
8	Lanja	2052285.33	1823172	3875457.33	51.39
9	Rajapur	5347459.12	3003110	8350569.12	66.01
	Total	**64199011.68**	**25792088**	**89991099.68**	**106**

Total Amount of CO_2 Sequestered by Vegetation and Soil

Values of CO_2 sequestered by vegetation and soil from tehsils of Ratnagiri district were shown in Table 13. Amount of CO_2 sequestered by vegetation was 235.43 M tonnes of CO_2. Amount of CO_2 sequestered by soil was 94.92 M tonnes of CO_2. Total amount of CO_2 sequestered from Ratnagiri district was 330.35 M tonnes of CO_2.

Table 13 Tehsil wise carbon sequestrated from Ratnagiri district

Sr. No.	Tehsils	Carbon sequestrated by vegetation (tonnes)	Carbon sequestrated by soil (tonnes)	Total carbon sequestrated from vegetation and soil (tonnes)	Average carbon sequestration rate (t/ha)
1	Mandangad	14259037.59	5398084.292	19657121.88	440.08
2	Khed	27403664.11	14627167.38	42030831.49	409.73
3	Dapoli	22956126.43	9911575.968	32867702.40	361.02
4	Guhaghar	21445328.08	9421508.432	30866836.51	444.19
5	Chiplun	35534065.32	12421398.72	47955464.04	428.19
6	Ratnagiri	34176714	11463339.33	45640052.89	467.14
7	Sangameshwar	52520795	13976140.72	66496936	524.42
8	Lanja	7525730.3	6686279.73	14212010.06	188.48
9	Rajapur	19609133	11016163.95	30625296.57	242.09
	Total	**235430593.8**	**94921658.52**	**330352251.8**	**389.48**

CONCLUSIONS

Total carbon stocks in soils of Ratnagiri district are found as 13.44 million tonnes of carbon upto 15 cm depth and 12.35 million tonnes of carbon for 15-30 cm depth. Amount of CO_2 sequestered by soil is 49.29 million tonnes of CO_2 at 0-15 cm depth and 45.63 million tonnes of CO_2 at 15-30 cm depth. Total carbon stock of Ratnagiri district is found as 89.99 million tonnes of carbon. Vegetation carbon stock is 64.20 million tonnes of carbon and soil carbon stock is 25.79 million tonnes of carbon. Vegetation has 2 to 2.5 times more carbon stock than soil. Amount of CO_2 sequestered by vegetation is 235.43 million tonnes of CO_2 and by soil is 94.92 million tonnes of CO_2. Total amount of CO_2 sequestered by Ratnagiri district is 330.35 million tonnes of CO_2. Thus, results show that total amount of CO_2 sequestration is highest in forest (56 %) followed by soil (29 %), horticultural plantation (15 %) and agricultural crop of paddy (0.19%) in Ratnagiri district. So, the present study concluded that about 24.39 % (total geographical area) of barren land in Ratnagiri district could be brought under vegetation to sequester higher amounts of CO_2 from the atmosphere. Hence, the challenge of climate change can be effectively mitigated by proper carbon management through vegetation and soil for extended periods.

REFERENCES

Andrasko, K. 1990. Climate change and global forests: current knowledge of potential effects, Adaptation and mitigation options. FAO, Forestry, Department, Rome.

Arya, A., S. Negi, C. Kathota, N. Patel, H Kalubarme and J. K. Garg. 2017. Carbonsequestration analysis of dominant tree species using Geo-informatics technology in Gujarat State (INDIA). *International Journal of Environment and Geoinformatics,* Vol. 4(2): 79-93.

Batjes, N. H. 1996. Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science,* 47: 151-163.

Batjes, N.H. 1999. Management options for reducing CO_2 concentration in the atmosphere by

increasing carbon sequestration in the soil. Report 410-2-031, Dutch National Research Programme on Global Air pollution and Climate Change and Technical paper 3; International soil reference and information centre, Wageningen.

Brakas, S. G. and J. B. Aune. 2011. Biomass and carbon accumulation in Land Use Systems of Claveria, the Philippines. *Springer Science+ Business Media.*

Brown, S., J. Sathaye, M. Cannell and P.E. Kauppi. 1996. Management of forests formitigation

of greenhouse gas emissions. In: Watson, R.T., Zinyowera, M.C., Moss, R.H. (Eds.), climate change 1995: Impacts, adaptations and mitigation of climate change, scientific analyses. *Contribution of working group II to the second assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, 773–798.

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer.*FAO*

Forestry Paper-134, Food and Agricultural Organization, Rome.

Cairns, M.A., I. Olmsted, J. Granados and J. Argaez. 2003. Composition and aboveground tree

biomass of a dry semi-evergreen forest on Mexico's Yucatan Peninsula. *Forest Ecology and Management*, 186(1-3): 125-132.

Cairns, M.A., S. Brown, E.H. Helmer and G.A. Baumgardner. 1997. Root biomass allocation in the world's upland forests. *Oecologia*, 111:1-1.

Chauhan, S.K., R.Sharma, B.Singh and S.C.Sharma. 2015. Biomass production, carbonsequestration and economics of on-farm poplar plantations in Punjab, India. *Journal of Applied and Natural Sciences*, Vol. 7(1): 452-458.

Dixon, R.K., M.C. Trexler, J. Wisniewski, S. Brown, R. A. Houghton and A.M. Solomon. 1994. Carbon pools and flux of global forest ecosystems. *Science,* 263: 185-190.

FAO. 2009. Assessment of the status of the development of the standards for the terrestrial essential climate variables. Biomass global terrestrial observing system Rome, 1-18.

FAO.1997. Estimating biomass and biomass change of tropical forests: a primer, by S. Brown.

FAO Forestry Paper No. 134, Rome.

FSI. 2004. Carbon stock in India's forests. Published by Forest survey of India, Ministry of

Environments and forests.

Guleria, V., A.Vashisht, A. Gupta, T. Salven, C. Thakur and P. Kumar. 2014. Carbon stocks and soil properties under nitrogen-fixing tress on degraded site in subtropical Himalayan region. *Indian Journal of Soil Conservation*, Vol. 42 (3): 293-297.

IPCC. 2006. IPCC guidelines for national greenhouse gas inventories, ed. H. S. Eggleston, L.

Buendia, K. Miwa, T. Ngara and K. Tanabe. Institute forGlobal Environmental Strategies, Japan.

IPCC. 2007. Climate change: The physical science basis. Contribution of working group I to thefourth assessment repot of the intergovernmental panel on climate change. Richard Alley *et.al*., IPCC Secretorial WMO, Geneva, Switzerland.

Kanime, N., R. Kaushal, S.K.Tewari, K.P. Raverkar, S.Chaturvedi and O.P. Chaturvedi. 2013.

Biomass production and carbon sequestration in different trees-based systems of central HimalaanTarai region. *Forests,Trees and Livelihoods*, 22(1): 38-50.

Lal, R. 2001. Potential of desertification control to sequester carbon and mitigate the greenhouseeffect. *Climate Change*, 51: 35-72.

Lasco, R. D, Joveno S. Lales, Ma. Theresa Arnuevo, Ina Q. Guillermo, Agnes C. de Jesus,

Reinero Medrano, Orlando F. Bajar and Cirilo V. Mendoza. 2001. Carbon dioxide (CO_2) storage and sequestration of land cover in the Leyte Geothermal Reservation. *Renewable Energy*. 25: 307–315.

Losi, C.J., T.G. Siccama, R. Condit and J.E. Morales. 2003. Analysis of alternative methods for estimating carbon stock in young tropical plantations. *Forest Ecology and Management*, 184: 355-368.

Mahajan, T. S. 2001. Status and distribution of micronutrients in relation to the properties oflateritic soils under mango orchards in South Konkan. Published Ph. D. Thesis submitted to Department of Agricultural Chemistry and Soil Science. Dr. B.S.K.K.V. Dapoli, Ratnagiri.Mohanraj, R., Saravanan J. and Dhanakumar S. 2010. Carbon stock in Kolli forests, Eastern Ghats (India) with emphasis on aboveground biomass, litter, woody debris and soils. *Biogeoscience and forestry.* Vol. (4):61-65.

Post, W.M. and K.C. Kwon. 2000. Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology*, 6:317-327.

Ramachandran, A., S. Jayakumar, R.M. Haroon, A. Bhaskaran and D.I. Arockiasamy. 2007.

Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamilnadu, India. *Current Science*, Vol. 92 (3): 323-331.

Rahmana, M., Md. Enamul Kabir, A.S.M. Jahir Uddin Akonc and K. Andod. 2015. High carbon stocks in roadside plantations under participatory management in Bangladesh. *Global Ecology and Conservation.* 3: 412-423.

Ravindranath, N. H. and M. Ostwald. 2008. Carbon inventory methods handbook for greenhousegas inventory, carbon mitigation and round wood production projects. *Advances in Global Change Research*. Springer-Verlag, Berlin. 121-154.

Ravindranath, N. H., B. S. Somashekhar and M. Gadgil. 1997. Carbon flow in Indian forests

Climate change, 35:297-320.

Schrag, D. P. 2007. Preparing to Capture Carbon. *Science.* Vol. 315, 812.

Srinivasarao, J.V.N.S. Prasad, K. Naresh, Ch. Naga Jyothi, Sangeeta Lenka, N.K. Lenka, T.J.

Purakayastha, H. Pathak, A.N. Ganeshamurthy, Rajbir Singh, A. Arunachalam, A. Subba Rao, B. Gangwar, B. Venkateswarlu and A.K. Sikka. 2013. Assessment of carbon sequestration in agriculture and agroforestry systems. Published by Central Research Institute for Dryland Agriculture.

Venkatesh, A. and R. Newaj. 2012. Carbon sequestration through Agroforestry. *Carbon*

management in Agriculture for Mitigating Greenhouse Effect.

Vashum, K.T. and S. Jaykumar. 2012. Methods to estimate above ground biomass and carbon

stock in natural forests - A Review. *Journal of Ecosystem Ecography*, 2(4):2-7.

L-16

Impact of Climate Change on Occurrence of Regional Droughts

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INTRODUCTION

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events and can result in unprecedented extreme events. Floods and drought have always been primary concerns of society. Despite stimulating achievements of science and technology in the 20th century, extreme hydrological events, particularly drought and floods, continue to affect regional human settlements and natural environments and interrupt developments by breaking continuity. Severe droughts and floods can be considered sustainable development enemies (Kundzewicz and Kaczmarek 2000). They lead to cause damage to agricultural farming and induce the threats of adversity and famine. Global climate change is one of the critical factors affecting the hydrological cycle (IPCC 2007). The highly vulnerable population of the world live in low and middle-income countries, which are experiencing a decline in food security, a rise in migration, and poverty (IPCC, 2012). The temperature rise in the twentieth century has already resulted in significant alterations to social and natural systems, including increased droughts, floods, and other extreme weather events. These alterations are causing unprecedented risks to vulnerable society (IPCC, 2012& 2014; Mysiak et al., 2016). The rise in temperature increases the moisture holding capacity ofthe atmosphere, precipitation, and atmospheric circulation pattern, e.g., changes in the rate of evaporation may intensify the hydrological cycle. Higher temperatures turn some part of snowfall into rainfall or the snowmelt season may occur earlier, consequently, the frequency of occurrence and magnitude of hydrologic extremes like floods and drought may increase significantly (IPCC 2001).

The global economy is adversely influenced very frequently due to droughts, especially in arid, semi-arid, and dry sub-humid regions. Climate change affects a variety of factors associated with drought. There is high confidence that increased temperatures will lead to more variation in precipitation falling as rain rather than snow, earlier snowmelt, and increased evaporation and transpiration. Thus the risk of hydrological and agricultural drought increases as temperatures rise. Various researchers in different parts of the world have reported a rise in land surface temperature in the twentieth century. A greater magnitude of increase in mean surface air temperature and land surface temperature have been identified in the last three decades (WMO 2005). Alley et al. (2007) reported that 11 of the 12 warmest years observed since 1850 occurred between 1995 and 2006.Easterling et al. (1997) analyzed the global mean surface air temperature and found that the diurnal temperature range is narrowing because of differential changes between daily maximum and minimum temperatures.

The intensification of drought incidence is one of the critical threats of the 21st century, which may affect food security notably. Accordingly, there is a need to improve the understanding of the regional impacts of climate change on droughts. Further, the greater dependence of people on natural resources and the impact of climate change on drought incidence, severity, and persistence play a crucial role in amplifying the challenge of managing water stress in various regions. Accordingly, possible global intensifications of drought conditions (Dai 2012) are of great concern for any agricultural area. This is particularly true for tropical developing countries because of their high dependence on rainfed systems (Rockström et al. 2010; Rost et al. 2009).Inconsistency of components characterizing the processes of the hydrologic cycle is responsible for the occurrence of hydrologic extremes (Ponce et al. 2000). Here, the hydrologic extremes refer to the circumstances when there is either too much water that may cause damages (floods), or too little of water that may cause droughts or water scarcity in sustaining normal regional activities and the ecosystem. Regions with higher rainfall variability and runoff are more vulnerable to droughts (Kundzewicz and Kaczmarek 2000).

Some definitions of climatic extremes choose to separate the nature of the event from its social and economic consequences. A climate extreme is a significant departure from the normal state of the climate, irrespective of its actual impact on life or any other aspect of the Earth's ecology.In the current prevailing literature, it is often stated that drought is a complex phenomenon and it is difficult to provide a precise and universally accepted definition of drought due toits varying characteristics and impacts across the different regions of the world (Wilhite, 2000; MoA, 2009). Further, the words 'drought', 'aridity', and 'water scarcity aremore often used synonymously. However, in a real sense, the abovewords are entirely different. Pandey et al. (2016) suggested a more precise definition of 'drought', aridity, and 'water scarcity, as givenbelow.Drought is defined as a relative deficit in a given area compared to its average or usual water availability, either in the form of rainfall, river flow, surface/ groundwater storage, or due to a combination of these for a certain period.*Thus, drought is a relative deficit and temporary phenomenon.*Aridity refers to a persistently short supply of water even in normal circumstances. It is a climatic attribute of the region. It applies to persistently dry regions, like, arid areas and deserts, where, water is always in short supply. *Thus, it is a permanent climatic feature of the region.* Water scarcity refers to long-term unsustainable use of water resources; which water managers can influence. *Or in other words,* it is associated with over exploitation of water resources when water demand is more than its availability. *Thus, water scarcity is a human-induced phenomenon.*

The primary purpose of this paper is to present the current level of comprehension on the relevance of climate change with droughts in different regions. It is hoped that thispaper may enhance furtherunderstanding and ability to cope with the adverse impacts of droughts on society in changing climate.

RELEVANCE OFCLIMATE CHANGE AND VARIABILITY ON DROUGHTS

Climate variability and climate change are strongly associated with the water and energy cycle and associated extremes, such as floods and droughts. The recurrent droughts seriously threaten the livelihood of billions of people who depend on land for most of their needs. Climate change and variability are primary concerns for agriculture. An increase in aerosols (atmospheric pollutants) due to the emission of greenhouse gases, such as Carbon Dioxide due to the burning of fossil fuels, chlorofluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), etc., Ozone depletion and UV-B filtered radiation, the eruption of volcanoes, the "human hand" in deforestation in the form of forest fires and loss of wetlands are causal factors for weather extremes. The loss of forest cover, which usually intercepts rainfall and allows it to be absorbed by the soil, causes precipitation to reach across the land, eroding topsoil, and causes floods and droughts. Paradoxically, the lack of trees also exacerbates dry-year drought by making the soil dry more quickly. Among the greenhouse gases, CO2 is the predominant gas leading to global warming as it traps longwave radiation and emits it back to the earth'ssurface. Global warming is nothing but the heating of the surface-atmosphere due to the emission of greenhouse gases, thereby increasing global atmospheric temperature over a long period. Such changes in surface air temperature and consequent adverse impact on rainfall over a long period are known as climate change. It is known as climate variability if these parameters show year-to-year variations or cyclic trends. In particular, the Intergovernmental Panel on Climate Change (IPCC) defines climate change as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. The ecosystems, agriculture, livelihoods, and settlements of aregion depend on its climate.For precise understanding, the difference between climatic variability and climate change can be described as follows.The year-to-year fluctuation of climate above or below long-term average value (the climate normal i.e. average of 30-or more year of records of climatic variable.Climate varies over seasons & years instead of day-to-day like weather.Climate Change is long-term continuous change (increase or decrease) to average weather conditions (e.g. average temperature OR the range of weather elements (e.g. more frequent and severe extreme events).Climate Change is slow and gradual, unlike year-to-year variability.

Researchers have establishedthat the greenhouse gases inatmosphere act as a blanket, which traps incoming solar radiations and keeps the earth's surface warmer than it otherwise would be. It is widely agreed that an increase in atmospheric greenhouse gaseswould magnify additional warming of the earth surface. It is expected that an increase in air temperature would cause an increase in potential evapotranspiration. However, the magnitude of the increase further depends on changes in sunlight, humidity, wind speed, rainfall, and vegetation characteristics. Actual evapotranspiration may increase or decrease depending on the availability of soil moisture. How individual catchment areas will respond to changing evapotranspiration rates and precipitation is not certain. It is likely, however, that drier hydrological regimes will be more sensitive to climate changes. Small changes in temperature and precipitation could cause relatively significant changes in river flows. Arid and semi-arid regions will, therefore, be particularly sensitive to reduced rainfall and increased evaporation and plant transpiration

From various studies, it has emerged that the all-India monsoon rainfall does not show any convincing trends as a whole; however, in some regions, increasing and decreasing trends are noticed (Shiuleeet al., 2013; Pandey et al., 2013). West coast, north Andhra Pradesh, and north-west India show increasing trend in seasonal rainfall while decreasing trend is observed over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala (-6 to -8% of normal over 100 years).Some of the significant changes in rainfall pattern observed in India are (i) the frequency of extreme rainfall events has increased significantly, and (ii) Mean annual surface air temperatures show significant warming of about 0.5^{o} C/100 year during the last century; (iii)Regions with more significant inter-annual variability of precipitation are more susceptible to frequent and severe drought (Pandey et al. 2016).

Regional climatic conditions drive droughts. Therefore, the happening and characteristics of droughts are related to regional climatic parameters (Ponce et al. 2000; Pandey and Ramasastri 2001, 2002). The most common climatic elements that govern regional drought characteristics are precipitation and temperature, and evapotranspiration.The existence and distribution of moisture in the atmosphere play a key role in the description of the climate of a region. The water vapour content in the atmosphere is maintained largely by evaporation from the ocean, anda smaller amount from inland water bodies, moist ground, and transpiration from plants and vegetation. There are large variations in the vapour pressure with time and location. Several climatic factors combine in a complex manner to influence precipitation over the earth. An estimate of annual precipitation averaged over the entire earth surface amounts to about 1000 mm (Trewartha and Horn 1980). However, precipitation is very unevenly distributed over the earth's surface. Among the terrestrial regions, some deserts receive very little rainfall (< 100 mm) while a few places receive even more than 10000 mm of annual rainfall (Critchfield 1983). Two factors chiefly account for meagerprecipitation of mid-latitude dry regions: (i) they may be situated in deep interiors of the large continent or separated from the ocean by mountain barrier so that precipitable water is meagre (Thornthwaite and Hare 1953), and (ii) geographical differences in the intensity and seasonality of precipitation are the other significant features contributing to its inequitable distribution over the terrestrial regions (Threwartha and Harn 1980). An increase in average global temperature may cause a rise in the moisture content of the atmosphere due to increased rates of evaporation. With 1°C sea surface temperature rise, atmospheric moisture-holding may increase by 6–8%. Increases in atmospheric moisture may lead to increased precipitation rates in some parts of the world (causing floods), whilst decreases may be experienced in other parts (leading to droughts) due to changes in energy and moisture transport patterns in the atmosphere and consequently, may lead a one in the 10-year extreme event (flood/drought) to become one in 3-year flood and one in 5-year drought events(Kaczmarek *et al.,* 1997). Thus, climate change and variability may have significant impacts on regional drought attributes.

REPORTED EVIDENCE OF CLIMATE CHANGE ANDASSOCIATED IMPACTS ON DROUGHTS IN INDIA.

The South Asian regions have been among the perennially drought-prone regions of the world. India, Afghanistan, Pakistan and Sri Lanka have reported droughts at least once in three years in the past five decades, while Bangladesh and Nepal also suffer from drought frequently. The primary matter of concern is its increasing frequency. Since the mid-1990s, prolonged and widespread droughts have occurred in consecutive years in India, Afghanistan and Pakistan while the frequency of droughts has also increased in Sri Lanka, Nepal and Bangladesh (FAO, 2002). In recent years, droughts have been occurring frequently, and their impacts are being aggravated by the rise in water demand and the variability in hydro-meteorological variables due to climate change (Mishra and Singh, 2010; Mishra and Singh, 2011). Further, the IPPC report and other climate model predictions indicate that global change is likely to increase the vulnerability of tropical countries to drought, and more so in South Asia (IPCC 1996, 2001).Climatic change processes result in two main predictions with implications for the duration and magnitude of droughts (IPCC 2007): i) precipitation will decrease in some regions, and ii) an increase in global temperature, which will be more intense in the northern hemisphere, will cause an increase in the evapotranspiration rate. For the global average, warming in the last (20th) century has occurred in two phases, from the 1910s to the 1940s (0.35^{O}C), and more strongly from the 1970s to the present (0.55^{O}C). An increasing rate of warming has occurred over the last 25 years, and 11 of the 12 warmest years on record occurred between 1995-2006(Alley *et al.,* 2007).

A review of some of the studies has indicated that there is no significant rainfall trend over India as a whole (Mooley and Parthasarthy, 1984; Thapliyal and Kulshrestha, 1991; Lal, 2001; Kumar et al., 2010). However, several studies have indicated that there have been significant trends over regional-scale rainfall patterns (Koteswaram and Alvi, 1969; Raghavendra, 1974; Chaudhary and Abhyankar, 1979; Kumar et al., 2005; Dash et al., 2007; Kumar and Jain, 2010). Rainfall distribution, changing patterns, and trend analysis during the past century on different spatial and temporal scales have been of great concern because of the scientific community's attention to global climate change. Various studies indicating the increasing or decreasing trend of rainfall over various parts of India have been reported. Significant negative rainfall trends were observed in the Eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, Uttar Pradesh, parts of northwest and north-eastern India and also some parts of Tamil Nadu. A significant increase in rainfall has also been noticed in Jammu and Kashmir and in some parts of the southern peninsular (Lal, 2001).

Climate projections for South Asia indicated that India is likely to experience a substantial reduction in non-monsoon season water availability in arid, semi-arid and dry sub-humid regions which, may cause losses in crop production and may limit other livelihood options (IPCC 2007).In India, largely populated regions such as coastal areas are exposed to climatic events such as cyclones, floods, drought, and significant declines in sown areas in arid and semi-arid zones that occur during climate extremes. The impact of climate change is expected to be significant in larger areas of India, covering Rajasthan, Andhra Pradesh, Gujarat, Maharashtra, Karnataka, Orissa, Madhya Pradesh, Tamil Nadu, Bihar, parts of West Bengal, and Uttar Pradesh, are expected to face more frequent and severe droughts due to climate changes.

In a report of the World Bank Group (World Bank 2013), it is indicated that the crop yields in India are expected to fall significantly because of extreme heat by the 2040s. Further, the evidence indicates that parts of South Asia have become drier since the 1970s with an increase in droughts leading to major consequences in the region. In 1987 and 2002-2003, droughts affected more than half of India's crop area and led to a huge fall in crop production. Droughts are expected to be more frequent in some areas, especially in north-western India, Maharashtra, Karnataka, Madhya Pradesh, Chhattisgarh, Jharkhand, Orissa, parts of Uttar Pradesh, Bihar and West Bengal.

OCCURRENCE OF REGIONAL DROUGHTS AND OBSERVED CHANGES IN RAIN FALL VARIABILITY–A CASE STUDY

A case study has been conducted for Ken Basin in the Bundelkhand region, in central India, to investigate the occurrence of droughts and rainfall trends over the Ken basin. A comprehensive analysis of annual, seasonal and monthly rainfall time series for 102 years (from 1901 to 2002) has been conducted using suitable methodologies. Both Mann-Kendall (MK) trend test and Sen's Slope Estimator tests have been carried out for annual and seasonal rainfall data series. Recently, various indices have been developed to identify and monitor droughts. Among the indices, the percentage departure and Standardized Precipitation Index (SPI) (Mckee et al 1993) are more commonly used in India (Alley 1985; Jain et al. 2015, MoA 2016). India Meteorological Department (IMD) defines an area/region to be drought-affected if it receives less than 75% of its normal seasonal total rainfall (Appa Rao, 1986). A simple approach to delineating excellent or bad monsoon years has been suggested by Banerjee and Raman (1976). A year is considered a bad monsoon year for an area if seasonal rainfall is deficient in more than two-thirds of the meteorological stations in that year. For the present study, a year and a monsoon season (June-Sep) are considered as drought year and drought season, respectively, if the total amount of rainfall over an area is deficient by more than 25% of respective mean values.

The Ken River basin lies between north latitudes 230 07' and 250 54' and east longitudes of 780 30' and 800 40'. The Ken River system is one of the major tributaries of River Yamuna, joining from its south river-bank. The river Ken originates near the village Ahirgawan in Katni district of M.P. at an altitude of 550.0 m above mean sea level (msl) and joins river Yamuna at an elevation of about 87.0 m above msl. It drains a total basin area of 28,692 km2 before joining the Yamuna River near Chilla village in Uttar Pradesh (U.P.). About 24,490 km2 and 4,202 km2 of the catchment area of Ken fall in M.P. and U.P., respectively. Fig. 1 shows the location map of the Ken Basin in India. The major part of the basin lies in Sagar, Damoh, Panna and Chattarpur districts of M.P. and the Banda and Hamirpur districts in U.P. The basin falls in the semi-arid to dry sub-humid climatic region of India with a single rainy season (June-September) followed by dry winter, and then a very dry summer. The average annual rainfall in the basin varies from 1250 mm near its origin to 800 mm near its junction with Yamuna River. The average annual rainfall of the basin is estimated in the order of about 1165 mm. The basin is fed by the southwest monsoon which starts from the middle of June and lasts till the end of September. Approximately 91% of the annual rainfall occurs during June to September (Table 1). The basin lies partly in Vindhyan scrap land. The basin's upper reaches are covered with thick forests whereas the middle and lower reaches are cultivable areas. Despite good annual rainfall, its erratic and non-uniform nature creates an acute water shortage during crop growing periods.

Figure 1: Location and Index Map of the Ken River Basin

Table 1: Long term average monthly, Annual and Seasonal rainfall (mm) at various raingauge stations

	Raingauge Stations												
	Banda	Chattarpur	Damoh	Fatehapur	Hamirpur	Jabalpur	Katni	Mahoba	Narsimha pur	Panna	Sagar	Satna	Ken Basin as a whole
Longitude	80.31	79.59	79.45	80.82	80.15	79.95	80.4	79.87	79.19	80.18	78.75	80.83	
Latitude	25.48	24.92	23.84	25.93	25.95	23.17	23.84	25.29	22.94	24.72	23.83	24.58	
Jan	22	22	18	20	19	19	22	21	14	23	15	26	**20**
Feb	11	13	17	11	10	23	23	11	15	18	12	20	**16**
Mar	11	10	12	10	7	19	17	8	15	13	7	16	**12**
Apr	4	4	6	4	4	7	7	4	7	6	3	5	**5**
May	5	5	7	5	5	12	12	5	10	6	7	8	**7**
Jun	89	106	135	87	81	162	151	90	138	117	119	113	**120**
Jul	321	352	356	295	306	354	350	335	352	351	375	336	**350**
Aug	390	396	399	348	347	381	399	369	353	411	394	400	**393**
Sep	173	182	192	164	171	193	193	177	213	191	203	184	**190**
Oct	26	26	32	30	24	40	34	23	35	27	26	26	**29**
Nov	12	16	16	9	12	17	13	16	22	14	19	13	**16**
Dec	9	9	10	8	8	12	13	9	9	11	10	10	**10**
Annual	1073	1142	1200	1000	992	1239	1234	1066	1183	1188	1191	1159	**1165**
Seasonal	973	1036	1081	893	905	1090	1093	970	1056	1070	1091	1034	**1052**

Observed Changes and Trends in Rainfall

The test statistics of rainfall trend analysis are presented in Table 2, the negative values ofMann Kendall's statistics and Sen's slope represent the decreasing trend and positive values represent the increasing trend. Sen's slope magnitude represents the identified trend's significance level. From Table 2 one can easily infer that the values of no significant trend exist if the entire period of record is considered since several climatic change studies have indicated that the rate of increase in global warming is at pace during the last fifty years (IPCC, 2007), i.e., during the period of the second half of the past century. Therefore, it is important to know the trend of the data series in the latter half of the century. For this purpose, the data series was divided into two parts, and trend analysis was carried out separately for both the time series of the first half (1901 to 1950) and the second half (1951 to 2002) of the past century. The trend statistics of both halves are also given in Table 2.

The values of Man Kendall's statistics and Sen's slope for the separate periods of 1901 to 1950 and 1951 to 2002 indicate opposite trends during both periods. It is evident from Table 2 that during the first half of the past century basin was under the strong influence of an increasing trend, while the basin faced significantly decreasing trend of annual rainfall from 1951 to 2002. The trend plots of annual rainfall for all the districts and both periods, i.e., 1901-1950 and 1951-2002, are shown in Figure 2. It can beseen from Fig. 2 that there has been decreasing trend from 1951 to 2002 in contrast to the increasing trend during 1901 to 1950. This indicates that during the past fifty years the basin has experienced decreasing rainfall trend. The seasonal rainfall trend also follows a similar pattern of decreasing rainfall from 1951 to 2002. The test statistics for seasonal rainfall for the entire period of record and separately for both periods are presented in Table 3.

To account for the seasonal variability of the changing climate, i.e., to identify any significant change in rainfall for the individual months, the MK trend statistics were also computed for each month (i.e., 102 values for each month) rainfall data of all the eight districts as well as for the Ken basin as a whole. Tables of monthly statistics are shown here. The monthly trend statistics revealed that the decrease in annual or seasonal rainfall from 1951 to 2002 is largely because of the rainfall reduction in July and August. However, few winter months also indicated a slightly increasing trend, but this rainfall rise is not significant compared to the decreasing trend during the monsoon months.

In addition to the annual and month-wise rainfall trend, the decadal rainfall trend analysis was also carried out based on the annual rainfall data of all districts of the Ken river basin. For this purpose, the entire available series of rainfall data from 1901 to 2002 (102 years) was divided into 10 subsets. Out of the 10 subsets, 9 subsets were of 10-years data length and the last subset constitutes the remaining 12 years of data. The decadal average rainfall values were estimated for each subset of data. The average rainfall for each decade is also plotted in Fig. 2, which reveals that the rain decreases during each decade from 1951 to 2002 for almost all stations except in the decade of 1971 to1980. It reveals a strong indication of increased 2rainfall variability in the Ken river basin. It shows that more frequent and severe drought events occurred from 1951 to 2002.

Scrutiny of decadal trend analysis reveals that the decadal average rainfall during the first two decades (i.e. 1901-1910 and 1911-1920) and the last two decades (i.e. 1981-1990 and 1991-2002) had been less than the annual average of the entire record. A summary of the decadal trend analysis is shown in Table 4.

Table 2 : Annual Rainfall Mann-Kendall Trend Test Statistics

District	Annual Rainfall Data period	Kendall's Tau	Mann-Kendall Statistic (S)	Var(s)	p-value (two tailed)	Test Interpretation	Sen's Slope	Trend*
Banda	1901-2002	-0.029	-147	119617.667	0.673	Accept H_0	-0.445	DT
	1901-1950	0.233	285	14291.667	0.018	Reject H_0	4.627	IT
	1951-2002	-0.226	-300	16059.333	0.018	Reject H_0	-6.116	DT
Chattarpur	1901-2002	-0.013	-69	119617.667	0.844	Accept H_0	-0.215	DT
	1901-1950	0.329	403	14291.667	0.001	Reject H_0	6.715	IT
	1951-2002	-0.229	-304	16059.333	0.017	Reject H_0	-6.406	DT
Damoh	1901-2002	-0.029	-151	119617.667	0.665	Accept H_0	-0.352	DT
	1901-1950	0.345	423	14291.667	0.000	Reject H_0	6.994	IT
	1951-2002	-0.231	-306	16059.333	0.016	Reject H_0	-6.139	DT
Hamirpur	1901-2002	0.006	33	119617.667	0.926	Accept H_0	0.074	IT
	1901-1950	0.252	309	14291.667	0.010	Reject H_0	4.905	IT
	1951-2002	-0.216	-286	16059.333	0.025	Reject H_0	-5.590	DT
Katni	1901-2002	-0.051	-265	119617.667	0.445	Accept H_0	-0.571	DT
	1901-1950	0.275	337	14291.667	0.005	Reject H_0	4.880	IT
	1951-2002	-0.190	-252	16059.333	0.048	Reject H_0	-4.439	DT
Panna	1901-2002	-0.037	-191	119617.667	0.583	Accept H_0	-0.487	DT
	1901-1950	0.309	379	14291.667	0.002	Reject H_0	6.163	IT
	1951-2002	-0.228	-302	16059.333	0.018	Reject H_0	-6.189	DT
Raisen	1901-2002	-0.038	-197	119617.667	0.571	Accept H_0	-0.643	DT
	1901-1950	0.339	415	14291.667	0.001	Reject H_0	8.998	IT
	1951-2002	-0.211	-280	16059.333	0.028	Reject H_0	-6.594	DT

Sagar	1901-2002	-0.011	-59	119617.667	0.867	Accept H_0	-0.218	DT
	1901-1950	0.352	431	14291.667	0.000	Reject H_0	8.109	IT
	1951-2002	-0.210	-278	16059.333	0.029	Reject H_0	-6.357	DT
Ken	1901-2002	-0.025	-127	119617.667	0.716	Accept H_0	-0.333	DT
	1901-1950	0.340	417	14291.667	0.001	Reject H_0	6.348	IT
	1951-2002	-0.229	-304	16059.333	0.017	Reject H_0	-6.101	DT

***IT= Increasing Trend; DT=Decreasing Trend; NT= No Trend**

Table 3: SEASONAL RAINFALL MANN-KENDALL TREND TEST STATISTICS

District	Annual Rainfall Data period	Kendall's Tau	Mann-Kendall Statistic (S)	Var(s)	p-value (two tailed)	Test Interpretation	Sen's Slope	Trend*
Banda	1901-2002	-0.033	-169	119617.667	0.627	0.05	-0.404	DT
	1901-1950	0.260	319	14291.667	0.008	0.05	4.551	IT
	1951-2002	-0.226	-300	16059.333	0.018	0.05	-6.214	DT
Chattarpur	1901-2002	-0.016	-81	119617.667	0.817	0.05	-0.193	DT
	1901-1950	0.355	435	14291.667	0	0.05	6.112	IT
	1951-2002	-0.240	-318	16059.333	0.012	0.05	-6.149	DT
Damoh	1901-2002	-0.035	-179	119617.667	0.607	0.05	-0.398	DT
	1901-1950	0.360	441	14291.667	0	0.05	6.415	IT
	1951-2002	-0.226	-300	16059.333	0.018	0.05	-6.348	DT
Hamirpur	1901-2002	0.008	43	119617.667	0.903	0.05	0.094	IT
	1901-1950	0.272	333	14291.667	0.005	0.05	4.884	IT
	1951-2002	-0.222	-294	16059.333	0.021	0.05	-5.316	DT
Katni	1901-2002	-0.062	-319	119617.667	0.358	0.05	-0.606	DT
	1901-1950	0.252	309	14291.667	0.010	0.05	4.232	IT
	1951-2002	-0.214	-284	16059.333	0.026	0.05	-4.714	DT
Panna	1901-2002	-0.037	-193	119617.667	0.579	0.05	-0.47	DT
	1901-1950	0.332	407	14291.667	0.001	0.05	6.08	IT
	1951-2002	-0.241	-320	16059.333	0.012	0.05	-6.74	DT
Raisen	1901-2002	-0.054	-279	119617.667	0.422	0.05	-0.881	DT
	1901-1950	0.337	413	14291.667	0.001	0.05	8.409	IT
	1951-2002	-0.252	-334	16059.333	0.009	0.05	-6.589	DT
Sagar	1901-2002	-0.031	-161	119617.667	0.644	0.05	-0.421	DT
	1901-1950	0.336	411	14291.667	0.001	0.05	7.601	IT
	1951-2002	-0.237	-314	16059.333	0.014	0.05	-6.816	DT
Ken	1901-2002	-0.025	-127	119617.667	0.716	0.05	-0.311	DT
	1901-1950	0.352	431	14291.667	0	0.05	6.011	IT
	1951-2002	-0.255	-338	16059.333	0.008	0.05	-6.261	DT

***IT= Increasing Trend; DT=Decreasing Trend**

Table 4: Decadal Trend Analysis Report for various gauging sites and Ken River Basin as a whole

	Banda	Chattar-pur	Damoh	Fateha-pur	Hamirpur	Jabalpur	Katni	Mahoba	Narsim hapur	Panna	Sagar	Satna	Ken-Basin
Jan	rise	rise	rise	rise	rise	no	rise	rise	rise	rise	rise	rise	rise
Feb	fall	no	no	fall	fall	fall	fall	fall	no	fall	rise	fall	no
Mar	fall	fall	fall	fall	fall	fall	fall	fall	no	fall	fall	fall	fall
Apr	rise	rise	fall	rise	rise	fall	fall	rise	fall	no	fall	fall	no
May	rise	rise	rise	rise	rise	fall	no	rise	no	rise	rise	rise	rise
Jun	rise	rise	rise	rise	rise	no	rise	rise	rise	rise	rise	rise	rise
Jul	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall
Aug	fall	no	no	fall	no	rise	no	no	rise	no	rise	no	no
Sep	no	fall	fall	rise	rise	fall	fall	no	fall	no	fall	no	no
Oct	rise	rise	rise	rise	rise	no	no	rise	no	rise	rise	rise	rise
Nov	fall	fall	fall	no	no	fall	fall	no	fall	fall	fall	fall	fall
Dec	rise	rise	rise	rise	rise	rise	rise	rise	rise	rise	rise	rise	rise
Annual	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall
Seasonal	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall	fall

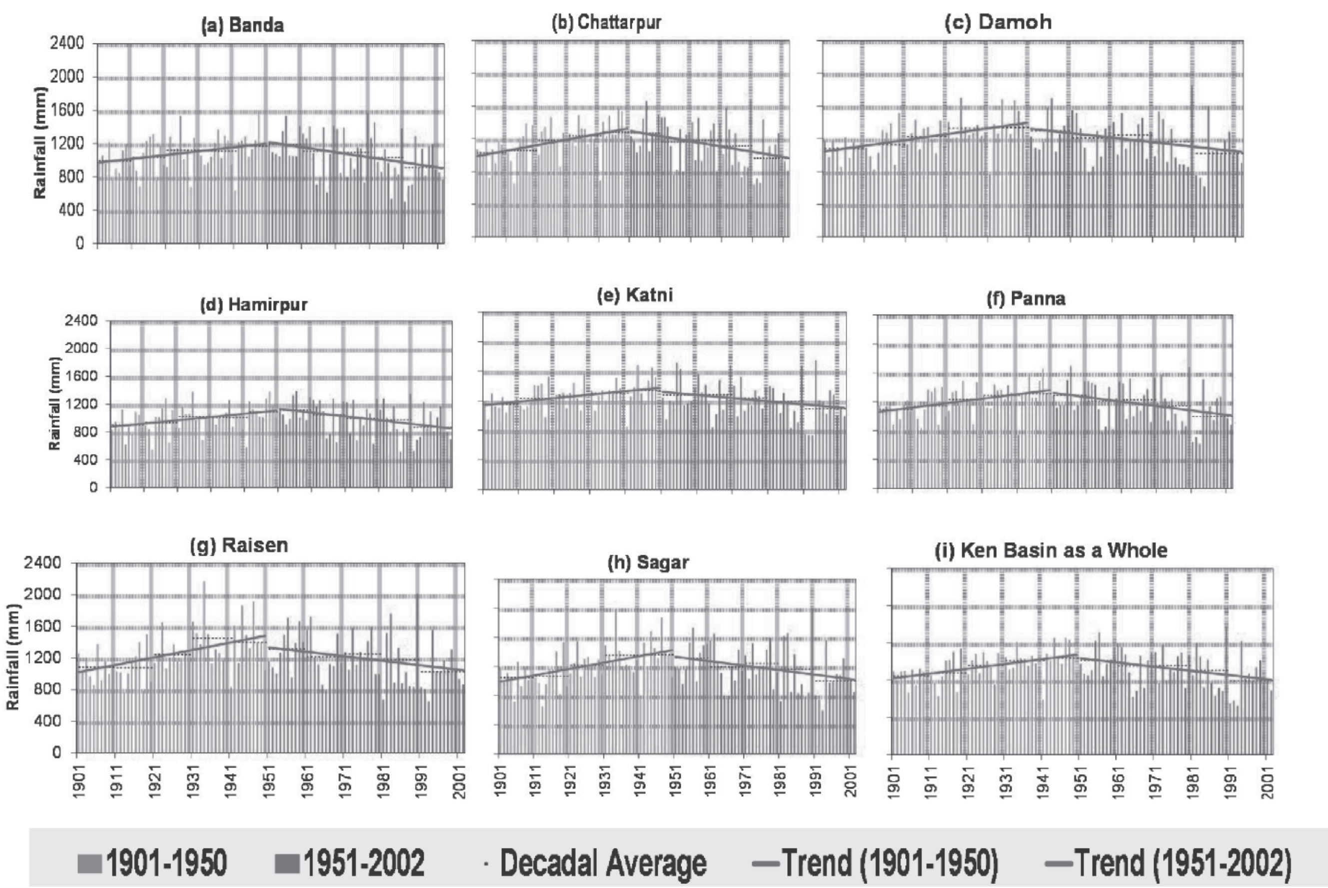


Figure 2: Annual Rainfall and linear trend for the period 1901 to 1950 (blue) and 1951 to 2002 (red) alongwith decadal average rainfall

Analysis of Observed Drought Frequency, Duration and Severity

Monthly rainfall data of 12 raingauge stations for 102 years from 1901-2002 have been utilized toanalyse the observed drought frequency, duration and severity in the basin. Thiessen polygon method was used to assess the area of influence of a particular raingauge station and for computation of area-weighted rainfall for basin as a whole (Figure 3).

Fig.3: Thiessen Polygon for Raingauge stations in the Ken River Basin

This analysis indicates that during the first half of the 20th study period (1901 to 1950), there have been 10 to 13 years of the return period of drought events in different districts; however, in the later half period from 1951 to 2002, there have been more frequent droughts with return period varying from 4 to 7 years (Table 5). Further, the Ken basin experiences a drought year once in every ten years in the years 1905,1913, 1918, 1928, and 1941 during the first half of the 20th century.In the later half of the century (1951-2002), the frequency of drought increased to once every five years, with the years 1965, 1966, 1968, 1979, 1987, 1989, 1991, 1992, 1993, 2002 observed as drought years in the basin. This increase in the frequency of occurrence of drought can be attributed to the effect of climate change.

Since Monsoon season rainfall plays a vital role in *kharif* crop production in the basin, analysis was also carried out for monsoon season rainfall, the study suggested that the seasonal rainfall deficiencies are even more pronounced with a similar trend of increased frequency of seasonal drought in the later half. The analysis also revealed that more area is under threat because of the increased drought frequency in the Ken Basin. The spatial distribution of drought over the Ken basin during the first and thelater half of the 20th century is shown in Fig. 4.

On the other hand, a monthly departure from the long term mean monthly rainfall for various gauging stations was analysed to investigate the severity of the drought frequency, i.e., the probability of receiving less than 50% rainfall during the month. Analysis of monthly rainfall departure during the first and the later half of the century revealed that monthly drought frequency is likely to increase during February, April, July, August, September and November. However, during the rest of the months, the drought frequency is expected to decrease.

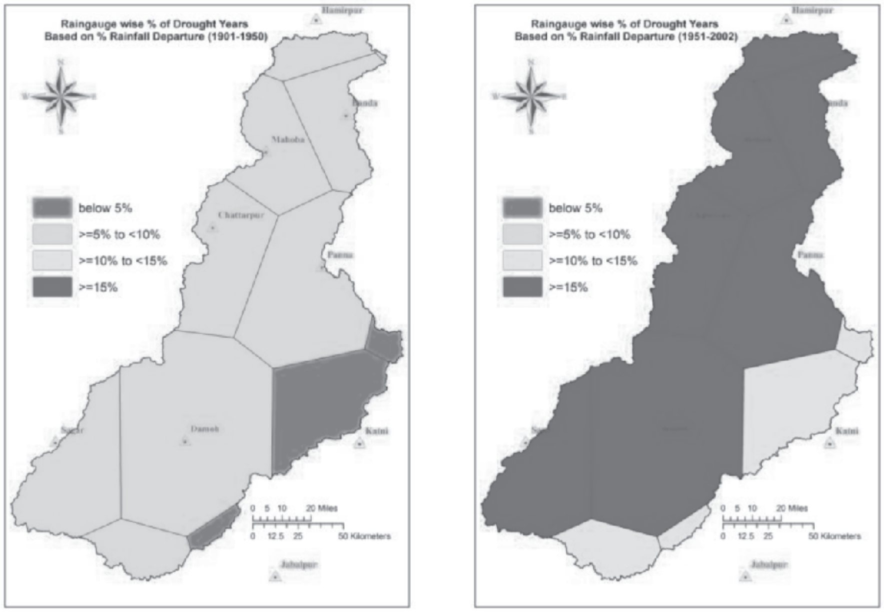


Fig. 4: Spatial Distribution of Drought in Ken River Basin due to climate change

Annual rainfall departure analysis indicates that the annual rainfall deficiency during the first half of the century ranges from -30% to -46 % at various gauging stations with a deficiency of - 37% for the Ken Basin as a whole. However, during the later half this deficiency increases from -33% to -57%, with a deficiency of - 44% for the Ken Basin. Similarly, the seasonal rainfall deficiencies range from -30% to -52% and -33% to -65% during the first and the later half of the century respectively. It is also evident from analysis that the occurrences of annual droughts correspond to seasonal droughts. It is further revealed that the deficiency in monsoon season (June to Sep) rainfall is primarily responsible for the occurrence of drought and subsequent water stress in the study area.

The plots of 102 years of annual and seasonal rainfall deficiency for gauging locations have been prepared. A sample of these plots for Banda is shown in Fig. 5. From these plots, it is evident that the magnitudes of monsoon season rainfall deficiency are more pronounced than that of annual value in most drought years.

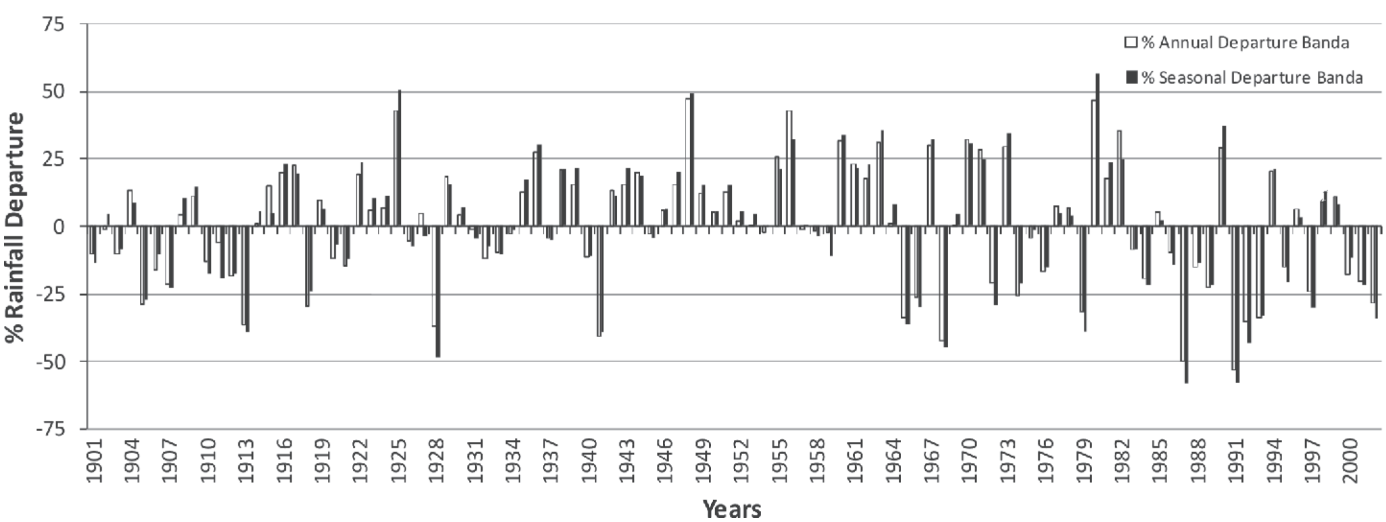


Figure 5: Annual and seasonal rainfall departure at Banda from 1901 to 2002

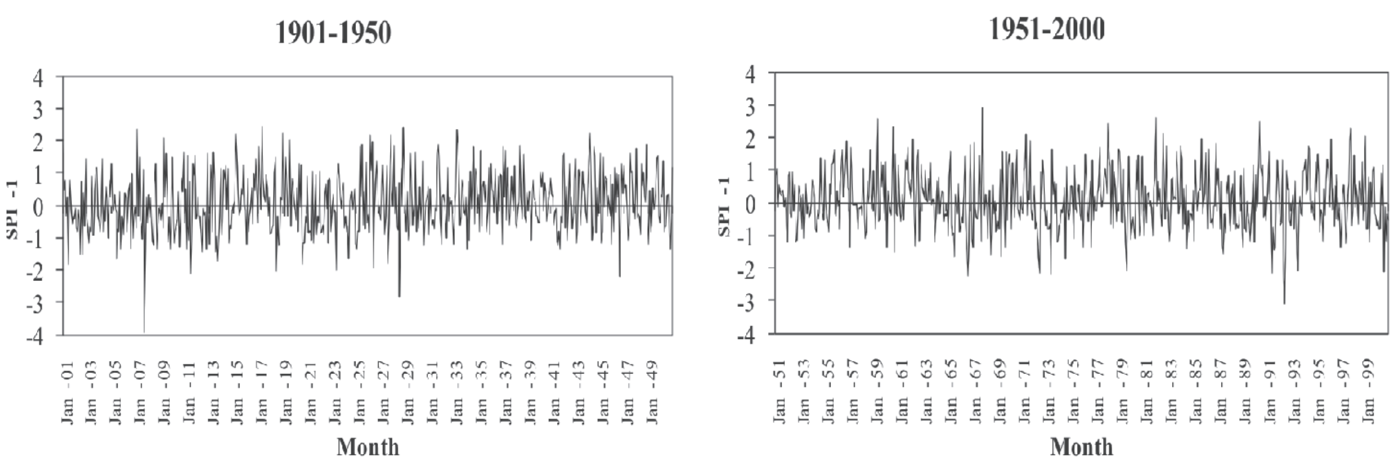
Table 5 : Number of drought years and drought return period during different periods of record for various districts in Ken river basin

Name of District	No. of Drought Years			Drought Return Period		
	1901-2002	1901-1950	1951-2002	1901-2002	1901-1950	1951-2002
Banda	15	5	10	7	10	5
Chattarpur	15	5	10	7	10	5
Damoh	12	4	8	9	13	7
Hamirpur	14	5	9	7	10	6
Katni	12	4	8	9	13	7
Panna	14	5	9	7	10	6
Raisen	16	5	11	6	10	5
Sagar	16	4	12	6	13	4
Ken Basin as a whole	**15**	**5**	**10**	**7**	**10**	**5**

Drought Severity Assessment Using Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) (Mckee *et al*., 1993) has been applied to quantify monthly precipitation deficit anomalies on multiple time scales (1-, 3-, 6- and 12 months) for the period during 1901-2002. Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation for a station. The SPI represents a statistical z-score or the number of standard deviations (following a gamma probability distribution transformation to a normal distribution) above or below that an event is demarcated with reference to the mean (Edward and McKee, 1997).

The SPI was used to indicate drought severity in this study. The SPI values for the rainfall data at each gauging station were calculated at 1, 3, 6, and 12-month time scales. However, the temporal characteristics of droughts in the Ken River basin were analyzed based on the SPI value of area-weighted rainfall for the Ken Basin as a whole. The sample plots of SPI of one-monthduration and 12-month duration for area-weighted rainfall of Ken basin for a period from1901-1950 and 1951-2000 are shown in Fig. 5. The analysis indicated more severe drought events in the later half of the past century in the basin. Analysis of the computed SPI series shows the basin has experienced droughts in terms of severity and duration in 1993-1994. A drought is defined whenever the SPI reaches a value of less than - 0.99 and continues until the SPI becomes positive again. The number of drought incidences along with their duration is shown in Table 6 and Table 7 for the period from 1901-1950 and 1951-2000, respectively.



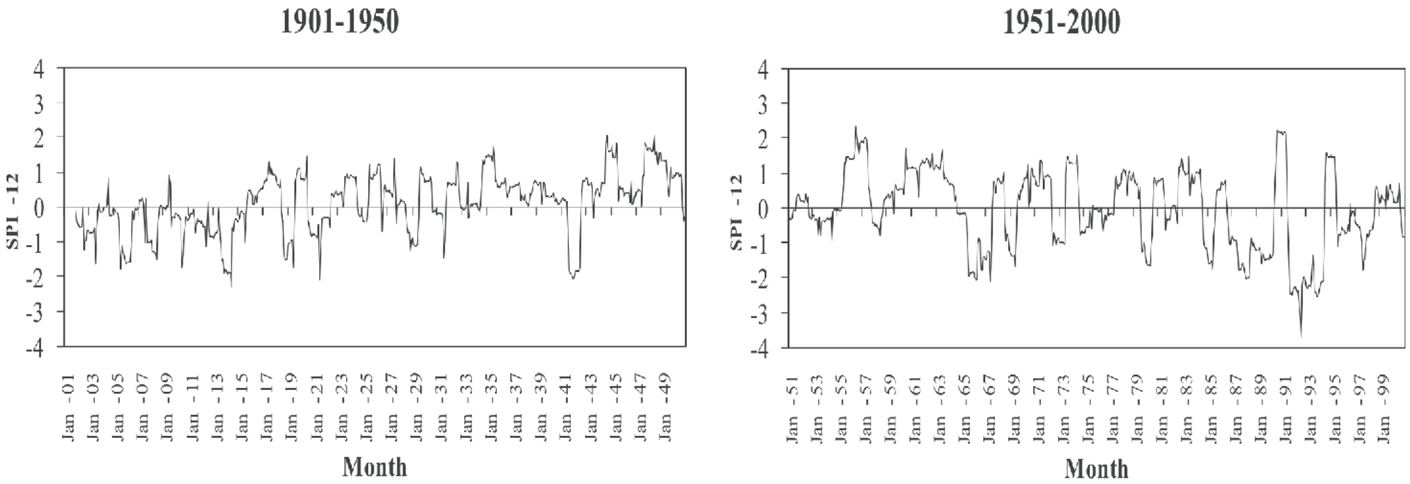


Figure 5: SPI Time Series of Ken River Basin for different time scales.

Table 6: Drought properties of SPI series in the Ken River basin during 1901 to 1950.

SPI Series	No.of Drought Months	No. of Drought Incidences	Duration of drought in months	Duration of drought in months	Duration of drought in months
			Minimum	Maximum	Average
SPI-1	68	58	1	3	1.17
SPI-3	95	51	1	5	1.86
SPI-6	78	31	1	7	2.52
SPI-12	67	17	1	12	3.94

Table 7: Drought properties of SPI series in the Ken River basin during 1951 to 2000.

SPI Series	No.of Drought Months	No. of Drought Incidences	Duration of drought in months	Duration of drought in months	Duration of drought in months
			Minimum	Maximum	Average
SPI-1	59	47	1	3	1.26
SPI-3	109	45	1	6	2.42
SPI-6	127	31	1	10	4.10
SPI-12	137	17	1	35	8.06

It is found that the number of drought incidences in the case of the SPI-1 is 58, with a maximum duration of 3 months for the entire period of study. However, the number of drought incidences in the case of the SPI-3 is 51 and 45, with a maximum duration of 5 months and 6 months for the first half and the second half of the century, respectively. The number of drought incidences in the case of the SPI 6 is 31, with a maximum duration of 10 months compared to 7 months during the first half of the past century. The number of drought incidences in case of the SPI 12 is 17, with a maximum duration of 35 months in the second half of the century, which occurred in 1993-1994. Based on the average time of drought, which is calculated by dividing the total number of drought months by the total number of drought incidences for a particular series (Mishra and Desai, 2005), it is clearly evident that the duration of drought has increased considerably in the later half of the past century in the basin.

Decadal Drought Severity Analysis

Decadal analysis of the drought was also analysed to assess the trend of drought severity in the basin. The accumulated sum of negative values was considered to assess the drought severity during the decadal periods fro 1901-1950 and 1951-2000. For this purpose, only negative values less than -0.99 were considered. This analysis indicated an increasing trend of severity in the basin's second half of the past century. The sample trend plot of one-month SPI for Ken basin is shown in Fig. 6.

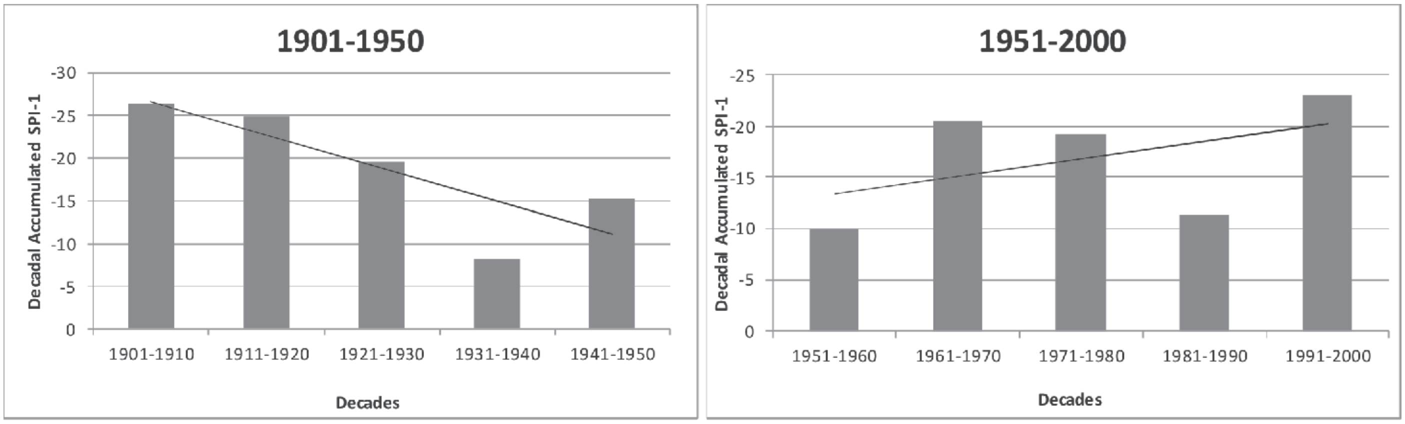


Fig.6: Decadal Trend Analysis of SPI-1 Severity at Ken River Basin.

CONCLUDING REMARKS

The key climatic elements governing regional drought characteristics are precipitation, temperature and evaporation. Therefore, climate variability and climate change are sturdily connectedtothe frequency of occurrence and severity of drought. The recurrent droughts seriously threaten the livelihood of billions of people who depend on land for most of their needs. The Indian economy is mostly agrarian-based and depends on the onset of the south-west monsoon and its distribution. The researchers reported that the observed monsoon rainfall at the All India level does not show any significant trend. However, substantial regional monsoon variations have been observed in other parts of India. A trend of increasing monsoon seasonal rainfall has been reported along the west coast, northern Andhra Pradesh, and north-western India (+10% to +12% of the normal over the last 100 years), while a trend of decreasing monsoon seasonal rainfall has been observed over eastern Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala (-6% to - 8% of the normal over the last 100years). Various studies indicating the increasing or decreasing trend of rainfall over various parts of India have been reported. Significant negative rainfall trends were observed in the Eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, Uttar Pradesh, parts of northwest and north-eastern India and also some parts of Tamil Nadu.

The studies haverevealed that the frequency of occurrence and severity of drought events has increased significantly in the past five decades, and this trend is expected to continue in the coming decades. The case study reported in this chapter for the Ken basin in the Bundel khand region in Central India indicated that there had been significant rainfall variability in different parts of the basin. The maximum rainfall deficiency for the Ken basin has been 37% (the year 1941) in the first half of the past century and 44% (the year 1993) from 1951 to 2002. The analysis of rainfall records revealed that the frequency of occurrence of the drought was significantly higher from 1951 to 2002 compared to the first half of the study period. The average drought frequency in the study basin was once every 10 years during the first half of the study period, and on average, it became once every 5 years in the latter part of the study period. The probability of annual and seasonal rainfall has significantly decreased from 1951 to 2002. The 102 years' rainfall data did not exhibit a significant rainfall trend. The rainfall had an increasing trend from 1901 to 1950. However, the separate analysis of rainfall records from

1951 to 2002 indicated a decreasing trend. Further analysis of the monthly rainfall trends revealed that the decreasing trendsare because of the reduction in rainfall during July and August. Because of the discussions presented above, it is clear that the frequency and severity of droughtshave increased significantly due to theobserved changes in key climatic elements, which have emerged as severe regional concerns with adverse impacts on the livelihoods of farmers in various regions in India.

REFERENCES

Alley, W.M. (1985). "The Palmer Drought Severity Index as a Measure of Hydrological Drought,"WaterResour. Bull., 21, 105–114.

Alley, R., T. Berntsen, N. L. Bindoff, Z. Chen, A. Chidthaisong, P. Friedlingstein, J. Gregory, G. Hegerl, M. Heimann, B. Hewitson, B. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, M. Manning, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, D. Qin, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, S. Solomon, R. Somerville, T. F. Stocker, P. Stott, R. J. Stouffer, P. Whetton, R. A. Wood, and D. Wratt (2007), Climate Change (2007): The Physical Science Basis, Summary for Policymakers, edited, IPCC Secretariat, c/o WMO, 7bis, Avenue de la Paix, C.P. N° 2300, 1211 Geneva 2, SWITZERLAND.

Appa Rao, G. 1986. Drought climatology, Jal Vigyan Samiksha, Publication of High Level

Technical Committee on Hydrology, National Institute of Hydrology, Roorkee.

Banerjee, A.K. and Raman, C.R.V., 1976. One hundred years of Southwest monsoon rainfallover India, Scientific Report No. 76/6, IMD, Pune, India.

Chaudhary A, Abhyankar VP. 1979. Does precipitation pattern foretell Gujarat climate

becoming arid. Mausam 30: 85–90.

Critchfield, H. J. (1983). "Atmospheric moisture." General climatology, Prentice Hall of India

Pvt. Ltd., New Delhi, 42–74.

Dash SK, Jenamani RK, Kalsi SR, Panda SK. 2007. Some evidence of climate change intwentieth-century India. Climatic Change 85: 299–321.

Edwards DC, Mckee TB. 1997. Characteristics of 20th century drought in the United States at

multiple time scales. Atmospheric Science Paper No. 63: 1–30.

FAO, 2002. Report of FAO-CRIDA Expert Group Consultation on Farming System and Best

Practices for Drought-prone Areas of Asia and the Pacific Region. Food and Agricultural Organisation of United Nations. Published by Central Research Institute for Dryland Agriculture, Hyderabad, India.IPCC, 1996, The Science of Climate Change, Contribution of Working Group I to the SecondAssessment Report of the Intergovernmental Panel on Climate Change, Cambridge University, Cambridge, UK.IPCC (2001). Climate Change–2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change–2001 (eds. J.T. Houghton), Published for the Intergovernmental Panel on Climate Change by Cambridge University Press.

IPCC (2007). Climate Change–2007: Final report on climate change by Intergovernmental Panel. Published for the Intergovernmental Panel on Climate Change, Cambridge University Press.

IPCC, 2012a: Meeting Report of the Intergovernmental Panel on Climate Change Expert

Meeting on Geoengineering. [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, C. Field, V. Barros, T.F. Stocker, Q. Dahe, J. Minx, K. Mach, G.-K. Plattner, S. Schlömer, G. Hansen, and M. Mastrandrea (eds.)]. IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam, Germany, 99 pp.

IPCC, 2014a: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate

Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel, and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–30.

Jain Vinit, R.P. Pandey, M.K.Jain, and HiRyon Byun (2015). Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin, Weather and Climate Extremes: ELSEVIER. Vol. 8, pp 1-11 Published Online (http://dx.doi.org/10.1016/j.wace.2015.05.002).

Kaczmarek, Z.D., Jurak, and Napioekowski, J. J. (1997). Impact of climate change on water

resources in Poland. Publication of Institute of Geophysics, Polish Academy of Science, E–1(295), p. 51.

Koteswaram P, Alvi SMA. 1969. Secular trends and periodicities in rainfall at west coast stations in India. Current Science 38: 229–231.

Kumar V, Jain SK, Singh Y. 2010. Analysis of long-term rainfall trends in India. Hydrological Sciences Journal 55(4): 484–496.

Kumar V, Singh P, Jain SK. 2005. Rainfall trends over Himachal Pradesh, Western Himalaya,

India. In: Development of Hydro Power Projects – A Prospective Challenge. Conference, Shimla, 20–22 April, 2005.

Kumar V, Jain SK. 2010. Trends in seasonal and annual rainfall and rainy days in Kashmir valley in the last century. Quaternary International 212: 64–69.

Kundzewicz, Z. W., and Kaczmarek, Z. (2000). "Copping with hydrological extremes." Jour. of Water International, 15(1), 66–75.

Lal M. 2001. Climatic change – implications for India's water resources. Journal of Indian Water Resource Society 21: 101–119

Mckee TB, Doesken, NJ, Kleist J. 1993. The relationship of drought frequency and duration to

time scales. In Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, USA; 179–184.

Mishra, A.K. and Desai, V.R. 2005. Spatial and temporal drought analysis in the Kansabati river basin, India. Intl. J. River Basin Management Vol. 3, No. 1 (2005), pp. 31–41.

Mishra, A.K. and Singh, V.P. (2010). A review of drought concepts. Journal of Hydrology, 391 :202-216

Mishra, A.K. and Singh, V.P. (2011). Drought modeling – A review. Journal of Hydrology, 403 :157–175.

MoA.(2016). Manual for Drought Management, Department of Agriculture and Cooperation, Ministry of Agriculture& Farmers Welfare, Govt. of India, December 2016, pp 9-54.

Mooley DA, Parthasarthy B. 1984. Fluctuations of all India summer monsoon rainfall during 1871–1978. Climatic Change 6: 287–301.

Mysiak, J., S. Surminski, A. Thieken, R. Mechler, and J. Aerts, 2016: Brief communication:

Sendai framework for disaster risk reduction – Success or warning sign for Paris? Natural Hazards and Earth System Sciences, 16(10), 2189–2193, doi:10.5194/nhess-16-2189-2016.

Pandey, R.P. and K. S. Ramasastri (2002), "Incidence of droughts in different climatic regions". Hydrological Sciences, IAHS, August especial issue 47(S), S31-S40.

Pandey, R.P. and K. S. Ramasastri (2001)”Relationship between the common climaticparameters and average drought frequency”. Hydrological Processes, 15(6), 1019-1032.

Pandey, R.P., Rakesh Kumar, R.D. Singh and C.S.P. Ojha (2013), 'Essence of Climate Change

on Hydrologic Extremes'. In book: “Climate Change Modeling, Mitigation, and Adaptation”, Chapter No 10: pp. 251-298. Publisher ASCE, USA (Editors:Rao Y. Surampalli, Tian C. Zhang, C. S. P. Ojha, B. Gurjar, R. D. Tyagi, and C. M. Kao,)doi: 10.1061/9780784412718.ch10.

Pandey R.P., MihailDaradur, Vinit K. Jain, and Manoj K. Jain (2016). Assessment of

Vulnerability to Drought Towards Effective Mitigation Planning: The Case of Ken River Basin in India. Journal of Indian Water Resources Society, IWRS, vol. 36, no. 4, pp. 36-48.

Ponce, V. M., Pandey R. P., and Sezan E. (2000). “Characterization of drought across climatic

spectrum.” Journal of Hydrologic Engineering, ASCE, 5(2), 222–224.

Raghavendra VK. 1974. Trends and periodicities of rainfall in subdivisions of Maharashtra state. Indian Journal of Meteorology and Geophysics 25: 197–210.

Shiulee Chakraborty, R. P. Pandey, U.C Chaube, S.K. Mishra (2013). Trend and variability

analysis of rainfall series at Seonath River Basin Chhattisgarh (India). International Journal of Applied Science and Engineering Research, Vol. 2, No. 4, pp 425-434.

Thapliyal V, Kulshrestha SM. 1991. Decadal changes and trends over India. Mausam 42: 333–338.

Thornthwaite, C.W., and Hare F. K. (1953). “Climatic Classification in Forestry.” FAO

Corporate Document Repository Unasylva, 9(2), 1–17. Available at <http:// www.fao,org/docrep/x5375e/ 5375202.htm> (accessed Feb. 2012).

Trewartha, G.T., and Horn L. H. (1980). “Atmospheric moisture and precipitation.” An

Introduction to Climate (5th Ed.). McGraw Hills Book Company, New York, pp. 41–232.

Wilhite D. A. 2000. “Drought as a natural hazard: Concept and definition.” Chapter 1 in

Drought: A Global assessment, Natural Hazards and Disaster Series, Vol. 1, Wilhite Donald A (eds.), Routledge Publisher, UK.

World Bank (2013). Turn Down The Heat: Climate Extremes, Regional Impacts and the Case for Resilience_a report of World Bank Group, http://climatechange.worldbank.org_.

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Robotics and Drones Applications in Agriculture

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INTRODUCTION

The world witnessed how extreme weather, deteriorating soil, drying lands and collapsing ecosystems make food production more and more complicated and expensive. Farmers in India have traditionally been practising flow irrigation which results in massive wastage of water, causing severe soil erosion, leaching of fertilizers, increasing the infestation of pests, diseases and weeds and suppressing crop yields. Indian farmers are challenged to grow more in several adverse conditions such as deteriorating soil, declining land availability, increasing weather fluctuation, and labor shortage. Smart agriculture is a broad term that collects agriculture and food production practices powered by Robotics and Drones, the Internet of Things, big data and advanced analytics technology.

Robotics is the branch of technology that deals with the design, construction, operation, structural depositions, manufacture and application of robots.Robots are designed or integrated with a specific task in mind and tailored to meet the unique needs of that task. When a mechanical or implied artificial agent, usually an electromechanical apparatus that is led by a computer program or electronic circuitry, and thus a type of an embedded system. Robots can be autonomous or semi-autonomous. The same robotic technology can be used in agriculture, so that the laborer involvement can also be reduced and time spent on the field can be reduced. The idea of robots in agriculture is not new, many robots have been introduced in agricultural field, which are autonomous or semi-autonomous.

In India, there are some challenges to enhance application of robotics and Drone in agriculture

- Less basic data availability
- Difficult to measure parameters under most unfavorable conditions.
- Limited internet access and cellular infrastructure
- Higher purchase and maintenance costs and resources
- The need for skilled operators
- In India, field sizes are fragmented. Where one farmer cannot afford the robotics/drone service
- Difficult to integrate with already implemented devices
- Currently, even the longest-running drones max out at around an hour of flight time before needing to return and recharge.

Key Drivers of Applications of Drone and Robotics in Agriculture:-

- Timely labour availability
- Shifting of youth to urban
- Skill and experience
- Harvesting is labour intensive
- Reduce crop losses by harvesting at proper time
- Uniform quality of output

- Precision, efficacy, reliability and minimization of soil compaction and drudgery.
- Multitasking, sensory acuity, operational consistency as well as suitability to odd operating conditions.

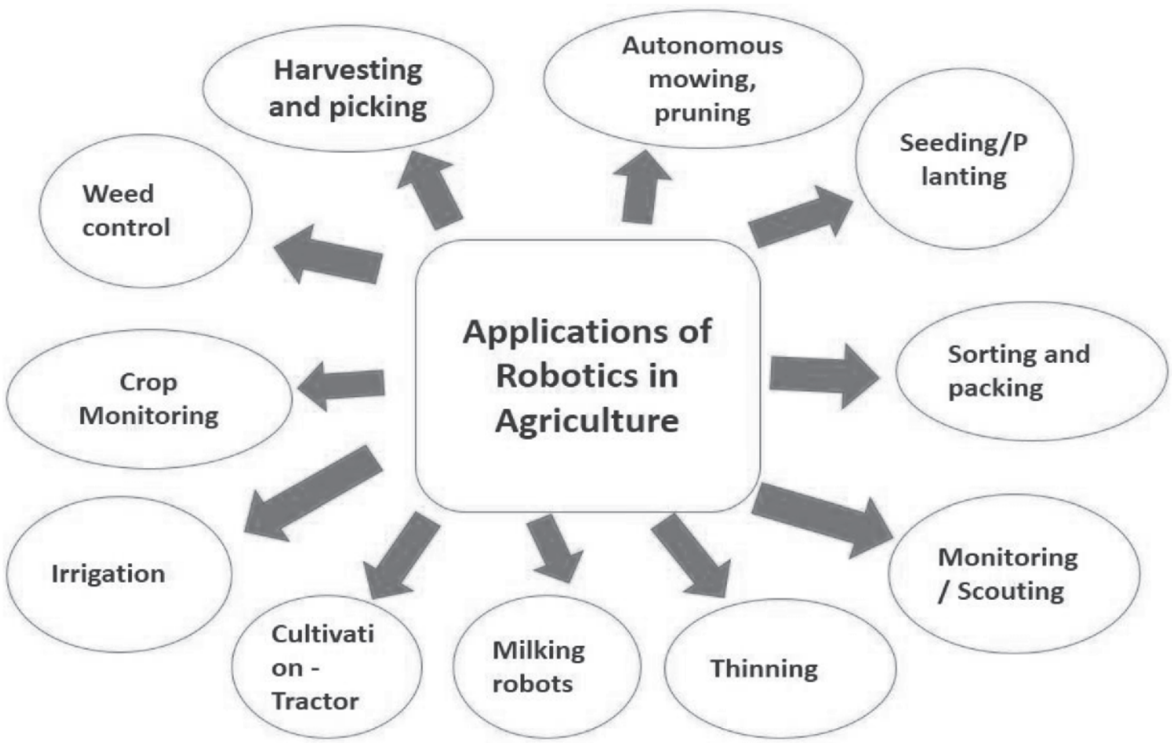
The various sources of power used for doing several agricultural operations from sowing to harvesting are compared table below

Comparison of Human Power, Machine and Robot

Type of Work	Human Power	Machine	Robot
Laborer	More	Moderate	Less
Time	More	Moderate	Less
Wastage	Moderate	More	Less
Pollution	No	More	No

Human power does not have a negative effect on the environment, but the operations will be more time-consuming with a moderate waste of inputs/produce. Machines can do several operations faster with moderate efforts but there a chance of high wastage and pollution due to use of various fuels for energy. The robots have the advantage of working more quickly, with no labor, negligible wastage and no pollution.

Some Applications of Robotics and Drones in Agriculture are highlighted as below.



- **Harvesting Robot :** Robots are well known for replacing humans with repetitive tasks. That is what they do at harvesting and picking. Harvesting is monotonous work that must be done to reap helpful food products. Robots are taking over the process to relieve humans from these tedious tasks. While planting and reaping basic food grains like wheat and barley can be done quickly by robots, others like fruit and vegetable harvesting need multi-talented robots. Labor shortages increased consumer demand, and high production costs have accelerated Automation in this sector, aiming to reduce costs and optimise harvests.

Harvesting and picking is one of the most popular robotic applications in agriculture due to the accuracy and speed that robots can achieve to improve the size of yields and reduce waste from crops being left in the field. The fruit harvester robot can locate and pick ripe fruits; Robot's "eye" scans the fruit plant and determines the number and position of ripe fruit. Image processing algorithms explicitly created for the robot can detect ripe fruit even if branches or leaves partially obscure it. Using this data, the four-fingered prosthetic hand locates fruits, opens the fingers and takes hold of the fruit. The robot balances pulling, bending, and torsion movements to detach the tasty treat. Harvesting and picking robots are becoming very popular among farmers, but there are dozens of other innovative ways the agricultural industry is deploying robotic Automation to improve their production yields. The demand for food is outpacing available farmland, and it's up to farmers to close this gap. Agricultural robots are helping them do just that.

- Autonomous precision seeding and Nursery Planting:- Sowing seeds is the basic process of beginning farming. Traditionally, farmers have been sprinkling seeds using their hands. When modern machinery came into effect, farmers used a 'broadcast spreader' attack to a tracker to sprinkle them. Although the process got simple, these attached features threw many seeds around the field, wasting it entirely. Thankfully, autonomous precision seeding is here to help. With a combination of robotics and geomapping, the mechanism can place the seeds exactly where it needs to be for good growth. Nursery planting is a go-to option for plan lovers. We can get vegetables and fruits for our daily usage by planting the needed crops at home. However, it is quite hectic to groom and water them regularly. This is where the robotic automation process gives its best. Robotic process automation takes care of all the nursery planting works, including watering regularly and plucking the vegetables or fruits when it is ripe.
- Micro-spraying robots:- While spraying pesticide repellent on the plants, most of the content ruins the soil. Although the ground is constantly plough to change its texture, there is less chance for the future plantation to escape the chemicals. It is also harmful to the environment. Therefore, farmers are using micro-spraying robots to narrow down the impacts. With futuristic computer vision technology, micro-spraying robots can detect weeds and spray a targeted drop of herbicide onto them.
- **Weeding robots:-** Weeds are the biggest enemies to farmers. Removing their notorious unwanted growth is both time-consuming and difficult. That is why farmers are now using robotics to counter the challenge. Autonomous robots, powered with computer vision technology, can precisely identify the weeds and yank them out before they can spread further.
- **Autonomous agricultural robots:** The autonomous agricultural robot is the most recent development that hit robotics from an agriculture perspective. With various features and unique technology onboard, these robots can multitask. They can do everything from cloud seeding, planting seeds, weed control, harvesting, environmental monitoring, and soil analysis. It can take care of end-to-end agriculture processes and replace challenging manual tasks with machinery.
- **IoT Sensors for robotics:-**Sensor-based systems for monitoring crops, soil, fields, livestock, storage facilities, or any critical factor was influencing production. IoT-enabled agriculture allows farmers to monitor their products and conditions in real time. They get insights fast, can predict issues before they happen and make informed decisions on how to avoid them. IoT solutions in agriculture also introduce Automation, such as demand-based Irrigation, fertilizing and robot harvesting. One of the benefits of using IoT in agriculture is the increased agility of the processes. Thanks to real-time monitoring and prediction systems, farmers can quickly respond to any significant change in weather, humidity, air quality, and the health of each crop or soil in the field. In extreme weather changes, new capabilities help agriculture professionals save crops. IoT in agriculture is not only a way to boost productivity and cut costs but also one of the primary measures to reduce the carbon footprint associated with farming and preserve energy and water resources. For instance, automated Irrigation based on smart sprinklers helps farmers

significantly reduce water consumption and thus makes agriculture more sustainable. Connected coolers and heaters in storage and transportation facilities create better preserving conditions for the product and help reduce waste. Intelligent LED lighting automatically adjusts to the changing needs and ensures every part of a greenhouse or storage space gets the right amount of light.

IoT and Robotics for Precision Farming:-The potential of precision farming for economic and environmental benefits could be visualized; through reduced use of water, fertilizers, herbicides and pesticides besides the farm equipment. Instead of managing an entire field based on hypothetical average conditions, which may not exist anywhere in the field, a precision farming approach recognizes site-specific differences within areas and adjusts management actions accordingly. IoT, AR, VR, and Automation can play a vital role in this context. Farmers usually are aware that their fields have variable yields across the landscape. These variations can be traced to management practices, soil properties and environmental characteristics. A farmer's mental information database about how to treat different areas in a field requires years of observation and implementation through trial-and-error. Today, that knowledge of field conditions is difficult to maintain because of the small farm holdings. Precision agriculture offers the potential to automate and simplify the collection and analysis of information. It allows management decisions to be made and quickly implemented in small areas within larger fields.

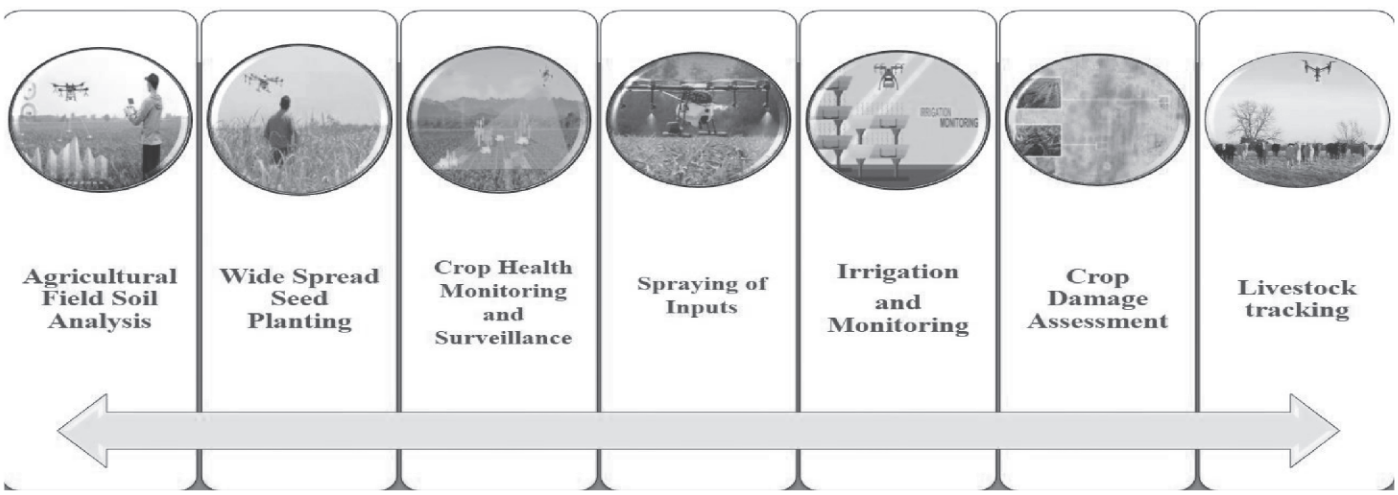
- **AI and IoT and Robots for Water Management:-**Climate change and the approaching water scarcity in the world is genuine. Therefore, saving water, by all means, is at the core of farming. Unfortunately, irrigation and fertilizing processes use a lot of water, most of which goes unused. To combat this challenge; robot-assisted precision irrigation emerges as a solution to reduce water wastage by targeting specific plants.The agriculture sector consumes the most considerable amount i.e. over 85 per cent of India's water. The consumption of water would escalate further with pressure from industrialization and urbanization. Events like droughts, heavy rains, unseasonal rains, hail storms, floods, etc. are rising due to climate change and have impacted the Indian economy adversely. Water demands are steadily rising. With growing pressures due to climate change, migration and population growth, creative and imaginative governance is needed to manage this precious resource. Incidentally, our country is endowed with vast seawater resources covering large parts of over a dozen of states and union territories. Ensuring purified seawater supply to a dedicated network would help people immensely.
- Among the total irrigated area in Gujarat, the canal irrigated area is only 9.76 lakh ha, which is only 22 % and the area washed by tank water is only 1%. Thus, the remaining 77% area is irrigated through only groundwater which requires more energy to lift the water. Hence, the only Agriculture sector consumes 49% of the state's total electricity. Surface water resources are over-appropriated in many basins. Freshwater supplies are increasingly threatened by pollution from industrial effluents and municipal waste. The consumption of energy and water is relatively high for agricultural production. Both of these are scarce national resources. Therefore, it is in the national interest to adopt newer technologies to reduce waste.
- A critical feature of agricultural water management is Automation in Irrigation. Automation in Micro Irrigation system help irrigator to have better control of farm and irrigation needs as well as peace of mind because the intelligent system can make decisions independently and operate remotely. Farmer can save a significant amount of water, electricity, time and manpower through intelligent control and Automation in the system. Internet of Things (IoT) based irrigation systems offer a variety of advantages over traditional irrigation systems. The systems can optimize water levels based on things such as weather predictions. Additionally, the intelligent irrigation controller receives local weather data to help determine the plant's water requirement. Less than 1% of the total area under MIS have adopted the automatic irrigation system due to unavailability of technical expertise and higher initial cost.

- **Sorting and packing robots:-**More than the actual agricultural work, sorting and packing demand many human operators. The need for human labourers in packing is drastically increasing in the fast-paced production space. Therefore, many farming companies are using sorting and packing robots to streamline the tasks at high speed without breaking. These robots can fast-track the packing process with coordination capability and line tracking technology.

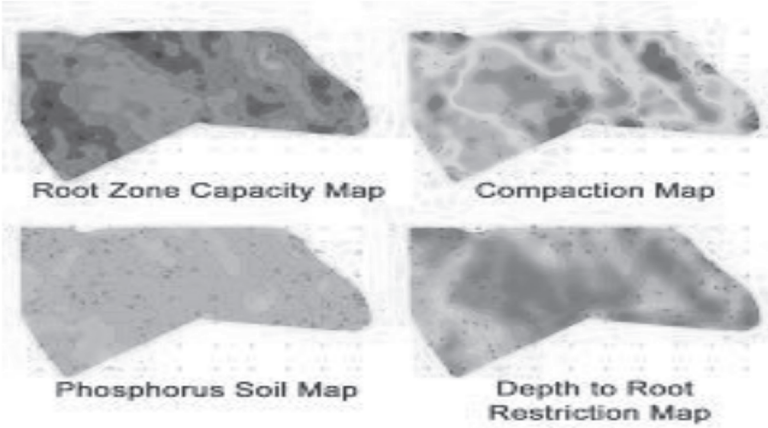
Applications of Drone in Agriculture

Drone technology has left a long-lasting impact on the Agriculture industry of India and its efficiency. Drone-powered solutions to farmers to increase productivity in crop monitoring to planting, Livestock Management, Pesticide Spraying, Crop Stress identification, Treatment Planning, Plant Growth Monitoring, Precision Farming, Scouting and much more. The high-tech Aerial Surveying drones are equipped with advanced sensors, such as RGB and Multispectral Sensors, to procure precise data. Advanced drone technology and Machine Learning for Precision Agriculture result in improved crop yields and profitability. Correspondingly, farmers' lower levels of standard input are required to grow crops and maintain land, water, fertilizer, herbicides, and insecticides. The combination of UAV Aerial Imagery with Machine Learning systems for Crop yield forecasts, accurate crop count, crop emergence analysis, irrigation monitoring, crop health, crop damage assessment, field soil analysis, etc. High-quality drone data and Photogrammetry guard crops to guarantee productivity and equip farmers with all benefits accessible. One of drones' most valuable tasks is remote monitoring and analyzing fields and crops. Imagine the benefits of using a small fleet of drones instead of a team of workers spending hours on their feet or in a vehicle travelling back and forth across the field to check crop conditions visually. This is where the connected farm is essential, as all this data needs to be seen to be helpful. Farmers can review the data and only make personal trips out into the fields when a specific issue needs their attention, rather than wasting time and effort by tending to healthy plants.

Applications of Drones



- **Agricultural Field Soil Analysis:-**2D and 3D maps for early soil analysis, helpful in planning seed planting patterns. After planting, drone-driven soil analysis provides data for Irrigation and nitrogen-level management. The soil quality of crops can either make or break a farmer's productivity. Soil Analysis is a crucial step to be taken by farmers during the crop-cycle. Our drones, such as the DJI Phantom 4 Pro, provide real-time and precise analysis of soil's overall health. One can discern issues surrounding soil quality, nutrient management, or dead soil zones through Precision Agriculture. This data supports farmers in determining the most effective farming patterns of planting, managing crops, and soil. Not to mention, field soil analysis also increases the safety and health of workers.



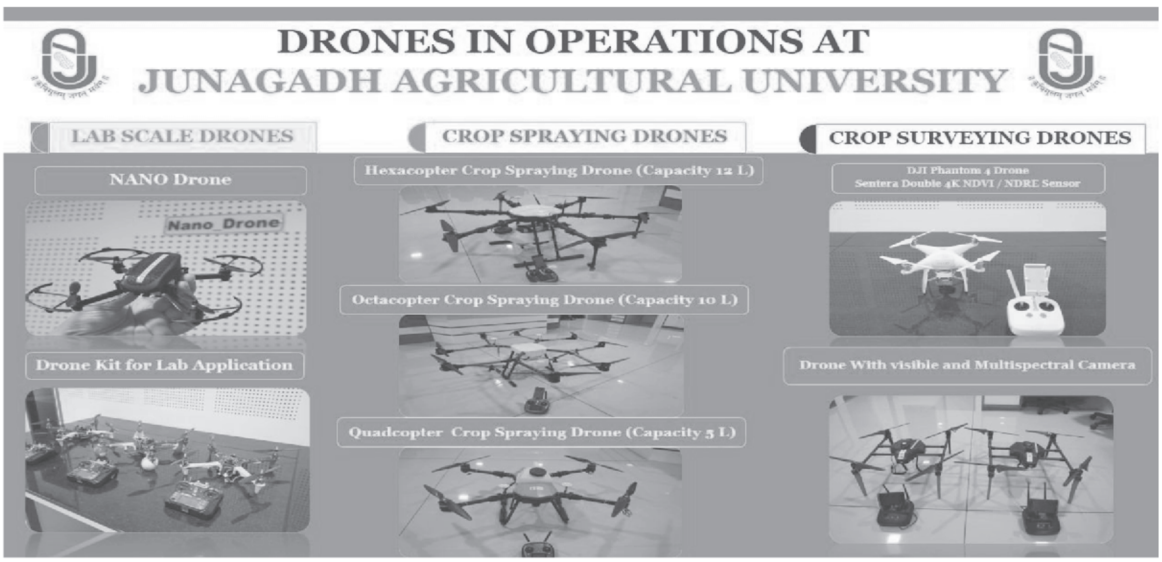
- **Crop Health Monitoring and Surveillance:-**Previously, Satellite Imagery offered the most advanced form of monitoring. But there were many drawbacks. Satellite images had to be ordered in advance and could be taken only once a day, Services were highly costly, and the images' quality typically suffered on certain days.Today, drones can show the precise development of a crop and reveal production inefficiencies, enabling better crop management. The drones furnished with Multispectral camera sensors can identify disease and stress in the initial stages, sometimes before it is even evident from the ground or with standard colour cameras. They also provide real-time imagery of the fields for precision agriculture.

  The data obtained is processed and analyzed during Irrigation Monitoring, Corp Health Monitoring, and other fundamental elements to encourage farmers to focus on treatment plans. Drones with hyperspectral, multispectral, or thermal sensors can identify which parts of a field are dry or need improvements. Additionally, once the crop is growing, drones allow the calculation of the vegetation index, which describes the relative density and health of the crop, and shows the heat signature, the amount of energy or heat the crop emits and generates crop water stress index (CWSI).

- **Spraying of Inputs:-**Conventional methods have shortcomings such as extra chemicals use, farm labour shortage, lower spray uniformity, environmental pollution, and less area coverage. These conventional methods cause a higher cost of pesticide application and are less effective in controlling pests and diseases.Crop Spraying Drone overcomes these shortcomings. In the field, it enhanced the Coverage Ability, Increased the Chemical Effectiveness, and Made the spraying job easier and faster.
- Nowadays, Drone can carry up to a 20-liter pesticide tank and follow pre-mapped routes to spray crops according to the requirements. Drones are showing great potential in covering the fields with difficult access for tractors and aircraft.

- **Crop Damage Assessment:-** Drone pilots can obtain high-resolution data that can provide vital information for measuring and documenting crop damage from unforeseen factors such as floods, fires, pests, weather events, etc. Data from drones with remote sensing capabilities and Photogrammetry acts as evidence for farmers or government authorities to claim crop insurance or to obtain an estimate accordingly. Data from advanced sensors represented as 2D or 3D Orthomosaics help farmers understand and find novel alternatives to increase crop yields and reduce crop damage simultaneously. By scanning a crop using visible and near-infrared light, drone-carried devices can identify which plants reflect different amounts of green light and NIR light.This information can produce multispectral images that track changes in plants and indicate their health. A speedy response can save an entire orchard.
- **Drone for Irrigation:-** Drone technology is advancing rapidly as these helpful devices have found purpose in countless new applications, including as a part of farm irrigation. The larger the farm, the harder it is to monitor what's happening in the fields. Even the best farm irrigation systems can fail or conditions could change to affect plant growth. Traditionally, monitoring fields has involved hours of driving to search for problems, some of which may be hard to detect. It can result in water and fertilizer wastage, over or under-irrigation, machinery failures, and other issues that cause reduced efficiency and increased plant death. Drones alleviate most of these problems by making it easier to see what's happening in the fields. Flying high over huge acreages, they offer farmers an aerial view of their crops to track progress and problems daily. Now recommended by many farm irrigation system services, drones provide a critical bird's eye view of crops so corrections can be made sooner rather than later. Drones equipped with Thermal Cameras and Remote Sensing capabilities can help defeat irrigation issues or areas receiving little or too much moisture.
- The topography of fields from RGB Imagery assists farmers in positioning and segregating the crops to maximize drainage, follow natural land runoff, and to avoid water logging. With our services, farmers will be able to adapt to different environments comfortably. Today's technologically advanced farm irrigation systems are designed to give farmers all the adjustability they need to program efficient Irrigation to save money and increase yield. Despite that programmability, observing results and frequently monitoring irrigation systems to detect breakdowns and other unexpected issues is essential. Farm irrigation system services find that many farmers now view flying a drone over crops to get a sky view of things as one of the easiest and most cost-effective ways to track it.Drones sensors can identify which parts of a field are dry or need improvements, Highlighting areas that insouciant soil moisture. Calculating the vegetation index, Show the heat signature, and the amount of energy or heat the crop emits.

- **Crop Count & Plant Emergence Analysis:-** With the drones' high-resolution data coupled with Machine Learning algorithms, we can efficiently present production information to track crop emergence, drive replanting decisions, and help predict yield. Data obtained with premium UAVs and Photogrammetry, our system yields 97% accuracy in its output. We represent these as 2D Orthomosaics for an in-depth understanding.
- **Livestock Tracking:-** Livestock Management production entails 24/7 monitoring and security. Livestock management has adopted drone use to streamline their day-to-day processes. Drones have been widely accepted because it helps save time and resources and have higher-level access to information. Drone help to view animal locations rapidly and remotely to keep track of their welfare, calving seasons and grazing patterns. You can also plan more time-efficient and cost-effective musters. Tracking your farm animals with Ag Drones is also safer for your employees and allows you to reduce labour costs.



Measures to support the application of robotics and Drone in agriculture

- To cope with these challenges, we must encourage investment in projects/infrastructure, and Partnering with private industries; extensive research and primary data are required for Indian conditions.
- Innovative technology choices require comparing conventional technologies and new ones, balancing traditional infrastructures with green alternatives, mixing local and global knowledge, adapting alternatives from abroad to local conditions, dealing with environmental and social impacts of the alternative technologies, *etc.*

Interventions of Junagadh Agricultural University:-

Artificial Intelligence, Robotics and Drone Lab at JAU, Junagadh established under Nation Agriculture Higher Education Project (NAHEP), IDP (ICAR) Several interventions were made under this development.

- Smart, automated greenhouse: Irrigation + Fertigation + Microclimate
- Agrivoltaic farming-Enhancing farmer's income and minimizing water use
- IoT-based automated Closed Canopy Chamber for instantaneous ETc-based Irrigation Water Management Dedicated Laboratory is established for Students where they can Dismantle and Assemble different components of different Drones for learning and Practising purpose. The students have developed the following models.
- Smart irrigation system with soil moisture monitoring and data storage in the cloud

- Rainfall recorder
- Time base smart sprinkler for plant
- Leaf analysis using AI
- Fruit quality inspection system based on AI
- The security system in farm with wireless live video streaming
- Solar panel movement based on sunlight
- Temperature and humidity monitoring and management system in storage house
- Monitoring and displaying weather ambient data in greenhouse

Agricultural research has to play a much more significant supportive role for implementing AI, Robotics and Drone technology and linking with private industries will be a crucial factor. For private businesses in capacity building and domain consultancy, hand-holding and support. There is enormous potential for artificial intelligence, robotics, drone technology and machine learning to revolutionize agriculture by integrating these technologies into critical markets on a global scale. Applications robots, drones, remote sensors, and computer imaging combined with continuously progressing machine learning and analytical tools for monitoring crops, surveying and mapping the fields; and providing data to farmers for rational farm management plans will help to save inputs, time, labour and money, increase the income. Precise applications will be beneficial for climate resilient agriculture along with environmental protection.

L-18

Potentials of processing and value addition of NTFPs and minor fruits: An opportunity for improving household income and livelihood security

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ABSTRACT

Non-Timber Forest Products (NTFPs) refer to all biological materials other than timber extracted from natural forests for human and animal Use and have both consumptive and exchange value. The NTFPs provide the products for food, shelter, medicines, fibres, energy and cultural artefacts to communities. They include fruits and nuts, vegetables, medicinal plants, gum and resins, essences, bamboo, rattans and palms; fibres and flosses, grasses, leaves, seeds, mushrooms, honey and lac etc. make significant contributions to rural livelihoods. India is one of the megadiverse nation harbor variety of NTFPs and minor fruits in different geographical regions of the country, while almost all indigenous communities have been involved in harvesting, collection, consumption and marketing of NTFPs and minor fruits since immemorial times. There is an organized collection, processing and marketing system for only a few nationalized NTFPs and important fruits.

In contrast, many others are exploited in an unorganized manner without proper institutional arrangement. Although support prices for some economically important NTFPs and minor fruits were declared from time to time by some state governments and cooperatives were created but still inadequate for commercial exploitation of potential sources. The postharvest processing and value addition are mostly lagging, affecting the quality and economic returns. The postharvest processing of NTFP material may include cleaning, peeling, grinding, shell separation, seed separation, fiber separation, grading, drying, storage or packaging of products, harvesting nearer to maturity, or collecting material with higher proportions of active ingredients. Many processing and preservation techniques such as blanching, drying, dehydration and freezing are being produced at both household and commercial levels with different minor fruits. Postharvest technologies also include pre-cooling, cleaning/washing, chemical treatments, trimming/sorting, packaging, curing, transportation, grading, storage, ripening, and distribution. Extending the shelf life of a commodity requires knowledge of all the factors that can lead quality deterioration or generation of helpful material. The processing and value addition increase the shelf life, improve the quality of products, and increase the prices at least 2-3 times higher than raw material. There is ample scope for processing and developing value added products from fruits like candy, jam, RTS, nectar squash, powders, jellies, tarts, chutneys, beverages, Pickle, concentrates, jelly powders, flakes, dried fruits pickle etc. The fostering of processing and value addition is possible through organizing imparting skill oriented trainings and establishing primary processing centres involving self-help groups (SHGs) and cooperative will help in mainstreaming and harnessing the potentials of NTFPs. Focusing on NTFP processing, the importance of the development and promotion of small-scale processing technologies in order to achieve high-quality products with longer shelf lives needs to be highlighted. Nevertheless, the proper policies and institutional support are crucial in realizing the expected benefits. The paper discusses the role of processing NTFPs and minor fruits in improving livelihoods and securing the subsistence needs of indigenous communities, which could be a stepping stone for sustainable development.

Keywords: Commercialization; NTFPs; Processing, Sustainable development, Value Addition

INTRODUCTION

The non-timber forest products (NTFPs) including wild fruits, forage, medicinal plants, construction materials, fuelwood, and raw materials for handicrafts have emerged as a significant source of food, nutritional and livelihood security among indigenous communities. Several studies overwhelmingly demonstrated the role of NTFPs in fulfilling households' subsistence and consumption needs in addition to diverse forms of income. The NTFPs and minor fruits fulfil the basic needs of food security via diversifying the traditional diets, supplying micronutrients (Mishra et al. 2021), maintaining cultural food habits, and acting as safety-net against malnutrition and many diseases commonly prevailing among indigenous societies. Nevertheless, thegrowing contribution of NTFPs, the efforts onsustainable utilization and marketing through postharvest storage, processing and value addition have not received desired level of attention. The livelihoods and economies could be substantially improved through holistic development by evolving complete value chain for many economically important NTFP including minor fruits (Kasture et al. 2008).

Minor fruits can be defined as those fruits which though are consumable to the human beings but are relatively less palatable than other mainstream fruits, which have lesser demand in the market, are grown to a limited extent only and are not usually cultivated in organized plantations with application of inputs (Mazumdar, 2004). Other terms that are used for these fruits are lesser-known fruits, underutilized fruits, less appealing fruits, under-exploited fruits, potential fruits, stray fruits, wild fruits etc (Mahapatra and Panda, 2012). Minor fruit species act as life support species in extreme environmental conditions and threatened habitats and have tolerance to survive under harsh climate conditions (Cheema et al. 2017).Food security means that all people, at all times, have physical, social and economic access to sufficient, safe, and nutritious food which meetsdietary requirements.

Livelihood security is defined as adequate and sustainable access to income and resources to meet basic needs (including adequate access to food, potable water, health facilities, educational opportunities, housing and time for community participation and social integration) (FAO, 2002). Livelihoods can be made up of a range of on-farm and off-farm activities that together provide a variety of procurement strategies for food and cash. Thus, each household can have several possible sources of entitlement, which constitute its livelihood. With the increasing population pressure, India is facing serious food security challenges, unemployment and environmental degradation. Staple crops face major challenges shortly and a diversification away from over-dependency on staple crops will be necessary as part of the progress towards the goal of achieving security of food production. Consumers are becoming increasingly conscious of their food basket's health and nutritional aspects. The tendency is to avoid chemicals and synthetic foods and preference for nutrition through natural resources. These underutilized fruits are the main sources of livelihood for the poor and play an essential role in overcoming the problem of malnutrition. The minor fruit crops play an important role in ensuring the livelihood security of rural communities in one or more of the following ways:

- Reduce the risk of over-dependency on minimal numbers of major staple food crops
- Help the poor for subsistence and income.
- Increase sustainability of agriculture through a reduction in inputs
- Help to preserve and celebrate cultural and dietary diversity,
- Use marginal and wastelands for agricultural purposes to meet the ever
- Value Addition in Minor Fruits of Eastern India 397 increasing food demand.

Forest resources are natural capital for rural people's livelihood that sustains them with assets, capabilities and means of living. Some of these forest resources are non-wood forest products (NWFP) or non-timber forest products (NTFP), which include all natural and biological materials except timber extracted for human Use (Rijal et al. 2011). Some have used the term to encompass service functions rendered by forestlands. NTFPs are components of forest ecosystems that exist in nature and are generally not cultivated. Some areas NTFP have highereconomic and social values than timber products. The products include fuel wood, charcoal, lac, broad range of edibles (fruits, honey, spices, fungi/mushroom, juices); decorative (leaves and twigs); medicinal (roots, bark, leaves, flower, fruits) and handicraft goods (rattan, vines, bamboo, grasses); wood carved or woven into pieces of art or utilitarian objects harvested from forests and wildlife products such as bones and skins for subsistence, social, cultural, ritual or religious, spiritual, science, ornamental, leisure and revenue purposes. Like timber, NTFPs can be further processed or value-added into consumer-oriented products (Kala, 2013). Tropical rain forests are particularly abundant with plants yielding edible items, essential oils, medicines, gums, resins, colourants, tannins and many others.

Non Timber Forest Products (NTFPs) for Sustainable Livelihood

Non-timber forest products (NTFPs) constitute an important source of livelihood for millions of people from forest fringe communities worldwide. In India, NTFPs are associated with socio-economic and cultural life of forest dependent communities inhabiting in wide ecological and geo-climatic conditions throughout the country (Kasture et al. 2008). The NTFPs provide the products for food, shelter, medicines, fibres, energy and cultural artefacts for many of the world's poorest people and a considerable proportion of the less poor. They include fruits and nuts, vegetables, medicinal plants, gum and resins, essences, bamboo, rattans and palms; fibres and flosses, grasses, leaves, seeds, mushrooms, honey and lac etc make significant contributions to rural livelihoods (Kala et al. 2013). Most rural households in developing countries and many urban households depend on the products to meet some part of their nutritional, health, house construction, or other needs. NTFPs can help fulfil households' subsistence and consumption needs, serve as a safety net in crises, and provide cash income. India has a long history of tree-based farming systems under diverse ecological conditions. Many agroforestry systems based on fruit trees are practised in one or the other part of the country. These systems not only provide fruits but also fulfil requirement of timber, food, fuel and fodder. Besides, they also generate employment, income, provide nutritional security, reduce greenhouse gas emissions, improve soil health and provide economic stability. Fruit-based agroforestry has been proven as an important tool for crop diversification.

Table 1: List of important minor fruit crops of India

Common name	Botanical name	Growth habit	Climate
Aonla	*Emblica officinalis*	Tree (medium size)	Sub-tropical
Ber	*Ziziphus mauritiana*	Tree (medium size)	Sub-tropical
Bael	*Aegle marmelos*	Tree (medium size)	Sub-tropical
Fig	*Ficus carica*	Shrub	Tropical to sub-tropical
Date palm	*Phoenix dactylifera*	Tree (monocot)	Arid sub-tropical
Jamun	*Syzygiumcumini*	Tree (large size)	Sub-tropical
Custard apple	*Annona squamosa*	Shrub/small tree	Tropical to sub-tropica
Chironjee	*Buchananialanzan*	Tree (small size)	Semi-arid sub-tropical
Mulberry	*Morus alba, M. rubra*	Tree	Sub-tropical, temperate
Mahua	*Madhuca indica*	Tree (large size)	Semi-arid sub-tropical

Rose apple	*Syzygiumjambos*	Tree (small)	Coastal (Tropical)
Wood apple	*Feronia limonia*	Tree	Sub-tropical
Pomegranate	*Punica granatum*	Shrub	Tropical, sub-tropical and temperate
Tamarind	*Tamarindus indica*	Tree (large size)	Tropical to sub-tropical
Karonda	*Carissa carandas*	Shrub	Sub-tropical

Classification of Non-Timber forest Products as per their different uses

There are various examples of NTFPs used for a wide variety of purposes: for daily needs, cash income, as a "safety net" in times of shortage, and as raw materials for industries.

They can be considered using the following classification:-

1) Fibrous products: bamboo, rattan, grass, stem hair or bark fibre
2) Edible products
   a) **Food products of trees:** roots, stems, leaves, flowers, bamboo shoots, fruits, nuts, oil seeds, seasoning, mushrooms, and beverages.
   b) **Animal products:** honey, fish, edible birds, eggs, insects, bush meat
3) Medicines, narcotics & cosmetics
4) Extracts from trees & plants: resin, rosin, latex, tannin, dyes, gums, wood oils, fats, spices, perfume, and aromatic oils.
5) Animals & products (non-edible): eggs, animals, birds & insects, hides, feet, teeth, bones, feathers.
6) Ornamental plants (e.g. Orchids)
7) Livestock Fodder & Bedding

Importance of Non-Timber Forest Products

- The subsistence value of NTFP's is significant for local people living in mountainous forested areas, since they often depend on them for their livelihood.
- NTFP's play a vital role in the local market economy of the rural poor, who generate a large part of their household income from selling NTFP's, and depend on them as a "safety net" in times of shortage or crisis.
- NTFP also provides products that are the raw materials of industry or are exported, earning valuable foreign exchange and are assumed to provide potential sources of new genes/products that are of value to the agricultural and pharmaceutical industries.

Scope of Non-Timber forest Products

NTFPs are primary or supplemental source of livelihood, mainly in the poor and developing nations. Non-Timber Forest Products (NTFPs) are essential to many rural economies. They include hundreds of species (traded or locally used) of forest products of biological origin (Mishra et al. 2021). Thousands of collectors, village traders and exporters gather NTFP for at least one season in a year. These natural products originating from forests and pasture ecosystems are increasingly recognized for their role in rural livelihoods, biodiversity conservation and export values. NTFPs contribute significantly to the forest economy of developed and industrialized nations also. NTFPs can be processed or value-added into consumer-oriented products. They have commercial importance and can contribute to the economic development of a region or a nation. In the recent years, the market of NTFPs has expanded, and this is an opportunity and a challenge for more sustainable, efficient and equitable management of NTFPresources (Mishra et al. 2021).

In particular, the processing of NTFPs has often been suggested to positively influence sustainable economic development in rural areas. However, despite rising interest and recognition of the potential contributions of such industries as key sources of employment and their strategic role in overall growth strategies of developing countries, many NTFP processing enterprises remain in the informal sector and an in-depth understanding of the underlying factors is lacking. The NTFP extraction multiplies the economy by generating employment and income in downstream processing and trading activities (Mishra et al. 2021). However, depletion of NTFPs resources on account of indiscriminate exploitation, deforestation and forest degradation have a major issue of concern that may affect the NTFP based livelihood and economics.

Fig 1: Non-Timber forest Products

Post Harvest Losses of Agroforestry and Horticulture Crops

Agroforestry and Horticulture crop is a perishable commodity. Due to this, they are wasted in large quantities due to the absence of facilities and know-how for proper handling, distribution, marketing and storage (Kumar et al. 2019).Many of these factors have synergistic effects, and the losses can be causes of postharvest losses more significant with a combination of factors. For example, a stored product's chemical, microbial, biochemical, or physiological activity is significantly influenced by the storage conditions, especially temperature. A temperature change can result in a two- to three-fold change in these activities. Loss of quality is the second cause of postharvest loss. This can be due to physiological and compositional changes that altert heappearance, taste,texture and produce less aesthetically desirable to end users.

A considerable amount of fruits, vegetables, Agriculture Produced and NTFPs produced in India is lost due to improper postharvest operations; Post harvest losses in fruits and vegetables are very high (20-40%). About 10-15% fresh fruits and vegetables shrivel and decay, lowering their market value and consumer acceptability; as a result, there is a considerable gap between the gross production and net availability (Dhurve *et al.* 2018) . To maximize agricultural production by employing modernized agricultural operations, high yield varieties, intensified planting, effective Use of growth promoters etc. Therefore, alternate measures should be adopted, including the intensification of agricultural production. One practical alternative to minimize postharvest losses that enhance agricultural product availability can reduce the gap between production and availability.

Causes of Post Harvest Losses

Postharvest losses of horticultural crops affect the nutritional status of the population and economy of the country. The different causes of postharvest food losses may be broadly grouped as primary and secondary.

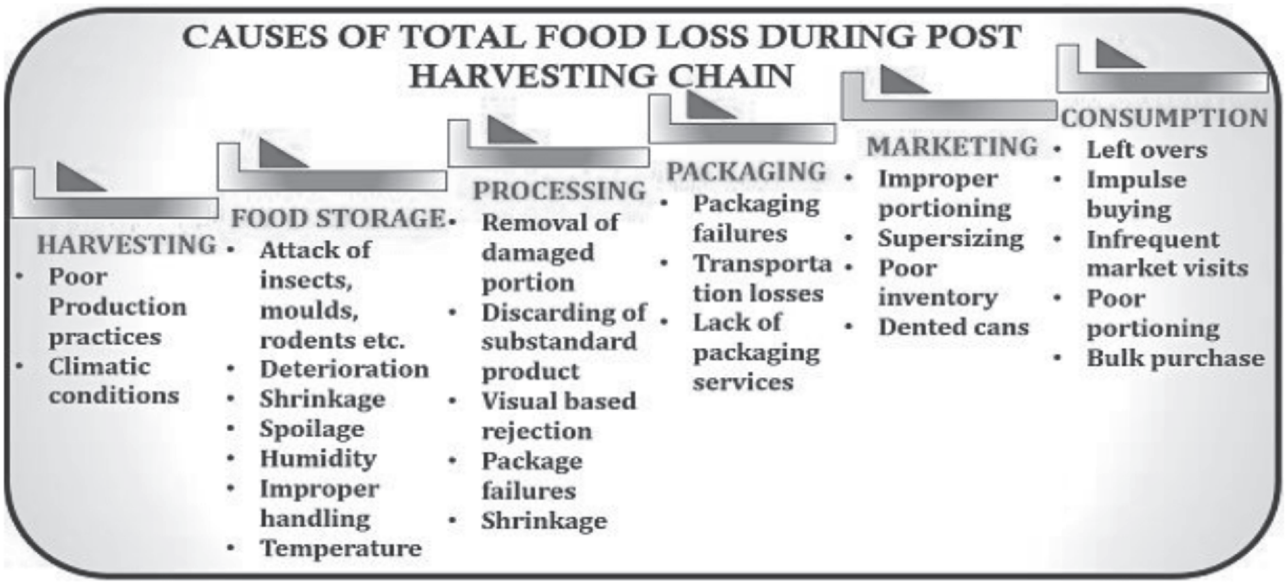

Fig 2: Post Harvest losses

Primary Causes

1. **Biological and microbiological:** Insects, pests, animals, and microorganisms (fungi and bacteria) are consumed or damaged.
2. **Chemical and biochemical:** Undesirable reactions between chemical compounds present in the food, such as browning, rancidity, enzymatic changes, etc.
3. **Mechanical:** Spillages, damages caused by abrasion, bruising, crushing, puncturing, etc.
4. **Physical:** Improper environmental and storage conditions (temperature, relative humidity, air speed, etc.)
5. **Physiological:** Sprouting, senescence, other respiratory and transpiratory changes.
6. **Psychological:** Human aversion or refusal due to personal or religious reasons.

Many of these factors have synergistic effects, and the losses can be caused of Postharvest Losses more significant with a combination of factors. For example, a stored product's chemical, microbial, biochemical, or physiological activity is significantly influenced by the storage conditions, especially temperature. A temperature change can result in a two- to three-fold change in these activities. This is a crucial factor utilized in cold and controlled atmosphere storage applications where the product is held at the lowest possible temperature without getting into chilling injury or freezer burn. On the other hand, if proper precautions are not taken in handling and transportation, increased product temperatures may result in a very rapid quality loss.

Secondary Causes of Losses

Secondary causes usually result from inadequate or nonexistent input and may lead to conditions favourable for primary causes. This includes improper harvesting and handling, inadequate storage facilities, inadequate transportation, inadequate refrigeration and/or inadequate marketing system. The various causes of postharvest spoilage can also be grouped based on biological and environmental factors (Kader, 1985).Loss of quality is the second cause of post harvest loss. This can be due to physiological and compositional changes that alter the appearance, taste, and texture and make produce less aesthetically desirable to end users. Economic loss is incurred because such produce will fetch a lower price.In many markets, there is no demand for second class produce, even at a reduced price, which leads to total economic loss even though the goods may still be edible.

The biological factors include:

1. **Respiration**: Respiration is a process by which all living cells break down organic matter into simple end-products by releasing energy and CO_2. The result is loss of organic matter, loss of food value and addition of heat load, which must be considered in refrigeration considerations. The higher the respiration rate of production, the shorter its shelf-life.
2. **Ethylene production**: Ethylene has a profound effect on physiological activities. Used in ripening chambers, it can trigger physiological activity even in trace amounts. Most living commodities produce ethylene as a natural product of respiration.
3. **Compositional changes**: Many changes occur during storage, some desirable and some undesirable. For example, loss of green color9 is desirable in fruits but not in vegetables. The development of carotenoid pigments may have nutritional importance. There will be changes in carbohydrates, proteins, and all other food components.
4. **Growth and development**: In most produce, there is continued growth and development even after harvest. Characteristic activities are sprouting of potatoes, onions and garlic, elongation of asparagus, and seed germination in fruits like tomatoes, lemons, etc.
5. **Transpiration**: Transportation refers to water loss resulting in shrivelling and wilting due to dehydration and is undesirable due to loss of appearance, salable weight, texture and quality.
6. **Physiological breakdown**: This includes freezing injury or frost damage in commodities subjected to temperatures below their freezing point which can occur in the field or during transportation/ storage. Chilling injury is mainly associated with tropical and subtropical commodities held for prolonged periods at temperatures between 5°C and 15°C. Heat injury can result in commodities being exposed to direct sunlight or excessively high heat for prolonged intervals (Kumari et al. 2018).
7. **Other factors**: These include physical/mechanical damage to the product occurring during harvesting, handling, storage and transportation, as well as spoilage due to pathological causes (attack by microorganisms such as bacteria and fungi). The environmental factors include temperature, relative humidity, atmospheric composition, light and other factors (fungicides, growth regulators, etc). It is generally recognized that higher temperatures will result in increased respiratory activity and lower shelf-life. Very high relative humidity conditions may lead to mould growth on produce surfaces, while lower relative humidity can result in desiccation. Lowering oxygen and increasing carbon dioxide levels in storage atmospheres have been successfully used to promote micro respiration in produce and thus extend the shelf-life.

Postharvest Shelf Life

Postharvest technologies have allowed agriculture industries to meet the global demands and large-scale production and intercontinental distribution of fresh produce with high nutritional and sensory quality.Once harvested, products are subject to the active process of senescence. Various biochemical and enzymatic reactions continuously change the produce's original composition until it becomes unmarketable. The period during which consumption is considered acceptable is known as the "post harvest shelf life" time. Postharvest shelf life is typically determined by objective methods like overall appearance, colour, taste, flavor, texture, etc.

These methods usually include a combination of sensory, biochemical, mechanical, and colorimetric (optical) measurements. Optimal postharvest treatments for fresh produce seek to slow down physiological processes of senescence and maturation, reduce/inhibit the development of physiological disorders and minimize the risk of microbial growth and contamination. In addition to basic postharvest technologies of temperature management, an array of others have been developed including various physical (heat, irradiation and edible coatings), chemical (antimicrobials, antioxidants and anti-browning) and gaseous treatments (Kumari et al. 2018).

Processing and Preservation

Food preservation has a vital role in the conservation and better utilization of fruits toavoid the glut and utilize the surplus during theoff-season. Many processing and preservation techniques such as blanching, drying, dehydration and freezing etc are being produced at both household and commerciallevels with different popular fruits cultivated worldwide(Meinhold and Darr, 2019). It is necessary toemploy modern methods to extend storage life for better distribution and also processing techniques to preserve them forutilizationin the off season in large and small scale.

Despite the large production, India has not been able to harness the power of food processing and preservation entirely by using various processing and preservation methods. Agriculture, agroforestry and horticulture products can be enhanced in terms of nutrient value and quality. Food fortification, enrichment, preservation, etc. are some techniques that should be adopted to promote the idea of value addition of food products in the food processing industries. Since, in today's jet age lifestyle, we not only need food products which are sustainably produced but those with a high nutrient value, focusing on value addition of food products is the need of the hour.

Processing and their Importance

When the world demands more advancements and arduous procedures to generate nutrient-rich and highly economical food products, India has taken a back seat in this sphere. We do not lack in terms of production but in terms of food processing.

Food processing and marketing are important for the following reasons:

a) It enables adequate substitution of imported food products.

b) It adds value and increases farmers' returns on their produce

c) It expands market opportunities

d) It improves shelf life to overcome seasonality and perishability

e) Postharvest processing, handling and marketing increase food availability at household and community levels and thus contribute to food security.

The food processing sector is constrained by:

Inadequate processing methods,

Lack of access to equipment and packaging,

Weak linkages with producers and poor marketing skills.

The sector remains largely unexploited, allowing imported foods to dominate internal markets.

Value Addition

Value addition is the process of improving the value of the product through processing, packaging and marketing (Meinhold and Darr, 2019). In other words, it changes or transforms a product from its original state to produce high-quality end product. Value addition has an important role in processing raw materials, avoiding waste, providing employment opportunities and thereby increasing people's economic condition. Value addition to food products has assumed two vital importance in our country due to diversity in socio-economic conditions, industrial growth, urbanization and globalization (Srivastava et al. 2017).It is not merely to satisfy producers and processors by way of higher monetary return but also with better taste and nutrition. Value is added by changing their form, colour and other methods to increase perishables' shelf life. Though with the effort of the Ministry of Food Processing Industry, the growth of this sector is accelerated. However; there is a need to discuss and sort out various related issues amongst people of various categories to increase the level of value addition and improve the quality of value-added food products for the domestic market as well as an export (Jena, 2013).

Value Added Products

Value added is frequently mentioned when discussing the future profitability of agriculture, agro forestry and horticulture(Pethiya and Surayya 2005). It can also be described as transforming the raw agricultural product into something new through packaging, processing, cooling, drying, extracting, and other processes that change a product from its original raw form (Srivastva and Kumar, 2006). In general, adding value is changing or transforming a product from its original state to a more valuable state. Many raw commodities have intrinsic value in their original state. Value addition has an important role in processing raw materials, avoiding waste, providing employment opportunities and thereby increasing people's economic condition.For example - Value added products from chill are chilli powder, chilli paste, chilli pickle and chilli sauces etc. Some another examples are given below in table 2.

Table 2: Value added product (Existing and New) from some fruits and vegetable

Fruit/vegetable	Existing products	New products
Mango	Pulp, RTS, squash, powder (amchur), slices in brine, pickle	Pulp/juice from in situ mangoes, pectin from just-ripe fruits
Apple	Juice, AJC, jam, jelly, cider, wine, pulp	Osmotically dried rings, canned apple, vinegar, carbonated juice, apple seed for nurseries, pectin, fi bre from pomace
Grapes	Raisin, juice	Carbonated juice/RTS
Litchi	Juice, squash, nectar/RTS	Carbonated drink
Tomato	Juice, sauce, ketchup, paste	Drying, powder
Cauliflower	Pickle, slices in brine	Frozen cauliflower heads, left over for drying powder
Carrot	Pickle, slices in brine, candy	Freezing and drying
Apricot	Pulp, squash, RTS, jam, appetizer, dried apricot	Osmotically dried apricot, oil, apricot oil-based cream, etc.
Peach	Canned peach, pulp, jam/chutney	Wine, kernel oil
Plum	Pulp, squash/appetizer, RTS, chutney, jam, wine/brandy	Plum sauce, seed oil

It can also be described as transforming the raw agricultural product into something new through packaging, processing, cooling, drying, extracting, and other processes that change a product from its original raw form.

Market forces have led to more significant opportunities for product differentiation and added value to raw commodities because of

(1) Increased consumer demands regarding health, nutrition, and convenience;

(2) Efforts by food processors to improve their productivity; and

(3) Technological advances enable producers to produce what consumers and processors desire.

(4) There are many opportunities in rural sectors under which they can add nutritional value, enhance their livelihood and improve their standard of living.

The processing and value addition through packaging products will enhance income and shelf life.

Post Harvest technology/postharvest management

Post Harvest technology / postharvest management can be defined as the branch of agriculture that deals with all operations right from harvesting or pre-harvesting stages till the product reaches the consumer, either in fresh (grains, apple, mango, tomato fruits, amla, imlie, mahua) or processed form (flour, juice, nectar, ketchup, candy) and waste utilization (pomace, peel, seed, skin, wood etc.) in a profitablemanner (Dhurve et al. 2018).

Postharvest technologies constitute an interdisciplinary science and techniques applied to agricultural commodities after harvest for conservation, quality control, processing, preservation, packaging, storage, transportation, marketing, and utilization to meet consumers' food and nutritional requirements according to their needs. This is a desirable alternative for many reasons. From this period, all action enters the preparation process for final consumption. Eg - pre-cooling - waxing - cleaning/washing - chemical treatments - trimming/sorting - packaging - curing, - transportation - grading - storage, ripening and distribution (Kumari et al. 2018). Extending a commodity's shelf life requires knowledge of all the factors that can lead to the quality deterioration or the generation of useful material.

Need for Post harvest technology

Fruits, Vegetables and ornamentals are ideally harvested based on optimum eating or visual quality. However, since they are living biological entities, they will deteriorate after harvest and reduce the quality of products. The rate of deterioration depends on their overall metabolism rate, but for many, it can be rapid. For example, in marketing chains where produce is transported from farm to end user within a short period, the rate of postharvest deterioration is of little consequence. However, with the increasing remoteness of production areas from population centers, the time lag from farm to market is considerable. The deliberate storage of certain products to capture better returns adds to this time delay between farm and end user, by extending the marketing periods into times of shorter supply. Thus a modern marketing chain puts increasing demands on produce and creates the need for the postharvest techniques that allow maintaining the quality over an increasingly longer period (Kumara et al. 2018).

Advantages of Post Harvest Technologies

There are several advantages to this approach:

1. **Economic advantages:** Careless harvesting and rough handling of perishable bruises and scar the skin, thus reducing quality and market price. Such damaged produce also fails to attract international buyers, bringing the exporting country less profit and a bad name. This ultimately results in substantial economic losses to the country. Wastage of food represents an economic loss. The economic loss increases as the food move down the food pipeline because the cost of food that is lost must be added to the costs of handling, transportation, storage, etc. Due to post-harvesting technologies minimizing this loss and the shelf life of product increases, the nation's economic condition also increases.
2. **Nutritional advantage:** Fruits and vegetables are rich sources of vitamins and minerals essential for human nutrition. These are wasted in transit from harvest to consumer representing a loss in the quantity of valuable food. This is important not only in quantitative terms, but also from the point of view of quality nutrition. Since less food is lost through post-harvesting technology and processing operation, there will be much more nutritious and wholesome food.
3. **Cost-effective:** The food supply is significantly increased without bringing another acre of land into production and without using greater energy, water and capital.
4. **Environmentally friendly:** It will reduce pollution and garbage disposal problems.

5. **Feedback incentive:** In some countries, the farmers could increase their production but cannot store food for extended periods. So there is no economic incentive to increase production because they know the increased output ends up as other waste. A reduction in postharvest losses would incentivize them to increase agricultural production.
6. **Consumer satisfaction**: Consumers will be more fully satisfied and receive more wholesome food.

Although it is simple to suggest minimizing losses during various postharvest operations, achieving the goal is quite challenging. In order to do so, one must first understand the various causes of postharvest spoilage of fruits and vegetables and the factors that influence them, and secondly, use the postharvest conditions/operations that will extend the shelf-life of the produce.

Importance of Post-Harvest Technology

1. Postharvest Technology losses reduction
2. Value addition
3. Contribution to the economy
4. Making availability of fruits and vegetables during off seasons
5. Tools for export earnings
6. Employment generation
7. Adding variety in taste and nutrition
8. Waste utilization
9. Home scale preservation
10. Supply of food to the defense forces
11. Special canned fruits for infants &childrens
12. Food supplier to the Astronauts

Role of Post Harvest Technologist

1. To provide nutritious, quality and safe food.
2. To develop new product & technologies - Discoveries - The best example for the highest post harvest life in the nature is the Swiss Apple - UttwilerSpatlauber, is well known for its excellent storability; it can stay fresh up to four months after harvested. However, it has not been widely cultivated because of its sour taste. Innovation –biotechnology has been used to extend the storage life in tomato and developed variety called FLAVR SAVR, using technology to reduce the activity of the enzyme endopolygalcturonase, which involved in the cell wall breakdown during ripening and fruit will remain firmer during ripening on and off the plant.
3. To develop new equipment, machines and determine their efficiency.

Eco-Friendly Option and employment generation

Minor fruit plants provide huge opportunity for livelihood improvement and community development. These fruits have a great economic potential and play a significant role in rural areas by providing nutrient supplementary diet and generating side income to the poor people. Hundreds of millions of people, mostly in developing countries, derive a substantial part of their subsistence and income from these wild plant products. Minor fruits provide staple food for indigenous people, serve as complementary food for non-indigenous people and offer an alternative source of cash income (Meinhold and Darr, 2018). It is felt that the abundance of such fruit plants in the wild habitat can be commercially cultivated with ease. In such cases, nutritionally rich fruit products in the form of jam, jelly, juice, pickle can be manufactured to generate income for poor rural people and reduce their economic and livelihood burden. For such sustainable processes, reasonable conservation practices and policies must also be formulated. The challenge of feeding the world's population has always been a critical issue for human societies. The development of agriculture, horticultural and agroforestry produce has greatly expanded food production and allowed rapid growth of human populations (Tewari et al. 2018). The long success of agriculture has confined much of the human population – now in large "metro cities" – from food production in rural areas, with an ever-shrinking proportion of the population involved in food production. India has always been pinned as one of the greatest agriculture-based countries of the world, and some section of its economy is generated through agroforestry and horticulture produce and manufacture. India is among the topmost vegetable and fruit producers in the world. India's food processing sector covers fruit and vegetables. After harvest, fruits and vegetables are liable to accelerate physiological, chemical, and microbial processes that invariably lead to deterioration and loss of wholesomeness. It is then necessary to institute some processing measures, such as reduction in moisture content, denaturation of endogenous enzymes and microorganisms, or packaging to curtail perishability. In the absence of such processing, massive postharvest losses can ensue. It is the responsibility of the food scientist or technologist to understand the processes contributing to food deterioration and spoilage and to device appropriate measures and methods of preservation to ensure food availability, acceptability and safety.

REFERENCES

Cheema, J., Yadav, K., Sharma, N., Saini, I. and Aggarwal, A. 2017. Nutritional qualitycharacteristics of different wild and underutilized fruits of terai region, Uttarakhand (India). *International Journal of Fruit Science*, 17(1): 72–81.

Deshmukh, B.S. and Waghmode, A. 2011. Role of wild edible fruits as a food resource:

Traditional knowledge. *International Journal of Pharmacy and Life Sciences*, 2: 919–24.

Dhurwe, R.K., Prajapati, R.K. Singh, L., Chandel, P.K. 2018. Documentation of local postharvest methods and value addition of different NTFPs in Narayanpur forest area of Chhattisgarh. International Journal of Chemical Studies 6(3): 2635-2643.

FAO (2002). The State of Food Insecurity in the World 2001. Rome.

Jena S. Development of a preserved product from underutilized passion fruit and evaluation of consumer acceptance. Journal of Food Research and Technology. 2013; 1(1):11-19.

Kala, C. P. (2013). Harvesting and Supply Chain Analysis of Ethnobotanical Species in the Pachmarhi Biosphere Reserve of India. American Journal of Environmental Protection, 1(2): 20-27.

Kasture, J., SwamyS. L., Mishra, A. 2008. Ethonobotanical studies on wild edible plant resources in dry tropical forests of Barnowpara, Chhattisgarh *Journal of Agricultural Issues*.

Kumar, N., Kumar, S., Singh, B., Mishra, B.P., Singh, B. and Singh, V. 2015. Traditionalpractices of utilization and conservation of non-wood forest products by Adi tribes of Arunachal Pradesh. *Journal of Applied and Natural Sciences*, 7(1): 111-118.

Kumar, S., Prasad, R, Kumar, A. and Dhyan, S.K. 2019. Integration of fruit trees in agroforestryfor sustainability and profitability of farming systems in arid and semi-arid regions. *Indian J. of Agroforestry.* Vol. 21(1): 95-99.

Kumari, K., Sinha, R., Krishna, G., Kumar, S., Singh, S. and Srivastav, A. K., 2018. Sensory and Nutritional Evaluation of Value Added Products Prepared from Mahua Flower. *Int. J. Curr. Microbiol. App. Sci.* Issue-7: 10.

Mahapatra, A.K., Panda, P.C. 2012. Wild edible fruit diversity and its significance in thelivelihood of indigenous tribals: Evidence from eastern India. *Food Secur*. 4, 219–234.

Majumder, B. C. (2004). Minor fruit crops of India- tropical and sub-tropical. Daya Publishing House, New Delhi.

Meinhold, K., Darr, D. 2019. The processing of non-timber forest products through small and medium enterprises—a review of enabling and constraining factors. *Forests* 10, 1026; doi:10.3390/f10111026

Mishra, A.;Swamy, S.L.; Thakur, T.K.; Bhat, R.; Bijalwan, A.; Kumar, A. 2021. Use of Wild Edible Plants: Can They Meet the Dietary and Nutritional Needs of Indigenous Communities in Central India. *Foods 10,* 1453. https://doi.org/10.3390/foods10071453

Pethiya BP, Surayya T. 2005. Economies of NWFP value addition and microfinance impact onforest dwellers livelihood in Madhya Pradesh. Invention Forestry Review, 7(3):227-231.

Rijal, A.; Smith-Hall, C.; Helles, F. Non-timber forest product dependency in the Central Himalayan foot hills. Environ. Dev. Sustain. 2011, 13, 121–140.

Srivastava, A., Bishnoi,S.K.andSarkar,P.K.(2017).ValueAdditioninMinorFruitsofEasternIndia: An Opportunity to Generate Rural Employment. *Fruits for Livelihood : Production Technology and Management Practices* Published by Agrobios(India), Jodhpur,India.pp.395-417.

Srivastava, A.; Bishnoi, S. K. and Sarkar, P. K. (2017). Value Addition in Minor Fruitsof Eastern India: An Opportunity to Generate Rural Employment. In: Dutta, A. K. and Mondal, B. (Eds.), Fruits for Livelihood: Production Technology and Management Practices Published by Agrobios (India), Jodhpur, India. pp. 395-417.

Srivatsava, R. P. and Kumar, S. (2006). Fruits and vegetables Drying/dehydration andconcentration. Fruit and Vegetables Prservation, Principles and Practices. 3rd Ed. IBDC publishers, Lucknow, UP, India. pp. 127-158.

Tewari, R. K., Ram A., Dev I., Kumar N., Chand L., Singh R. and Kumar D. 2018. Minor fruit trees in agroforestry for addressing nutritional, medicinal, fodder and timber needs. *Indian J. of Agroforestry*. Vol. 20 (1): 91-97.

L-19

Impact of Socio-Economic Determinants on Farm Level Adaptations to Climate Change

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The study examines the socio-economic impact of farm-level adaptation strategies to climate change in South Gujarat region of India based on cross-section data collected from 2400 households. This study uses a multivariate probit econometric technique to analyze the determinants of farm-level adaptation strategies. The study has revealed that farm size, access to credit, possession of machinery and awareness of climate change are the decisive determinants of farm-level climate-change adaptation variables. The awareness generation on changes in climatic conditions among farmers would have a more significant impact on increasing adaptation to changes in climatic conditions. Policies aimed to strengthen the agricultural information system in the region to provide timely information to the farmers about the climatic conditions, climate change impacts and adoption of adaptation strategies such as change in sowing dates, use of improved seed varieties, adoption of modern technologies, etc.

Keywords: Climate change, adaptation, probit, socio-economic *etc*.

INTRODUCTION

The climate changes threaten both biodiversity and human life, with thousands of publications demonstrating the impacts across ecosystems and economic and social structures (Williams *et al*., 2008). Globally, an unprecedented increase in emissions of greenhouse gases has led to broader climate change impacts. The climatic changes directly affect precipitation and temperature patterns, which are vital natural inputs in agricultural production (Arimi, 2014). One of the major effects of climate change is the rise in atmospheric temperature, which leads to a water deficit (Chinvamo, 2010; Mitin, 2009). The climate is changing fast and the mitigation efforts to reduce the emission sources or enhance greenhouse gas sinks will take a long time. Adaptation strategies to climate change are critical and of concern in India, where the vulnerability of agriculture is high because the ability to adapt is low. Climate change is expected to affect food and water resources critical for livelihoods in India, where much of the population, especially the poor, rely on local supply systems sensitive to climatic variations. A disturbance in the existing ecosystem and water resources availability will have distressing implications for agriculture development and are expected to add to the challenges climatic changes already pose for poverty eradication (De Wit and Stankiewicz, 2006; Hassan,2010). The adaptations help the farmers achieve their food, income and livelihood security objectives in the face of changing climatic and socio-economic scenarios, including climate variability, extreme weather conditions such as droughts and floods and volatile short-term changes in the existing agri-markets (Kandlinkar and Risbey, 2000). The farmers can reduce the potential damage by adopting tactical responses to these changes. The analysis of adaptation strategies is therefore essential for finding ways to help farmers in India.

The adoption of practices and technologies for adaptation to climate change and variability is crucial forfarmers to cope with the changing climate scenario and reduce agricultural losses due to unreliable and erratic rainfall patterns(Ndamani and Watanabe,2015). According to IPCC (2007), the implementation of adaptation measures by the farmers would be critical in addressing the inevitable impacts of climate change and variability.

The success of adaptation strategies depends onthe farmers' adaptive capacity as it greatly influences the vulnerability of the farming community and regions to the effects of climate variability. According to Bryant *et al*. (2000), adopting adaptation strategies to mitigate the effects of climate variability on agriculture is determined by how farmers' perceptions of climate change and variability are translated into agricultural decisions. Several studies have reported different adaptation strategies in agriculture such as diversification of crops, use of hybrid varieties, use of drought-resistant crop varieties, changing the dates of planting, harvesting, irrigation, switching from crop cultivation to livestock rearing and soil conservation measures.

Agriculture is inherently sensitive to climatic conditions and is one of the most vulnerable sectors to the impacts of global climate change (Parry and Carter, 1989; Reilly, 1995). Adaptation is an imperative component of any policy response toclimate change in this sector (Mizina*et al.* 1999; Reilly and Schimmelpfennig, 1999). Several studies show that without adaptation, the climate change would be problematic for agricultural production, agricultural economies and the farming community; but with adaptation, the vulnerability can be managed to a great extent, and copious opportunities can be realized (Nordhaus, 1991; Easterling*et al.,* 1993; Rosenzwieg and Parry, 1994; Fankhauser, 1996; Smith, 1996; Mendelsohn, 1998; Wheaton and McIver, 1999). In Canadian agriculture, studies have identified the climate change risks and have noted the needs and opportunities for planned adaptations (Brklacich*et al.,* 1997; Maxwell *et al.,* 1997; Bryant *et al.,* 2000). Adaptation is often considered as a government policy response in the agriculture sector, it also involves decision-making by agri-business and producers at the farm level (Smit, 1994; Benioff*et al.,* 1996; Adger and Kelly, 1999). Adaptations in agriculture vary with respect to the climatic stimuli to which adjustments are made (i.e., various attributes of climate change, including variability andextreme events) and according to the divergent farm types and locations, and the economic, political and institutional situation in which the climatic stimuli are experienced and management decisions are made (Chiotti & Johnston, 1995; Tol*et al*., 1998; Smit *et al.,* 1999; Bryant *et al.,* 2000; Smit& Skinner,2002).

Climate change adaptation has the potential to contribute significantly to the reductionsin negative impacts from changes in climatic conditions. Hence, adaptation measuresare essential to help vulnerable communities better to face extreme weather conditionsand associated climatic variations. In our country, although some efforts have been made to examine the farmers' perceptionsof climate change and farmers' choice of adaptation strategies to mitigate the climate change effect, the farmers mostlyopt for strategies in combination with other measures to mitigate the climate change effect. Therefore, there isa need for a better understanding of farmers' perceptions oflong-term climatic changes, their adaptation measures and the factors influencing the simultaneouschoice of adaptation strategies. Knowledge about adaptation methods and factorsaffecting farmers' choice of adaptation strategies will help design policies totackle the challenges that climate change may impose on the farmers (Wondimagegn and Lema, 2016).

Timely and accurate climate forecasts can improve farm household well-being, while weak forecast information can actually bedetrimental to poor farmers (Agarwal, 2008b; Agarwal andPerrin, 2008). The ability to respond to the climate forecastsand the benefits obtained from their use is determinedby the policy and institutional environment as well asthe socio-economic position of the farmers' household(Ziervogel*et al.*, 2005; Vogel and O'Brien, 2006;Arimi,2014).

Increasing system resilience is directly related to enhancing of adaptive capacity of farmers (Verchot*et al*., 2007), and an effective adaptation policy must be built on a wide variety of economic, social, political and environmental information (Spittlehouse and Stewart, 2003).

Different models have been used to analyze the determinants of climate change adaptation strategies on crops (Deressa*et al*., 2009; Kurukulasuriya and Mendelsohn, 2008; Hassan and Nhemachena, 2008;Nhemachena and Hasan, 2008; Seo and Mendelsohn, 2008; Akinnagbe and Irohibe,2014; Arimi,2014; Onyekuru,2017).This study has used multinomial probit model to analyzethe determinants of climate change

((Hassan and Nhemachena, 2008; Deressa*et al.*, 2008;ACCCA, 2010; Sofoluwe*et al*., 2011; Nzeadibe*et al*., 2011; Aemro*et al*., 2012; Nhemachena *et al*.,2014 andWondimagegn and Lema,2016).

Adaptation to climate change is significant if the farmers wish to counter its potentiallyunfavourable impacts (Kabubo-Mariara and Karanja, 2007; Stern, 2007; Hassan andNhemachena, 2008; Reidsma*et al.*, 2009). The adaptive measures when implemented canprotect the livelihoods of poor farmers and their ensure food security by reducing the potentialnegative impacts and reinforcing the advantages associated with the climate change (Bradshaw*et al.*, 2004; IPCC, 2007; Reid *et al.*, 2007; Bryan *et al.*, 2009).

Thenumber of studies on farm level adaptation strategies and theirdeterminants is growing (Seo and Mendelsohn, 2008; Bryan *et al.*, 2009; Reidsma*et al.*, 2010).However, adaptations in agriculture vary across countries. Moreover, the farmers practise different adaptationstrategies depending on the climatic conditions, farm types andother political, economic and institutional factors (Deressa*et al.*, 2009;Reidsma*et al.*, 2010; Hisali*et al.*, 2011). More precisely, adaptation choices are context-specificand change from area to area and over time (Smit and Wandel, 2006). Therefore,country-specific or area-specific studies of climate change adaptation are very much required.

A better understanding of current farmer climate change adaptation measures and their determinants is the key to policy planning for future successful adaptations in the agricultural sector. This study highlights the farmers'current adaptation options and their determinants. The study suggests that a deeper knowledge about the local adaptation measures that the farmers are using would provide better ways of building support to farmers' local adaptation measures to enhance the use and adoption of adaptation measures in the agricultural sector. Consent to the coping strategies of local farmers has the potential to facilitate widespread use and adoption of adaptation measures and provide beneficial impacts in reducing the predicted adverse effects of changes in climatic conditions on agricultural production. Support for the local coping strategies requires a better understanding of the local practices, which will be an important helpin designing focused policies aimed at enhancing adaptation strategies to climate change in agriculture

The present study adds to the existing literature by analyzing the determinants of farmers' choicebetween alternative adaptation measuresin the study area. Our analysis isdifferent from other adaptation studies in that we consider farmers' actual adaptation measuresbeing adopted by them. This can be compared with Maddison's analysis (2006) of farmers'perceptions of climate change and the adaptations they perceive as appropriate, using the sample of South Gujarat farmers. We also consider the choice across many adaptation measuressimultaneously. This can be compared with the studies that analyze such joint endogenous decisionsin separate analyses for crop selection (Kurukulasuriyaand Mendelsohn, 2006b), irrigationmodelling (Kurukulasuriyaand Mendelsohn, 2006c), and livestock choice (Seoand Mendelsohn,2006b). The present study has employed the multinomial probitapproach to conduct theintended analyses.

Material and methods

Analytical framework: The approaches commonly followed in an adoption-decision study involvingmultiple choices are the multinomial logit (MNL) and multinomial probit (MNP) models. BothMNL and MNP models are important for analyzing farmers' adaptation decisions as these are usuallytaken jointly. These approaches are also appropriate for evaluating alternative combinations ofadaptation strategies, including individual strategies (Hausman and Wise, 1978; Wu and Babcock,1998 and Hassan, 2008).

The multinomial probit model (MNP) specification for discrete choice models doesnot require the assumption of the independence of irrelevant alternatives (IIA) property (Hausman and Wise, 1978), and a test for this assumptioncan be provided by a test of the 'covariance' probit specification versus the 'independent' probitspecification, which is very similar to the logit specification. The main drawback of using theMNP model is the requirement that multivariate normal integrals must be evaluated to estimate theunknown parameters. This complexity makes the MNP model an inconvenient specification testfor the MNL model (Hausmanand McFadden, 1984).

Nhemachena et al. (2014) use a multivariate probit econometric technique to analyze thedeterminants of adaptation measures (relationships betweenidentified adaptation measures and the explanatory variables). Themultivariate probit model simultaneously models the influence of theset of explanatory variables on each adaptationmeasure while allowing the unobserved and unmeasured factors(error-terms) to be freely correlated (Lin *et al*., 2005; Green, 2003;Golob & Regan, 2002). Complementarities (positive correlation)and substitutabilities (negative correlation) between different optionsmay be the source of the correlations between error terms(Belderbos*et al*., 2004).

The farmers might consider some combinations of adaptation measurescomplementary and others competing. The univariate technique ignores the potentialcorrelations among the unobserved disturbances in adaptationmeasures by neglecting the common factors. This may significantly lead to statistical bias andinefficiency in the estimates (Lin *et al*., 2005; Belderbos*et al*., 2004;Golob and Regan, 2002).

According to Nhemachena*et al*. (2014), a multinomial discrete choice model is another alternative for acomplicated multivariate model with seven endogenous discretechoice variables. In the multinomial discrete choice model, the choice set is made up of all combinations of adaptation measures. The usefulness of an MNL is limited by the property ofindependence of irrelevant alternatives. Under such situations, estimation of multinomial probit (MNP) and "mixed" or 'random'coefficientsMNL are more appropriate and simulation methods, bothBayesian and non-Bayesian, can be used to the estimate parameters oflarge MNP and mixed logit models (Golob and Regan, 2002). However, theshortfall of this technique is that all the multinomial replications of amultivariate choice system have problems in interpreting theinfluence of explanatory variables on the original separateadaptation measures.

This study uses a multivariate probit econometric technique toovercome the shortcomings of the univariate and multinomialdiscrete choice techniques. Following Lin *et al*. (2005), themultivariate probit econometric approach used for this study ischaracterized by a set of *n* binary dependent variables y_i(withobservation subscripts suppressed), such that:

$$Y_i = 1 \text{ if } x\,\beta_i + \varepsilon_i > 0\ ,$$

$$= 0 \text{ if } x'\beta_i + \varepsilon_I \leq 0\ ,\ i = 1,2,\ldots,n, \qquad \ldots(1)$$

Where,x is a vector of explanatory variables,β_1, β_2,…, $\beta_n$are the conformable parameter vectors, andε_1, ε_2, …, $\varepsilon_n$are random error-terms distributed as multivariate normal distribution with zero means, unitary variance and an $n \times n$ contemporaneous correlation matrix$R = [\rho_{ij}]$, with density $\phi(\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n; R)$.

The likelihood contribution for an observation is the *n*-variate standard normal probability:

$$\Pr(y_1 \ldots\ldots y_n | x = \int_{-\infty}^{(2y_i-1)x'\beta 1} \int_{-\infty}^{(2y_2-1)x'\beta 2} \ldots\ldots \times \int_{.}^{(2y_n-1)x'\beta_n} \phi(\varepsilon_1, \varepsilon_2 \ldots \epsilon_n; Z'RZ)\, d\epsilon_{n\ldots\ldots}\, d\epsilon_2\, d\epsilon_1 \ldots \quad (2)$$

Where, Z= diag[$2y_1$-1,-------, $2y_{n-1}$].

The maximum likelihood estimation maximizes the sample likelihood function, a product of probabilities (Eq. 2) across sample observations. The computation of maximum likelihood function using multivariate normal distribution requires multi-dimensional integration. Several simulation methods have been put forward to approximate such a function, with GHK simulator (Geweke, 1996; Hajvassilion *et al.*, 1996) widely used (Belderbos *et al*., 2004).The marginal effects of explanatory variables on the propensity to adopt each of the different adaptation measures are calculated as:

$$\partial P_i / \partial x_i = \phi(x'\beta)\ \beta_i, \quad i = 1,2,\ldots, n \qquad \ldots(3)$$

Where, P_i is the probability (or likelihood) of event$i$ (that is increased use of each adaptation measure),ϕ (·) is the standard univariate normal cumulative density distribution function, and $x$andβ are the vectors of regressors and model parameters respectively (Hassan, 1996).

The econometric analysis with cross-sectional data is usuallyassociated with the problems of heteroscedasticity and multicollinearityand the effect of outliers in the variables. Multicollinearity amongexplanatory variables can lead to imprecise parameter estimates. We have calculated the Variance Inflation Factor (VIF) for each explanatory variable to explore the potential multicollinearity among theexplanatory variables. The VIFs have been found to range from 1.07 to 1.53, whichdoes not reach the convectional thresholds of 10 or higher,as used inregression diagnosis (Lin *et al*., 2005). In the analysis,multicollinearity does not appear to be a problem. To address thepossibilities of heteroscedasticity in the model, we have estimated arobust model that computes a robust variance estimator based on avariable list of equation-level scores and a covariance matrix.

Description of Data: A cross-section of a household survey of farmers of South Gujarat was conducted in the years 2016-17 to 2018-19. The surveycovered all seven districts of the South Gujarat region. During the survey, two thousand four hundred sixty households were interviewed.This studyhas used part of the large datasetfor the project that included farmers' perceptions on climate change,their adaptation strategies, and their perceived barriersto responding to the perceived climate changes.The temperature and precipitation data were compiled from IMD, Pune's office and the NAU research station, Navsari.

Dependent and Independent Variables: The dependent variables perceived for the model were eight dummyvariables: using change in varieties,mechanization, manipulation of agronomic practices, crop and farm diversification, drainage, irrigation, change in sowing dates, etc. Adoption of different planting dates (given the high perceptionsthat the timing of rains is changing); diversification from farming tonon–farming activities; increased use of drip irrigation, and increased useof water and soil conservation techniques were taken as equal to one if the householdused the adaptation option,and zero otherwise. Summary statisticsof the identified main adaptation measures are presented in Table 1.

The explanatory variables included in the model are based on the reviewof adoption literature studies and our view of theoretical work; however, this remains rather explorative given the lack of straightforward available theoretical predictions. The independent variablesin this study represent many factors that affect the use ofadaptation options at the farm level. Although there might be manyfactors affecting farmers' use of adaptation options, this studyhas identified seventeen independent variables listed in Table 2 to bethe most appropriate in explaining the use of different adaptation options byfarming households. In the empirical model, each explanatory variable has been included in all eight equations to help test if the impactof variables differs from one adaptation option to the other.Descriptive statistics of the explanatory variables and theexpected impact of adaptation options are presen ted in Table 2.The household socio-economic characteristics like farmingexperience, access to public agricultural extension services, credit, mixed cropand livestock farming systems, private property and noticing climatechange are expected to have a significant positive impact on the use ofadaptation measures at the farm level.

The results in Table 2 show that the average age of the household headwas 51 years. On access to public agricultural extension services, about 30% of the respondentshad contact with extension agents. Access to credit is a significant determinant in adopting adaptationstrategies; about 82% of the sampled households had access to credit. However, there were apparent differences in access to information; for instance, about 55% of the farmers whoadopted at least one strategy had access to climate-related information.

Results and Discussion

The study has estimated a multivariate probit model, and forcomparison, a univariateprobit model was also used for each of theeight adaptation options. The results from the multivariateprobit model of determinantsof adaptation measures arepresented in Table 3. The results of correlationcoefficients of the error terms are significant (based on t-teststatistics) for any pair of equations, indicating that theyare correlated. The results on correlation coefficients ofthe error terms suggest that there arecomple mentarities(positive correlation) between different adaptation optionsbeing used by the farmers. The results support the assumption of interdependence between differentadaptation options, which may be due to complementaritiesin different adaptation options and also from omittedhousehold-specific and other factors that affect the uptake ofall the adaptation options. Another important point that emerged from the results is that substantial differences inthe estimated coefficients across equations supportthe appropriateness of differentiating between adaptationoptions.

The univariateprobit models can be viewed as arestrictive version of the multivariate probit model with alloff-diagonal error correlations set to zeros (that is,$P_{ij}=0$ for$i>j$) (Lin *et al*., 2005; Belderbos*et al*.,2004). A likelihood ratio test based on the log-likelihoodvalues of the multivariate and univariate models indicates significant joint correlations,x^2 (17) =35.087 ; probability >x^2= 0.0000 justifying the estimation of the multivariate probit thatconsiders different adaptation options as opposed toseparate univariateprobit models and consequently, theunsuitability of aggregating them into one adaptation or adaptation variable, as was the case reported by Maddison (2007).

The socio-economic characteristics of farmers' variables that are statistically significant included the age of household-head which exhibited a negative relationship in influencing the decision on adoption of farm diversification and modern methods of irrigation. At the same time, the changes in variety, mechanization, and manipulation of agronomic practices were positive but not significant. The shift in sowing dates was found to be positive and significant, showing that the age of household-head influences the sowing date. The negative relationship suggests that the younger farmers have longer planning horizons and are more likely to adopt compared to their older counterparts, possibly for being innovative and keen to try new farming methods and technologies to improve agriculture productivity. The elderly farmers were not likely to be aware of recent innovations in agriculture and/or were reluctant to try new methods. The result aligns with the studies of Gould *et al.*(1989); LaparandPandey(1999); Burton *et al*. (1999); Denkyirah*et al*. (2017); Ali and Erenstein(2016); Ojo and *Baiyegunhi (2018)*who found a negative effect of farmers' age on the adoption of different variables. The coefficient of household size was negative and significantly influenced the farm diversification and drainage system. A positive association between household size and climate change adaptation strategies has also been found in the change of variety,manipulation of agronomic practices and crop diversification. The larger family size is expected to enable farmers to take up labour-intensive adaptation measures. Alternatively, a large family might be forced to divert part of its labour force to non-farm activities to generate more income. These results are corroborated by several studies (Croppenstedt*et al*., 2003; Dolisca*et al*., 2006; Nyangena, 2007; Anley *et al.,* 2007; Birungi, 2007;Deressa*et al*., 2009; Abid *et al*., 2015; Ali and Erenstein, 2016). Education hada significant and negative relationship in influencing the decision to adopt farm and crop diversification. In contrast, a positive but non-significant relationship was found between drainage and change in sowing dates. Okoye (1998) and Gould *et al*. (1989) found that education negatively correlated with adaptive decisions.

Except for farm diversification, household-head sex has shown a positive and significant relationship in influencing the decision to adopt the majority of climate change adaptation variables. Large farm land holdings are likely to have more capacity to try out and invest in the climate risk adaptation strategies through the use of change in variety, mechanization, manipulation of agronomic practices and crop diversification. At the same time, a negative and significant relationship is found in farm diversification and irrigation means holding size is directly related with farm diversification. The farmers' experience increases the probability of uptake ofall adaptation options. The highly experienced farmers are likely to have more information and knowledge onthe changes in climatic conditions and crop and livestock management practices. The coefficient of years of experience in farming is positive and statistically significant in influencing the choice of mechanization and change in the sowing-date adaptation strategy. This implies that the years of farming experience significantly increase the probability of choosing mechanization and change in the sowing-date adaptation strategy. Family labour typically plays a vital role in climate change adaptation. The coefficient for family labour is positive and statistically significant in influencing the choice of adaptation strategies through the use of all climate-change adaptation strategies.

The study has revealed that access to credit is a significant determinant of climate-change adaptation decisions. With resource limitations, the farmers may fail to meet the costs of adaptation and, at times, cannot benefit from available information. Several studies (Kandlinkarand Risbey, 2000; Gyinadu*et al*., 2015; Mmbando and Baiyegunhi, 2016; Ojo and Baiyegunhi,2018) have also opined that inadequate funds or lack of funds could impede the adoption of farm management practices in the developing economies. The coefficient of access to credit is positive and statistically significant for the choice of variety change, mechanization, farm diversification and change in sowing-dates adaptation strategies. The adaptation strategies could be expensive, with some requiring the purchase of new, improved seeds, while others could be capital intensive. Thus, in the absence of credit, the farmers may find it difficult to adopt any adaptation strategy even if they are provided with information on climate change, as they might not be able to purchase the requisite inputs.The coefficient of access to public agricultural extension services is positive and statistically non-significant in influencing the choice of change in variety, agronomic practices, crop diversification and drainage adaptation strategies.

The annual income of farmers has a positive and significant relationship with the adaptation variables such as the change in variety, farm and crop diversification, and irrigation system.

The awareness of temperature and rainfall patterns and other weather information has potential benefits of taking action against climate risk and deciding on adopting agricultural technologies. The temperature pattern is significantly and negatively related to the change in variety, manipulation of agronomic practices, drainage system, irrigation and the date of sowing adaptive strategies. The rise in mean annual temperature increases the probability of farmers responding to changes in management practices. The increasing atmospheric warming is associated with decreased water resources (surface and ground), and high evapotranspiration rates. This increases water scarcity and its shortages for food production and other uses. In response to rising temperatures, the farmers tend to change their crop and livestock management practices to suit the changing temperature regimes.The change in timings of rains has a positive but non-significant effect on climate change adaptation strategies. Getting sentient on climate change increases the probability ofuptake of adaptation measures. The farmers who are awareof changes in climatic conditions have higher chances oftaking adaptive measures in response to the observeddifferences. It is an importantprecondition forfarmers to take responsive measures inadapting to changes in climatic conditions (Madison,2007). The coefficient of noticed climate change is positive and statistically significant in influencing the change in crop variety, mechanization, manipulation of agronomic practices, crop diversification, irrigation and change in sowing dates adaptation strategies. The ownership of a tractor has a positive and significant relationship with the change in crop variety, mechanization, manipulation of agronomic practices, crop diversification,and adaptive irrigation strategies of the farmers. The use of heavy machinery on the farm has a positive and significant influence on mechanization and crop diversification. The use of heavy machinery has a negative and significant influence on farm diversification and drainage adaptive climate change strategies. The farmers having animal power are positively and significantly influenced by the change in crop variety and farm diversification of climate change adaptive practices.

The awareness generation on changes in climatic conditions among farmers would have a greater impact on increasing adaptation to changes in climatic conditions. It is therefore important for the governments, meteorological departments and ministries of agriculture to generate awareness about the changes in climatic conditions through all possible/alternative communication pathways that have a reach to the farmers.

Conclusion

The study has estimated a multivariate probit model and for comparison, a univariate probit model for each of the eight adaptation options. The results have indicated that the majority of farmers are engaged in adaptive strategies to climate change. The model results confirm that out of eight adaptation strategies that the farmers are aware of, the 'use of improved varieties' was ranked first among the farm adaptive measures, while the 'change in drainage system' was ranked as least utilized. Socio-economic factors such as household-head age, education level of household-head, family size, farm size, family income, gender and farming experience of household-head were found to be significantly related to adaptation strategies.

The coefficient for access to credit, farmer's annual income and information on climate change have been found to be positive and statistically significant. The farmers who are conscious of changes in climatic conditions have higher chances of taking appropriate adaptive measures. The possession of heavy machinery has revealed a positive and significant influence on farm mechanization, land use patterns and crop diversification. Policies aimed at improving the critical factors that influence climate adaptation strategies.

REFERENCES

Abid, M., J.Scheffran, U.A.Schneider, and M.Ashfaq: Farmers' perceptions and adaptation strategies to climate change and their determinants: The case of Punjab province of Pakistan. *Earth System Dynamics*, 6(1): 225 (2015).

Adger, W.N., and P.M.Kelly : Social vulnerability to climate change and the architecture of entitlements. Miti. & Adapt. Strat. for Glob. Change 4(3/4), 253–266 (1999).

Aemro, T., K.Mengistu, and T.Beyene: Climate change adaptation strategies of smallholder farmers: the case of Bible District, East Hararghe Zone of Oromiya Regional State of Ethiopia.*Journal of Economics and Sustainable Development*, 3(14): 2222-1700: 2222-2855 (2012).

Agarwal, A. : The role of local institutions in adaptation to climate change. Paper prepared for a workshop on social dimensions of climate change organized by the Social Development Department, The World Bank, Washington, DC, March 5–6: 2008. 15. (2008b).

Agarwal, A. and N.Perrin: Climate adaptation, local institutions, and rural livelihoods. IFRI Working Paper, W081-6. International Forestry Resources and Institutions Program, University of Michigan (2008a).

Akinnagbe, O.M. and I. J.Irohibe: Agricultural adaptation strategies to climate change impacts in Africa: A Review. *Bangladesh J. Agril. Res*. 39(3), 407-418 (2014).

Ali, A., and O.Erenstein: Irrigation water saving through adoption of direct rice sowing technology in the Indo-Gangetic Plains: empirical evidence from Pakistan. *Water Practice and Technology*, 11(3): 610-620 (2016).

Anley, Y., A.Bogale and A.Haile-Gabriel: Adoption decision and use intensity of soil and water conservation measures by smallholders subsistence farmers in Dedo District, Western Ethiopia." *Land Degradation and Development* 18: 289-302. (2007).

Arimi, K.: Determinants of climate change adaptation strategies used among fish farmers in Epe Local Government Areas of Lagos state, Nigeria. *Journal of the Science of Food and Agriculture*, 94 (7): 1470–1476 (2014).

Belderbos, R., M.Carree, B.Diederen, B.Lokshin and R.Veugelers: Heterogeneity in R&D cooperation strategies. Int. J. Indust. Organ. 22:1237-1263. http://dx.doi.org/10.1016 / j.ijindorg.2004.08.001 (2004).

Benioff,Ron., G.Sandra and L.eds.Jeffrey: Vulnerability and Adaptation Assessment: An International Guidebook. Dordrecht, the Netherlands: Kluwer Academic Publishers (1996).

Birungi, P.B.: The linkages between land degradation, poverty and social capital in Uganda. PhD thesis, Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa (2007).

Bradshaw, B., H.Dolan and B.Smit: Farm-level adaptation to climatic variability and change: crop diversification in the Canadian prairies", *Climatic Change*. 67(1), 119-141 (2004).

Brklacich, M., C.Bryant, B.Veenhof and A.Beauchesne: Implications of global climatic change for Canadian agriculture: a review and appraisal of research from 1984-1997. In G. Koshida and W. Avis, eds. Canada Country Study: Climate Impacts and Adaptation. Toronto: Environment Canada (1997).

Bryan, E., T. T.Deressa, G. A. Gbetibouo and C.Ringler: Adaptation to climate change in Ethiopia and South Africa: options and constraints. Environmental Science & Policy, 12(4): 413-426 (2009).

Bryant, C.R., B.Smit, M.Brklacich, T.Johnston, J.Smithers, Q.Chiotti and B.Singh: Adaptation in Canadian agriculture to climatic variability and change.*Climate change*, 45: 181–201(2000).

Burton, M. D.Rigby and T.Young: Analysis of the determinants of adoption of organic horticultural techniques in the UK. *Journal of Agricultural Economics*, 50: 47–63 (1999).

Chiotti, Q. and T. Johnston: Extending the boundaries of climate change research: Modeling the farm-level decision-making complex,*The Journal of Rural Studies,* 11(3): 335-350 (1995).

Croppenstedt, A., M.Demeke and M.M.Meschi: Technology adoption in the presence of constraints: the case of fertilizer demand in Ethiopia. *Review of Development Economics*, 7(1): 58–70 (2003).

De Wit, M. and J.Stankiewicz: Changes in surface water supply across Africa with predicted climate change. Science, 311: 1917–21 (2006).

Denkyirah, E.K., E.D.Okoffo, D.T.Adu and O.A.Bosompem: What are the drivers of cocoa farmers' choice of climate change adaptation strategies in Ghana?.*Cogent Food & Agriculture*, 3(1):2-21.Retrieve from https://doi.org/10.1080/ 23311932. 2017.1334296 (2017).

Deressa, T. T., R. M.Hassan, C.Ringler, T.Alemu and M.Yesuf: Analyzing the determinants of farmers' choice of adaptation methods and perceptions of climate change in the Nile Basin of Ethiopia. (IFPRI Discussion Paper 00798) (2008).

Deressa, T. T., R. M.Hassan, C.Ringler, T.Alemu and M.Yesuf: Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia.*Global Environmental Change*, 19 (2): 248-255 (2009).

Dolisca, F., R.D.Carter, J.M.McDaniel, D.A.Shannon and C.M.Jolly: Factors influencing farmers' participation in forestry management programs: A case study from Haiti. *Forest Ecology and Management,* 236: 324-31 (2006).

Easterling, W.E. III., P.R.Crosson, N.J.Rosenberg, M.S.McKenny, L.A.Katz and K.A.Lemon: Agricultural impacts of and response to climate change in the Missouri-Iowa-Nebraska-Kansas (MINK) region. *Climate Research*, 24: 23-61 (1993).

Fankhauser, Samuel: The potential costs of climate change adaptation. In J.B. Smith, N. Bhatti, G. Menzhulin, R. Bennioff, M. Budyko, M. Campos, B. Jallow and F. Rijsberman, eds. Adapting to Climate Change: An International Perspective. New York, N.Y.: Springer (1996).

Geweke, J.: "Variable selection and model comparison in regression," in *Bayesian Statistics*, Vol. 5, eds. J. M. Bernardo, J. O. Berger, A. P. Dawid, and A. F. M. Smith, London: Oxford Press, pp. 609–620 (1996).

Golob,T.F., and A.C. Regan: Trucking industry adoption of information technology: A multivariate discrete choice model. Transportation Research Part C, 10(3):205-228. Retreive from https://www.researchgate.net/publication/222701744(2002).

Gould, B.W., W.E.Saupe and R.M.Klemme: Conservation tillage: The role of farm and operator characteristics and the perception of soil erosion. *Land Economics,* 65: 167–82 (1989).

Greene, W. H.: Econometric Analysis, Prentice Hall, Upper Saddle River, New Jersey (2003).

Gyinadu, A., J.Eudes, A.Bakang and C. K.Osei: Determinants of adoption of yam minisett technology in Ghana. A case study of yam farmers in the Kintampo North District of Ghana. *Journal of Agricultural Economics, Extension and Rural Development*, 3(7): 293-302(2015).

Hajivassiliou, V., D.McFadden and P.Ruud: Simulation of Multivariate normal rectangle probabilities; methods and problems. *J. Eco,* 72:85-134 (1996).

Hassan, R. and C.Nhemachena: Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. Retrieve from (2008).

Hassan, R.M.: Planting strategies of maize farmers in Kenya: a simultaneous equations analysis in the presence of discrete dependent variables. *Agric. Econ*, 15: 137-149 (1996).

Hassan, R.: Implications of climate change for agricultural sector performance in Africa: policy challenges and research agenda. *Journal of African Economies*, 19, Supplement 2: 77–105 (2010).

Hausman, J.and D.Wise: A conditional probit model for qualitative choice: Discretedecisions recognizing interdependence and heterogeneous preferences. *Econometrica,* 46: 403–26 (1978).

His, E., P.Birungi and F.Buyinza: Adaptation to climate change in Uganda: Evidence from micro-level data. *Global Environmental Change*, 21(4): 1245-1261 (2011).

Kabuto-Mariara, J. and K.Karanja: The economic impact of climate change on Kenyan crop agriculture: a Ricardian approach. World Bank Policy Res. Series Work. P. 4334 (2007).

Kandlinkar, M. and J.Risbey: Agricultural impacts of climate change: If adaptation is the answer, what is the question?.*Climatic Change*, 45: 529–39 (2000).

Kurukulasuriya, P. and R.Mendelsohn Endogenous irrigation: The impact of climate change on farmers in Africa. Centre for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No. 18, University of Pretoria, South Africa (2006b).

Kurukulasuriya, P. and R.Mendelsohn: Crop selection: adapting to climate change in Africa. CEEPA Discussion Paper No. 26. Centre for Environmental Economics and Policy in Africa. University of Pretoria (2006c).

Kurukulasuriya, P. and R.Mendelsohn: A Ricardian analysis of the impact of climate change on African cropland.*AfJARE,* 2: 1-23 (2008).

Lapar, A.L. and S.Pandey: Adoption of soil conservation: the case of the Philippine uplands. *Agric. Econ*., 21: 241–256. (1999).

Lin, C.T.J., K.L.Jensen and S.T.Yen: Awareness of Food-Borne Pathogens among US consumers. *Food Quality and Preference*, 16 (5): 401-412 (2005).

Maddison, D.: The perception of and adaptation to climate change in Africa. CEEPA. Discussion Paper No. 10. Centre for Environmental Economics and Policy in Africa. Pretoria, South Africa: University of Pretoria, South Africa (2006).

Maddison, D.: The perception of and adaptation to climate change in Africa. In: Policy Research Working Paper 4308. Washington DC: The World Bank. (2007).

Maddison, D, M.Manley and P.Kurukulasuriya: The impact of climate change on African agriculture, A Ricardian approach. Policy Research Working Paper 4306, The World Bank Development Research Group.Magadza, C. H. D. (1994). Climate change: Some likely multiple impacts in Southern Africa. *Food*

Policy, 19(2): 165-191 (2007).

Maxwell, B., N.Mayer and R.Street: The Canada Country Study: Climate Impacts and Adaptation, National Summary for Policy Makers, Environment Canada (1997).

Mendelsohn, R.: Climate-change damages.in W.D. Nordaus, (ed.), Economics and Policy Issues in Climate Change, Washington, D.C., Resources for the Future (1998).

Mitin, A.: Documentation of selected adaptation strategies to climate change in rice cultivation. East Asia Rice Working Group. 8 (2009).

Mizuna, S.V., J.B.Smith, E. Gossen, K.F. Spiecker and S.L.Witkowski: An Evaluation of Adaptation Options for Climate Change Impacts on Agriculture in Kazakhstan. Mitigation and Adaptation strategies for Global Change 4: 25-41 (1999).

Mmbando, F. E., and. J. S.BaiyegunhiL: Socio-economic and institutional factors influencing adoption of improved maize varieties in Hai District, Tanzania. *Journal of Human Ecology*, 53 (1): 49–56 (2016).

Nhemachena, C., R.Hassan and J.Chakwizira: Analysis of determinants of farm-level adaptation measures to climate change in Southern Africa. *Journal of Development and Agricultural Economics,* 6(5):232–241(2014).

Nhemachend.,C. and R.Hassan: Micro-level analysis of farmer's adaptation to Climate change in southern Africa. IFPRI Discussion Paper, No 00714. August 2007, pp 15-17 (2008).

Nordhaus, William D.: To Slow or Not to Slow: The economics of the greenhouse effect. *Economic Journal*, 101(444): 920–37 (1991).

Nyanga, W.: Social determinants of soil and water conservation in rural Kenya. Environment, Development and Sustainability, 10(6):745-767. Online (2007).

Nzeadibe, T.C., C.L.Egbule, N.Chukwuone and V.Agu: Farmers' perceptions of climate change Governance and adaptation constraints in Niger delta region of Nigeria.African technology Policy Network, Research Paper No. 7 (2011).

Ojo, T. and L.Baiyegunhi: "Determinants of Adaptation Strategies to Climate Change among Rice Farmers in Southwestern Nigeria: A Multivariate Probit Approach," 2018 Conference, July 28-August 2, 2018, Vancouver, British Columbia 277011, International Association of Agricultural Economists (2018).

Okoye, C. U.: Comparative analysis of factors in the adoption of traditional and recommended soil erosion control practices in Nigeria. *Soil & Tillage Research*, 45: 251– 63 (1998).

Parry, M.L. and T.R.Carter: An assessment of the effects of climatic change on agriculture.*Clim. Change,* 15: 95–116 (1989).

Reid, S., B.Smit, W.Caldwell and S.Belliveau: Vulnerability and Adaptation to Climate Risks in Ontario Agriculture. Mitigation and Adaptation Strategies for Global Change, 12: 609-637. Online https://doi.org/10.1007/s11027-006-9051-8 (2007).

Reidsma, P., F.Ewert, A. O. Lansink and R.Leemans: Vulnerability and adaptation of European farmers: a multi-level analysis of yield and income responses to climate variability.*Regional Environmental Change*,9(1):25-40 (2009).

Reilly, John: Climate change and global agriculture: Recent findings and issues. *American Journal of Agricultural Economics,* 77:727-733 (1995).

Reilly, J. and D.Schimmelpfennig: Agricultural impact assessment, vulnerability, and the scope for adaptation. *Climatic Change*, 43:745-88 (1999).

Rosenzweig C. and M.L.Parry: Potential impact of climate change on world food supply. *Nature,* 367:133–138 (1994).

Seo, S. N. and R.Mendelsohn: Climate change adaptation in Africa: A microeconomic analysis of livestock choice. CEEPA Discussion Paper No. 19. Centre for Environmental Economics and Policy in Africa, University of Pretoria (2006).

Seo, S. N. and R.Mendelsohn: Measuring impacts and adaptations to climate change: A structural Ricardian model of African livestock management. *Agricultural Economics*,38:151-165 (2008).

Smit, B.: Climate, compensation and adaptation, in J. McCulloch and D. Etkin (eds.), Proceedings of a Workshop on Improving Responses to Atmospheric Extremes: The role of insurance and compensation, Toronto, Environment Canada/The Climate Institute, pp. 2.29–2.37 (1994).

Smit, B. and M.W.Skinner: Adaptations options in agriculture to climate change: a typology. *Mitigation and Adaptation Strategies for Global Change*, 7: 85-114 (2002).

Smit, B. and J.Wandel Adaptation, adaptive capacity and vulnerability.*Global Environmental Change*, 16(3):282-292 (2006).

Smit, B., R.Ian Burton, J.T.Klein and R.Street: The science of adaptation: a framework for assessment. *Mitigation and Adaptation Strategies for Global Change,* 4:199-213 (1999).

Smith, Joel B.: Standardized Estimates of climate change damages for the United States. *Climatic Change*, 32(3): 313–26 (1996).

Sofoluwe, N. A., A. A.Tijani and O. I.Baruwa: Farmers' perception and adaptation to climate change in Osun State, Nigeria. *African Journal of Agricultural Research*, 6(20): 4789-4794. Retrieved online at http://www.academicjournals.org/AJAR (2011).

Spittlehouse D.L. and R.B.Stewart: Adaptation to climate change in forest management. BC *Journal of Ecosystems and Management*, 4 (1) Retrieved from (2003).

Stern, N.: The economics of climate change: the Stern review, Cambridge University Press, Cambridge (2007).

Tol, R. S. J., S.Fankhauser and B.Smith Joel: The scope for adaptation to climate change: What can we learn from the impact literature?.*Global Environmental Change* 8(2): 109-123 (1998).

Verchot, L.V. ,M.V.Noordwijk, S.Kandji, T.Tomich, C.Ong, A.Albrecht, J.Mackensen, C.Bantilan, K. V. Anupama and C.Palm: Climate change: linking adaptation and mitigation through agroforestry.*Mitigation and Adaptation Strategies for Global Change*,12 (5):901–918. (2007).

Vogel, C. and K.O'Brien: Who can eat information? Examining the effectiveness of seasonal climate forecasts and regional climate-risk management strategies. *Climate Research*, 33:111–122 (2006).

Wheaton, E. E. and D.C.McIver: 'A framework and key questions for adapting to climate variability and change', *Mitigation and Adaptation Strategies for Global Change,* **4:** 215–225 (1999).

Williams, S. E., L. P.Shoo, J. L.Isaac, A. A.Hoffmann and G.Langham: Towards an Integrated framework for assessing the vulnerability of species to climate change. PLOS Biology, 6 (12): 2621–2626 (2008).

Wondimagegn Tesfaye and Seifu Lemma: Climate change perception and choice of adaptation strategies: Empirical evidence from smallholder farmers in east Ethiopia.*International Journal of Climate Change Strategies and Management*, 8(2):253-270 (2016).

Wu, J.and B.A.Babcock: The choice of tillage, rotation, and soil testing practices: Economic and environmental implications. *American Journal of Agricultural Economics* 80: 494– 511 (1998).

Ziervogel, G., M.Bithell, R.Washington and T.Downing: Agent-based social simulation: a method for assessing the impact of seasonal climate forecasts among smallholder farmers. *Agricultural Systems*, 83 (1): 1–26 (2005).

Table 1: Definition of variables used in the empirical analysis

Variable	Definition	Values/measure	Expected impact
X1	Age of household-head	Number of years	±
X2	Education of household-head	Literate =1 and Illiterate=0	±
X3	Sex of household-head	1=male and 0=female	±
X4	Farming experience	Number of years	+
X5	Household size (No.)	Number of Members	+
X6	Farm size (hectare)	Hectares	+
X7	Family labour	Number of Members	+
X8	Annual income	(Rs.)	±
X9	Temperature pattern	Increase=1 and Decrease =0	±
X10	Change in timings of rains	1=yes and 0=no	±
X11	Noticed climate change	1=yes and 0=no	+
X12	Access to credit	1=yes and 0=no	±
X13	Possession of animal power	1=yes and 0=no	±
X14	Possession of a tractor	1=yes and 0=no	±
X15	Possession of heavy machines	1=yes and 0=no	±
X16	Access to agricultural extension facility	1=yes and 0=no	±
X17	Access to weather information	1=yes and 0=no	±

Table 2: Summary statistics of independent variables and their expected impacts on adaptation measures

Variable	Variable	Mean	Maximum	Minimum	Standard deviation	Skewness	Kurtosis
X1	Age of household-head	51.346	79.000	21.000	10.248	-0.040	-0.106
X2	Educationof household-head	5.387	2.409	0.000	15.000	1.059	-0.406
X3	Sex of household-head	0.950	1.000	0.000	0.218	-4.137	15.127
X4	Farming experience	27.724	50.000	5.000	0.205	-0.200	-0.761
X5	Household size (No.)	5.933	2.407	23.000	2.000	3.967	1.441
X6	Farm size (hectare)	2.524	0.100	18.750	2.645	8.532	2.614
X7	Family labour	2.422	9.000	1.000	1.347	1.020	4.249

X8	Annual income	4.615	5.776	3.790	0.009	-0.162	-0.796
X9	Temperature pattern	0.938	1.000	0.000	0.242	-3.623	14.123
X10	Change in timings of rains	0.934	1.000	0.000	0.248	-3.503	13.270
X11	Noticed climate change	0.850	1.000	0.000	0.357	-1.960	4.843
X12	Access to credit	0.570	1.000	0.000	0.495	-0.281	-1.923
X13	Possession of animal power	0.072	1.000	0.000	0.258	3.314	11.980
X14	Possession of a tractor	0.222	1.000	0.000	0.416	-0.207	1.339
X15	Possession of heavy machines	0.196	1.000	0.000	0.398	1.528	3.334
X16	Access to agricultural extension facility	0.313	1.000	0.000	0.464	0.805	-1.353

Table: 3: Results of multivariate probit analysis of adaptation measures

Variables		Change in variety	Mechanization	Manipulation of agronomic practices	Crop diversification	Farm diversification	Drainage	Irrigation	Change in sowing dates
C	Constant	-3.088**	-3.755**	-3.318**	-6.515**	-1.410	-1.195	-3.734**	-3.033**
X1	Age of household-head	0.003	0.003	0.004	0.002	-0.023**	-0.002	-0.010	0.012**
X2	Education of household-head	-0.312	-0.302	-0.297	-0.352*	-0.669**	0.132	-0.119	0.050
X3	Sex of household-head	1.124**	1.057**	1.139**	1.217**	-0.119	0.602**	1.113**	1.021**
X4	Farming experience	0.202	0.250*	0.183	0.178	-0.142	0.011	0.012	0.284**
X5	Household size (No.)	0.054	-0.003	0.038	0.080	-0.313**	-0.252*	-0.043	-0.017
X6	Farm size (hectare)	0.057*	0.063**	0.060**	0.091**	-0.062**	0.010	-0.058**	0.071**
X7	Family labour	0.168**	0.189**	0.177**	0.233**	0.314**	0.116**	0.065	0.104**

X8	Annual income	0.250*	0.139	0.199	0.380**	0.574**	0.164	0.642**	0.088
X9	Temperature pattern	-1.165**	0.166	-0.782**	-0.632*	-0.078	-1.333**	-0.815**	-1.061**
X10	Change in timings of rains	0.160	0.137	0.011	-0.744	0.100	-0.172	0.234	-0.090
X11	Noticed climate change	1.253**	1.078**	1.402**	4.173**	-0.058	0.272	2.419**	1.146**
X12	Access to credit	0.268*	0.379**	0.246	0.270	0.269*	0.068	-0.162	0.550**
X13	Possession of animal power	0.050**	0.051	0.082	-0.046	1.317**	0.159	-0.145	-0.168
X14	Possession of a tractor	0.446*	0.433**	0.563**	0.120	-0.298*	0.090	0.903**	0.424**
X15	Possession of heavy machines	0.397	0.438**	0.304	0.523**	-0.676**	-0.784**	0.056	0.249
X16	Access to agricultural extension facility	0.062	-0.042	0.069	0.080	-0.036	0.020	-0.414**	-0.045
X17	Access to weather information	-0.047	-0.028	0.000	-0.037	0.294	0.089	-0.327	-0.196

* significant at 10% ** significant at 5%

Table4: Correlation matrix of independent variables

Variable	Age of household-head	Education of household-head	Sex of household-head	Farming experience	Household size (No.)	Farm size (hectare)	Family labour	Annual income	Temperature pattern	Change in timings of rains	Noticed climate change	Access to credit	Possession of animal power	Possession of a tractor	Possession of heavy machines	Access to agricultural extension facility	Access to weather information
Age of household-head	1.000																
Educationof household-head	-0.038	1.000															
Sex of household-head	0.089	0.097	1.000														
Farming experience	-0.185	0.096	0.055	1.000													
Household size (No.)	0.027	-0.093	0.065	-0.202	1.000												
Farm size (hectare)	0.273	0.165	0.073	0.150	-0.156	1.000											
Family labour	-0.105	-0.169	-0.022	-0.158	0.447	-0.296	1.000										
Annual income	0.199	0.199	0.101	0.163	-0.137	0.680	-0.357	1.000									
Temperature pattern	-0.025	-0.061	-0.062	-0.001	-0.044	0.097	0.054	0.042	1.000								
Change in timings of rains	-0.049	-0.051	-0.051	0.032	-0.047	0.139	-0.051	0.193	0.049	1.000							
Noticed climate change	-0.106	-0.086	-0.068	0.050	-0.089	0.124	-0.020	0.194	0.278	0.543	1.000						
Access to credit	0.066	-0.055	0.082	0.070	-0.014	-0.013	0.094	-0.122	0.089	-0.089	-0.132	1.000					
Possession of animal power	-0.069	-0.185	-0.019	-0.033	0.073	-0.075	0.172	-0.058	-0.041	0.060	0.088	0.067	1.000				
Possession of a tractor	0.209	0.207	0.072	0.156	-0.194	0.564	-0.387	0.652	-0.123	0.069	-0.063	-0.088	-0.133	1.000			
Possession of heavy machines	0.308	0.144	0.112	0.181	-0.289	0.565	-0.370	0.551	0.036	0.042	0.047	0.054	-0.129	0.484	1.000		
Access to agricultural extension facility	-0.110	-0.018	-0.178	-0.058	0.060	-0.131	0.019	-0.035	-0.024	0.101	0.158	-0.365	0.115	-0.061	-0.206	1.000	
Access to weather information	-0.050	-0.007	-0.049	0.058	-0.112	0.061	-0.086	0.050	-0.021	-0.024	-0.057	0.048	0.002	0.098	0.100	0.039	1.000

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Environment Impact Assessment of Coastal Ecosystems

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Coastal ecosystems are the unique habitats formed by plants and other organisms that can thrive at the borders between ocean and land, where they must live in saltwater and changing tides. Like forests, many of these coastal ecosystems are full of plants that help regulate the Earth's temperature. As the plants in these ecosystems grow, they pull carbon out of the air and store it in their tissue, roots, and the soil beneath them. This keeps carbon out of our atmosphere, where as the greenhouse gas carbon dioxide, it would otherwise trap heat and warm the planet.Coastal ecosystems play a critical role in global climate and the carbon cycle by sequestering carbon. Carbon storage rates per unit area exceed those of terrestrial ecosystems.

The Coastal zone in India assumes its importance because of high productivity of its ecosystems, concentration of population, exploitation of renewable and non-renewable natural resources, discharge of waste effluent and municipal sewage, development of various industries and spurt in recreational activities.

Environmental Impact Assessment (EIA) is a well-established environmental management tool, as evidenced by its widespread use in most countries' legal frameworks and international law and in the standards of major lending institutions.

One primary objective of EIA is to support project licensing with sound and social responsive technical and scientific knowledge on the likely environmental effects. However, even though EIA regulations apply to public and private projects likely to have a significant environmental impact, they are principally aimed at land-based development proposals. Thus, EIA often does not cover projects in the marine environment in areas of national sovereignty or jurisdiction.

The marine environment is host to a diverse set of highly productive and complex ecosystems, contributing significantly toward biodiversity maintenance, food and energy provision, and the creation of economic and cultural benefits. EIA should have a critical role when assessing and planning economic-driven activities affecting the marine environment, such as aquaculture, nautical tourism, wave-energy, and exploration for hydrocarbons, sands and gravel.The coastal and marine ecosystems provide services vital to the hundreds of millions moving toward the coasts in search of a better life. Being the ocean's first frontier, these ecosystems are increasingly under threat.

The combined effects of mass movements of people towards coastal areas, a growing appetite for protein, energy derived from charcoal and other factors are compounded due to a lack of effective coastal governance and appropriate infrastructure investments, such as basic sewage treatment facilities, leading to the severe degradation of marine and coastal environments. This degradation means that our earth's blue forests and associated ecosystems - the mangroves, seagrasses, salt marshes, and coral reefs - are losing their ability to provide the fundamental services upon which human well-being depends. The provision of shelter and food for juvenile fish species, which often thrive across mangrove, seagrass and coral reef habitats, is one crucial example of the blue forests ecosystem services. While mangroves and coral reefs, in particular, help improve local food security in the coastal tropical regions, such ecosystems are equally crucial to the world's seafood supply.

Coral reefs and blue forests ecosystems form key nurseries for about a quarter of the ocean's fish and thus provide revenue for both local communities and the international fishing industry, upon which developed nations depend heavily. For example, US imports from wild and aquaculture based fisheries account for approximately 86% of the seafood consumed in the country.While blue forest ecosystems often prove critical to fisheries on multiple scales, they also play a role in facilitating tourism and protecting coastlines from erosion. They may even offer new income-generating opportunities due to their rich biodiversity and vast, untapped potential for bioprospecting.

Environmental Impact Assessment (EIA) is considered a standard decision-making tool in most countries worldwide. EIA aims at integrating ecological considerations in the decision-making system, avoiding or minimizing adverse impacts, protecting natural systems and their ecological processes, and implementing principles of sustainable development.

The coastal zone is an interface between the land and the sea, which comprises coastal land, intertidal area, and coastal ecosystems, including rivers, estuaries, marshes, wetlands and beaches. India has a coastline of about 7516 kms, of which the mainland accounts for about 5422 kms, Lakshadweep coasts extend to 132 kms, and Andaman & Nicobar Islands have a coastline of approximately 1962 kms. The coastal zone is endowed with an extensive range of natural resources. Besides the coastal waters, the other significant ecosystems in the coastal environment are Mangroves, Coral reefs; Sea Grass; Mud Flats; Estuaries/backwaters; Lagoons; Sand Dunes etc. The coastline supports a substantial human population dependent on the rich coastal and marine resources. However, increasing human population, urbanization and accelerated developmental activities has put huge pressure on the fragile coastal ecosystems of India. Ministry of Environment, Forest and Climate Change (MoEF&CC) and the Ministry of Earth Sciences (MoES) are the two nodal Ministries which deal primarily in the coastal and ocean areas. The Environment (Protection) Act, 1986 authorizes the central Government to protect and improve environmental quality, control and reduce pollution from all sources, and prohibit or restrict the setting and/or operation of any industrial facility on ecological grounds. The Government has issued notifications under Section 3 and 5 of the Environment Protection Act 1986 to regulate coastal space activities to protect the coastal environment from various anthropogenic activities. Coastal Regulation Zone Notification (CRZ) 2019 which was superseded by its earlier versions in 1991 and 2011 implemented by MoEF&CC, aims to classify the coastal area into different zones and manage the activities in an integrated manner. Pre-audit studies conducted to understand the risks in coastal zone management revealed large-scale CRZ violations in the coastal stretches. Incidence of illegal construction activities (reducing coastal space), effluent discharges from local bodies, industries and aquaculture farms have been recorded from various data sources. It was imperative to assess the implementation of Coastal Zone Regulation Notification 2011 by the coastal states as well as the centre to evaluate the Government of India's efforts towards protecting and conserving the coastal environment.

Also, given the significance of Sustainable Development Goals and the commitments of the country towards achieving them, we need to attempt to evaluate the efforts viz. planning, implementation and delivery mechanism towards attaining the targets under SDG 14- Life Below Water. As per a recent report, several coastal zone projects were approved despite environmental impact assessment (EIA) inadequacies.

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Corporate Social Responsibility for Sustainable Agriculture Development: Perspectives and Way Forward

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Sustainability in Agriculture is a critical \issue which needs urgent attention and action. The agriculture sector requires a significant investment to address the current challenges and achieve Technology led agricultural growth. No single agency can address these challenges in the public or private sector. There is a need for a pluralistic ecosystem including various actors such as Governments, Private agribusiness companies, NGOs, and Producers' organizations leveraging Corporate Social Responsibility (CSR) funds for overall agriculture and farming community development. India Inc. has taken on the mantle, and corporate-powered sustainability is the buzzword. There is an increased emphasis from businesses of all sizes on the need for more efficient and greener ways to decrease industrial carbon footprints and support not-for-profit organizations as part of their corporate social responsibility efforts to bring about sustained change. Corporate Social Responsibility (CSR) spending in agriculture is far less compared to many other sectors like education, healthcare, art and culture, etc. Very meagre amount of CSR funds has been spent in the agricultural sector despite the vast potential for investment in the industry.CSR activities in agriculturecover a wide range of issues such as rainwater harvesting, solar pump, organic farming, seed management, soil management, delivery of agro information as well as a marketplace ecosystem, etc. The methodology of this research is based on secondary data. This paper explores the various perspectives associated with CSR initiatives and significant focus areas for CSR funds in the agriculture sector in India. It also tries to assess the associated challenges and strategies for achieving sustainability in agriculture and combating climate change.

Keywords: Corporate Social responsibility, Sustainable Agriculture, Climate change

INTRODUCTION

The agriculture sector is critical for India's economic development and food security as the country, the majority of the rural households depend on agriculture as their livelihood. The country's transition from a food deficient to a food surplus country has been achieved through technological interventions, appropriate planning, policy support and hard work put in by Indian farmers. Today India is the largest producer and exporter of many commodities. Yet itis confronted with severe challenges which include non-remunerativeness, degradation of natural resources, climate change, low adoption rates and technology diffusion, low level of processing and value addition, lack of adequate infrastructure, exploitation by the intermediaries, inadequate credit support and many other associated problems. With the growing demand for food, the country's agriculture sector is caught between providing food at affordable prices and generating the necessary income to meet the basic standard of living for most of the population. About 70% of the arable land in India is drought-prone, 12% is flood-prone, and 8% is cyclone prone. The Fifth Assessment Report of the IPCC has predicted that there will be a significant drop in agriculture yield in the country owing to climate change. All these challenges further aggravate due to the lack of adequate investments in agriculture.

Sustainability in Agriculture is a critical issue which needs urgent attention and action. Agricultural production contributes to climate change significantly as it contributes a quarter of the greenhouse gas emissions in a year in India. Agriculture also dominates the country's freshwater use, accounting for about 70% of total consumption. Besides, the increasing use of chemical fertilizers due to government subsidies has increased dependence on groundwater for irrigation. This is responsible for groundwater depletion in several states such as Haryana, Punjab, Rajasthan and Delhi. It puts a strong case for the public sector to partner with the private sector through CSR to bring sustainability to the Indian Agricultural Sector.

Any kind of value, whether functional, hedonic, symbolic or cost value, has to be co-created by working with the stakeholders while meeting expectations that businesses promise to their customers. With this goal in mind, corporations engage in value creation with the community through supporting corporate social responsibility and sustainability programs. These programs require maximum stakeholder participation in the value creation process, especially in selecting, designing and delivering such programs. These engagements foster stakeholder action and instil a sense of pride and confidence in them. Furthermore, these programs help the stakeholders to gain trust and confidence by maintaining transparency.(BijoylaxmiSarmah *et al*.,2015)

The agriculture sector requires a big investment to address the current challenges and achieve Technology led agricultural growth. Any single agency cannot address these challenges either in the public or private sector. There is a need for a pluralistic ecosystem including various actors such as Governments, Private agribusiness companies, NGOs, and Producers' organizations leveraging Corporate Social Responsibility (CSR) funds for the overall development of agriculture and the farming community. The gradual transformation in CSR in India has gone beyond philanthropy to comprehensive community development with more commitment. Similarly, the Government has also started looking at corporate as partners and involving them in the process of development.

Climate Change and Food Security

A recent report by the Intergovernmental Panel on Climate Change (IPCC), a United Nations body that assesses climate change impact, states that developing economies are at more significant risk due to challenges brought by global warming. From rising sea levels that increase the risk of flooding to shifting weather patterns that threaten food production, impacts of climate change are global in their scope and unprecedented in scale. Climate change is real and the responsibility to act is now collective. All individuals, corporates, academics and not-for-profits need to work together as a 360-degree support ecosystem to provide a safe environment for future generations.

Food Security is always the first enterprise to be hit due to climate change. As per the Food and Agriculture Organisation of the United Nations (FAO), climate change is projected to negatively impact all four pillars of food security – availability, access, utilization and stability and their interactions. Low-income producers and consumers are likely to be most hit due to a lack of investments in adaptation and diversification measures. It not only leads to a spike in food prices or production loss but also poses a risk to maintaining a healthy diet resulting in severe malnourishment. Many fruits and vegetables considered essential to ensure balanced diets are at the risk of getting extinct due to the spread of diseases caused by climate change. Across the globe, some foods are at risks such as banana cultivation affected by black fungus, soybeans and many more. Many native Indian foods like Red Okra from Karnataka, Black Rice from Gujarat, Red Corn from Tamil Nadu, once considered indigenous foods are on the verge of extinction or already extinct. Whenever a plant goes extinct, it disrupts the entire ecosystem built around it.

Corporate Social Responsibility

The World Business Council for Sustainable Development (2000) defines CSR as "the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large". A focus of CSR is also developing relationships between business, society and its key stakeholders such as employees, customers, investors, suppliers, communities, and special interest groups (Hick, 2000). According to the United Nations Industrial Development Organization, Corporate Social Responsibility is defined as a business management concept whereby companies integrate social and environmental concerns into their business operations and interactions with their stakeholders. Corporate social responsibility (CSR) can be summarized as "*the voluntary behavior of companies to go beyond the legal requirements of the country in which they operate, given their long-term interests for integrating economic, social and environmental impacts to their operations*".

CSR is considered a comprehensive business model, not just another basic activity of the company. CSR is a concept where businesses take responsibility for their impacts on the environment and society beyond their economic impacts. CSR may be looked at in terms of 'Creating Shared Value' wherein a business can help the progress of agriculture, and the agriculture sector can help businesses to improve and flourish.(Balasubramani,2017)CSR is generally understood as being the way through which a company achieves a balance of economic, environmental and social imperatives while at the same time addressing the expectations of shareholders and stakeholders.

On April 1, 2014, India became the first country to legally mandate corporate social responsibility. The CSR law or more popularly known as the CSR mandate, applies to every company registered under the Companies Act, 2013, and any other previous companies law qualifying having a net worth of rupees five hundred crores or more or having a turnover of rupees one thousand crores or more or having a net profit of rupees five crores or more during a financial year. The new rules in Section 135 of India's Companies Act make it mandatory for companies of suchspecified turnover and profitability to spend two per cent of their average net profit for the past three years on CSR. The law also stipulates that CSR activities should be undertaken only in 'project/program' mode across several categories which includes hunger and poverty, education, health, gender equality and women empowerment, skills training, environment, social enterprise projects and promotion of rural and national sports.(Parveen Kumar, 2022)

Corporations are legal entities with two fundamental responsibilities: to generate profit for the owners and their partners and to comply with the law. A broad or modern vision moves beyond them to include moral, ethical, and philanthropic responsibilities. Modern view considers CSR as an umbrella term for various theories and practices that recognize: (1) corporations are responsible for their impact on society and the environment, sometimes beyond legal compliance and responsibility of individuals; (2) companies are responsible for the behaviour of others with whom they do business (e.g., suppliers in the supply chain); and (3) companies need to manage their relationship with society in general, whether for reasons of commercial viability or to contribute to society. (Ortega *et al.*, 2016)

India Inc. has taken on the mantle and corporate-powered sustainability is the buzzword. There is an increased emphasis from businesses of all sizes on the need for more efficient and greener ways to decrease industrial carbon footprints and support not-for-profit organizations as part of their corporate social responsibility efforts to bring about sustained change. India Inc. looks committed to finding new and sustainable ways to work on the basis of three key pillars of investment: environmental, socially responsible, and governance (ESG). The social responsibility pillar consists of moves that benefit the company's employees, consumers, and the wider community. As for the economic or governance pillar, the idea to maintain honest and transparent accounting practices and regulatory compliances takes the front seat.(Arora, 2022)

Government Initiatives

To make agriculture more productive, sustainable, remunerative and climate resilient, the government of India have conceptualized some initiatives. The *National Mission on Agricultural Extension and Technology* was initiated to restructure and strengthen agricultural extension to enable the delivery of appropriate technology and improved agronomic practices to the farmers. The *Pradhan Mantri Krishi Sinchayee Yojana* was launched to achieve convergence of investments in irrigation at the field level, expand the cultivable area under assured irrigation, improve on-farm water use efficiency, enhance recharge of aquifers and introduce sustainable water conservation practices. *Pradhan Mantri Fasal Bima Yojana* was launched to provide financial support to farmers suffering from crop loss or damage due to unforeseen events. It is also aimed at stabilizing farmers' incomes to ensure their continuity in farming. The government has also initiated a pan-India electronic trading portal called as *National Agriculture Market*, which networks the existing agricultural Produce Market Committee (APMC) mandis to create a unified national market. (CSR Journal,2019)*India's PM Poshan scheme is a great example of how locally sourced produce is used to prepare school meals to meet the local palette which also enables employment for the local population. More such PPPs are needed to ensure nutrition sustainably. Acquiring local produce and eating local has been discussed as effective methods of reducing carbon footprint.(Arora, 2022)*

CSR in Agriculture

Farmers are the largest stakeholders of our society and form the bottom of the pyramid. About 70 per cent of our population lives in rural India and the majority are engaged in agriculture, yet it contributes only 14 per cent to the economy. It is a fact that our country cannot progress leaving farmers behind to fend for themselves. At every stage of farming activity, right from seed treatment to postharvest handling and marketing, interventions are needed. Postharvest losses account for 6–18 per cent; and 50 per cent of losses occur at the farm level. Simple interventions like mechanized cleaning, grading and drying at the village level can reduce postharvest losses and distress sales can be avoided. (Patil, 2016) More investment is needed to address problems like bottlenecks in the supply chain and better market conditions for farm products. It is time for corporate to join hands and does their bit through CSR participation. (Upadhyay, 2019)

Corporate social responsibility is of growing interest in the globalized marketplace, especially in the areas of agribusiness and the food industry; however, within these industries, the CSR definition and scope remain a challenge highly dependent on the view, be if classical or modern, from which it is operationalized. Development of agriculture has contributed not only to a rapid increase in food production but also to environmental and social issues (De Olde and Valentinov, 2019) like GHG emissions. CSR initiatives which try to reconnect agriculture and society, usually cause confrontations. Agribusiness leaders understand and practice CSR, which is inconsistent with farm workers' living conditions and health in Mexico (Ortega et al., 2016).CSR models, regulations, and voluntary standard adoption in agriculture are 5–10 years beyond that of the industry and, thus, require empirical data to explain the wide variety of standard development and adoption within the unique context of agriculture.(Poetez et al., 2013)

Mandatory CSR (Corporate Social Responsibility) spending introduced by the Indian Government is an effective step for speedier and overall development in the country.(Upadhyay,2019) According to a survey, CSR spending patterns by the top 200 BSE listed companies revolved around livelihood, environment, education, healthcare and rural development. Among the spending, rural development received the least attention. Corporate Social Responsibility (CSR) spending in agriculture is far less in comparison to many other sectors like education, healthcare, art and culture, etc. Very meagre amount of only 3% of CSR funds has been spent in the agricultural sector by the companies though there is huge potential for investment in the sector. (Parveen Kumar,2022) Unfortunately, the words 'agriculture' or 'farming' don't figure per se in schedule VII (Section 135, Companies Act 2013), which speaks of activities that may be included by companies in their CSR policies. Nevertheless, it doesn't mean the end of the road; there is ample scope and flexibility to take CSR activities in the farming sector under 'rural development' (Patil, 2016). Some large firms were voluntarily spending a part of their earnings on CSR initiatives even before the provisions introduced relating to CSR in the Companies Act 2013.

Figure 1 : CSR Thematic Focus by Corporates

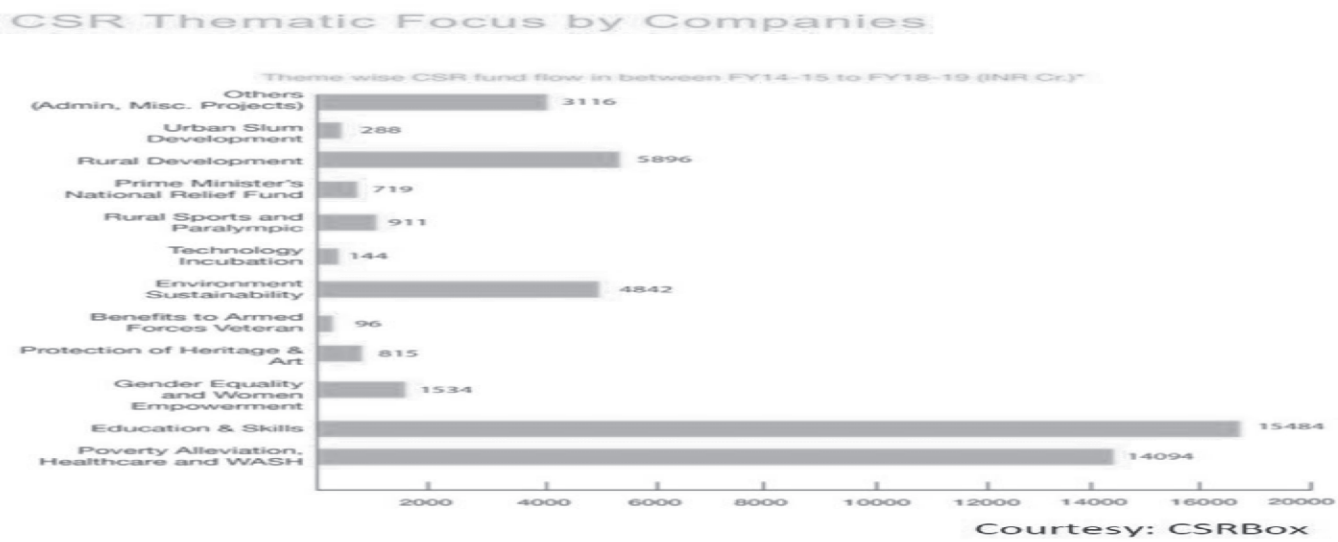
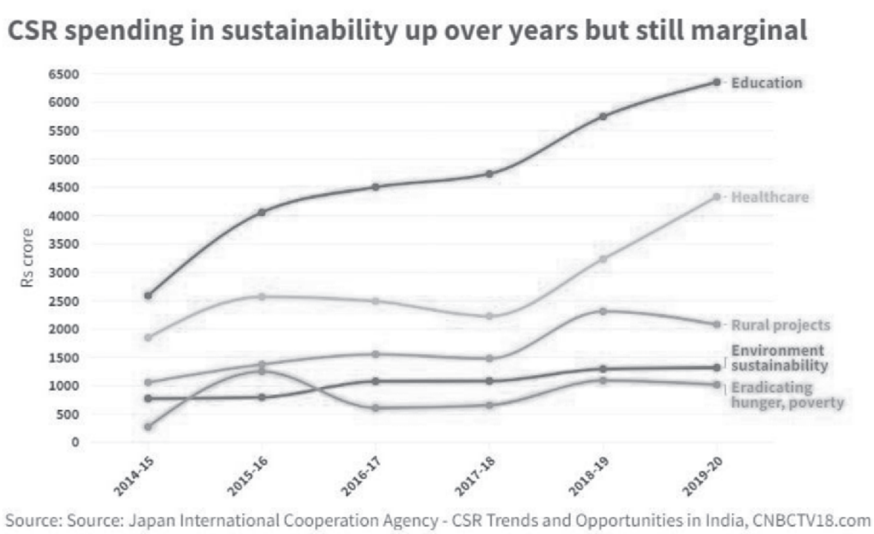


Fig 2 : CSR Spending in Sustainability (2014-15 to 2019-20)



As per the latest data by Japan International Cooperation Agency on 'CSR Trends and Opportunities in India', only 6.84 per cent of the total amount is being spent on Environment sustainability and 10.63 per cent on rural development projects, compared to 30.16 per cent share in education and 18 per cent in health care. The data shows that the spending on environmental sustainability improved by about 70 per cent and 96 per cent for rural development from 2014-15 to 2019-20. In contrast, it increased by 145 percent for education and 134.50 per cent for healthcare. Many companies respond to needs expressed by communities and/or governments, which largely prioritize urgent needs such as health, education livelihoods while undervaluing essential needs such as gender equality, environmental sustainability, etc. Sectors such as clean energy, water conservation and agroforestry require technical knowledge and domain knowledge to assess solutions that CSR may not always possess. According to a report by CSR Journal, the top 100 companies for CSR spending in India are Infosys, Tata Chemicals, ITC, Vedanta, JSW Steel, NTPC, HDFC Bank, Indusland Bank, HCL Technologies and others are spending on the environment. CSR initiatives toward the environment predominantly include afforestation, reforestation, setting up waste-to-energy plants, recycling and river cleaning (JICA, 2021).

Focus Areas

Upadhyay (2019) conducted a study aimed at finding out the spending patterns of CSR corpus using publicly available expenditure data on agriculture by 20 Indian corporates. CSR activities in agriculture covered a wide range of issues such as rainwater harvesting, the introduction of solar pumps, organic farming, seed management, soil management, delivery of agro information as well as a marketplace ecosystem, etc. It stressed the need for more investment to address problems like bottlenecks in the supply chain and better market conditions for farm products to improve the income level of farmers.

To facilitate the ICAR institutes to seek financial support from Industries under Corporate Social Responsibility within the ambit of CSR Rules, 2014, ICAR has developed a guideline called 'The ICAR Guidelines for utilization of Corporate Social Responsibility Funds 2020. The Schedules VII of the Companies Act, 2013 provides an umbrella for the activities that can be taken up through CSR. The same could be further broken into specifics of Sciences and Technology and agricultural extension. Fortunately, the schedule does specify that Scientific Research and agricultural extension as an admissible activities. This activity also enjoys exemptions under the Income Tax rules.

The ICAR Guidelines for utilization of CSR Funds 2020 aim at identifying research activities for attracting CSR funds and facilitating the effective utilization of the obtained funds from the public as well as private companies /enterprises/industry/organizations having no conflicts of interest. The funds received from the contributors will be utilized to carry out/enhance/augment various research and farmers' outreach activities as per the provisions of MoU/MoA/LoI of ICAR and the Contributor(s); and Government of India guidelines.

Admissible Activities under CSR under ICAR mandate:

As per the mandate of ICAR following areas may be considered under CSR activities:

Sr. No.	Activities	R&D Activities which can be supported under CSR
1	**Eradicating extreme hunger and poverty**	• Research and Agricultural Extension/Education Funding which help in enhancing availability, access and affordability of food item 247 • Capacity building and income augmentation through skilling of farmers and scientists, and other stakeholders • Seed and planting materials research which helps livelihood improvement • R&D for diversification of farm activities for higher income • Livelihood projects creating rainwater harvesting structures and maintenance of water bodies, etc.
2	**Promotion of education**	• Infrastructure like classrooms, buildings, sports complexes, libraries, etc. for higher agricultural education, Construction of Hostels, SC/ ST/girls Hostels, Modernization of Classrooms, Experiential Learning Centers

3	**Promoting gender equality and empowering women**	• R&D for farm tools for women farmers • Capacity building of women farmers • Development of gender-friendly farm equipment • Women farmers/trainees hostels in KVKs, • Women entrepreneur's training by KVKs
4	**Reducing child mortality and improving maternal health**	• R&D projects on healthy foods; and biofortification of food crops • Awareness and capacity building of women farmers for homestead food like nutrithali, nutrigarden • Food systems and product diversification • Establishment of a centre of excellence on natural food products in tribal areas
5	**Combating human immunodeficiency virus, acquired immune deficiency syndrome, malaria and other diseases**	• Development of vaccines for viral diseases in livestock • Swachchata Initiatives in ICAR institutes and KVKs Development of nutraceuticals from sea wastes/fish wastes
6	**Ensuring environmental sustainability**	• R&D Projects on NRM, biodiversity • Sustainability, Climate Change Management, • Preservation and protection of flora & fauna, livestock and animal welfare, fish • Query Management and coastal management • Agroforestry, carbon sequestration • Conservation of soil, water, forests, degraded lands, • Reclamation of problem soils, drought and flood management • Maintaining the quality of soil, air & water • Development and promotion of model watersheds
7	**Employment enhancing vocational skills**	• Training of trainers and farmers • Projects under Student READY, Farmers First, ARYA, • Support to Technical/ Vocational Institutions/ programmes for their self-development, training for agricultural expert
8	**Social business projects**	• Rural and agriculture development projects Development of jobs related to agro products i.e., Dairy/ Poultry/farming and others

9	**Fund technology incubators located within Central Universities**	• Funding to Agri-Business Incubation (ABI) Center located in different deemed Universities and Central Agricultural Universities 248 • Funds provided to the AgriBusiness Incubation (ABI) Center located within ICAR institutions for upscaling technology and developing market linkages
10	**Such other matters as may be prescribed**	• Secondary agriculture and development of new products and protocols • Training of rural youth for self-employment

Source: ICAR guidelines for utilization of CSR Funds 2020

Focus Areas for CSR in Agriculture for Sustainable Development

Balasubramani, 2016 identified these seven major focus areas for CSR in Agriculture as discussed below:

- **Environmental Sustainability:** Environmental issues are most critical to the agriculture sector as the Environment plays a vital role in agricultural production and has a great influence on the growth, development and yield of crops, the incidence of pests and diseases, water needs and fertilizer requirements. Environment changes may cause damage to crops, soils and affect the soil quality, air quality, water quality and biodiversity of flora and fauna. Therefore, investment through CSR funds to sustain the environment is the need of the hour.
- **Natural Resource Management:** Agriculture uses 70 per cent of the water resources. Population growth, extreme events of climate change, over-exploitation, imbalanced external application of input, changing land use patterns, changing food habits, etc., are increasing the pressure on fragile natural resources. Hence, conservation, optimum use and recycling of natural resources are crucial for ensuring sustainable food and nutritional security. Studies show that watershed activities undertaken under CSR have significantly impacted crop productivity, increased cropping intensity, increased greenery coverage, reduced surface runoff and facilitated groundwater recharge, reduced soil erosion, and increased fodder availability, helping to increase the milch animal population. Watershed activities have also helped the communities to address food security and livelihood issues without degrading natural resources. Therefore, there is a lot of scope for investment in natural resource conservation and management as CSR activities.
- **Innovation and Technology-led Development**: There is a huge potential for investment under CSR in creating innovation and technology-led growth. Someimportant areas that can revolutionize the profitability of agriculture are Information and Communication Technology, on-farm mechanization, precision farming, smart climate technologies, real-time weather information, dissemination of weather-based advisory services through ICT platforms, the establishment of custom hiring centres, etc.
- **Social Development:** The success of agriculture is critical for the survival of all rural communities and for feeding the whole population. Empowering women in rural areas will make the largest difference to the whole family. Malnutrition in rural areas needs to be tackled at the source - agriculture and rural communities. Engaging youth is critical for the long-term viability of agriculture. Therefore, there is a huge investment potential for social capital development through training, developing and nurturing them as producer's organizations etc.

- **Entrepreneurship Development:** Globally, agriculture is expanding beyond the limits of mere crop cultivation and animal husbandry for the livelihood of the rural population. Activities like diversification, value addition, precision farming, high-tech agriculture, Agripreneurship, organic farming etc. are gradually getting due attention of people involved in redefining agriculture. There is considerable linkage and growing interdependence between agriculture and industry. All-round development of agriculture is possible only with effective exploitation of entrepreneurial behaviour skills as well as material resources. CSR funds can be productively utilized for creating the required infrastructure, enhancing entrepreneurial skills, providing access to credit and finance, creating training facilities, linking them to the market etc.
- **Livestock Development:** Though India possesses enormous livestock resources, production and productivity are significantly less. The future growth of Indian agriculture lies in paying more attention to the livestock sector, as returns on investment are higher in this sector. The sector shows high potential for contribution to GDP. The potential interventions in Livestock would be breed improvement, nutritional support, health management, the establishment of a cattle development center, milk collection center, chilling center, milk processing center, promotion of Goat / Sheep and backyard poultry as an enterprise etc.
- **Market Development:** Markets are core to economic growth. Working the whole agricultural value chain is needed for profitable and viable agriculture as an enterprise. This not only enables farmers to have access to required inputs but also brings their products to the market in an efficient and effective way. Untapped opportunities exist for creating value chains for Agriproduce. There is a lot of scope for investment in market development and reducing the level of intermediaries.

Some CSR Initiatives in Sustainable Agriculture development

In order to uplift the lives of *'annadaatas'*, the corporates of India have initiated various projects for the benefit of farmers under the ambit of Corporate Social Responsibility (CSR). Some of the top CSR projects for the benefit of farmers in India include:

Name of Company	Project Name and partners	Activities undertaken
Mahindra & Mahindra	Krishi Mitra launched in support of Swades Foundation, BAIF Development Research Foundation and Dr Panjabrao Deshmukh Krishi Vidyapeeth, (2017-18) Rs.4.99 crore	The farmers were trained in effective farming practices, including soil health, crop planning, and creating model farms with bio-dynamic farming practices, thereby increasing crop productivity through the Wardha Family Farming Project, KrishiMitra and Integrated Watershed Development Project. The project also provided for soil testing, advisory services, drip irrigation, community farming, seed culture farming, agriculture extension services, infrastructure development and capacity building for the benefit of the farmers.

HUL	Project Mooo under Prabhat Initiative in partnership with UDAY – a skill development organization partnered with the National Skills Development Corporation (NSDC). Launched in 2013	The project is a holistic AgTech solution that aims to tackle milk deficit, traceability and private extension through dairy farm management and Information and Communication Technologies (ICT) training. The project was launched at MohiKhurd Village in Rajpura, Punjab, India. This included awareness camps on dairy as a sustainable business, providing digital & financial literacy, visiting farmers at doorsteps with a team of dairy experts and empowering farmers digitally through *MoooFarm* mobile application. It helps farmers in calculating their costs and profits. The app maps the life cycle of each cattle owned by farmers, sends need-based alerts, offers learning videos and tools, connects to local experts, etc. In order to ensure last-mile connectivity, each farmer was provided with Information and Communication Technologies (ICT) training as well by the Village Level Entrepreneurs. It has spread over 18 locations in India and has directly reached out to over 1.7 million people.
Adani Ports and Special Economic Zone Ltd	Farmer support programme Adani Foundation collaborated with the KVK (KrishiVigyan Kendra) Launched -2017-18	The Foundation with 1,050 farmers from 35 villages of the Tiroda region of Maharashtra, effectively implemented an SRI (System of Rice Intensification). Foundation empowered farmers by training them in low-water, labour-intensive and organic methods. Under its SLD (Sustainable Livelihood Development) programme, Adani Foundation supported farmers by providing each with five kilograms of paddy (Siri NP – 405) seeds and 50 kilograms of vermicompost for taking upSRI. The programme achieved its prime objective of promoting organic methods of paddy cultivation.SRI method assisted farmers in reducing their cultivation costs by 33% and increasing their crop productivity by 51%. The Adani Foundation initiated a cow-based livelihood programme, a fly ash utilization programme and the formation of Farmers' Producer's Company at Tirora, Maharashtra.
ITC Limited	Sustainable Agriculture Programme (2017-18) by ITC Rural Development Trust 50.45 crores	The Sustainable Agriculture programme attempts to de-risk farmers from erratic weather events through the promotion of smart climate agriculture premised on the dissemination of a relevant package of practices, adoption of appropriate mechanization and provision of institutional services. Currently, 4.15 lakh acres are covered under the Sustainable Agriculture programme. Of these, 1.14 lakh acres were covered through ChoupalPradarshan Khets, demonstration farms to disseminate scientific and technological best practices, directly benefitting more than 64,000 farmers. In pursuit of Company's long-term sustainability objective of increasing soil organic carbon, 37,500 compost units were constructed. The 'Village Adoption Programme' pioneered by Company's Agri-Business presently covers 190 model villages in Andhra Pradesh, Karnataka, Telangana and Rajasthan.

Welspun India Limited	Agriculture Support (2018-19) Implementing Partners: Welspun Foundation for Health & Knowledge	The Company has contributed to CSR in the drought-prone Vidarbha region in Maharashtra and Kutch in Gujarat through sustainable farming interventions, which encompass a complete farm management solution – from farm to retail. They undertake soil sampling and demonstrate ways to improve organic carbon as well as furrow irrigation method to bring down cultivation costs & boost yields. Interventions include tree plantation, Intercrop / Border crop and Gap filling by another crop, distribution of training material on identifying beneficial insects, and formation of a Biodiversity Committee in villages, leading to increased awareness. Training is provided on optimum utilization of water and the importance of critical stages of irrigation. They recommend alternate furrow irrigation & promote micro-irrigation, which has resulted in 34% less water consumption.
McCain Foods	Project Utthan BAIF Development Research Foundation.	The company's Project Utthan focuses on livelihood enhancement and Improvement in the overall quality of life of small farmers through suitable interventions. The company jointly initiated agriculture-based livelihood project in 4 villages of Vijaynagar block, District Sabarkantha of Gujarat, with BAIF Development Research Foundation. The company has launched a 'Smart Farming Program' in India, which spans from Gujarat to Lahaul-Spiti, Punjab and Rajasthan with over 1000 farmers. Currently, more than 1/3rd of the company's contracted volume of potatoes is grown under the Good Agricultural Practices (GAP) scheme. The farmers associated with McCain Foods grow these crops under drip and sprinkler irrigation with the overall vision of growing and distributing better quality potatoes for the customers without disturbing the region's biodiversity.
Coal India Limited	Project Utthan (2019) Pune-based non-profit BAIF (formerly BharatiyaAgro Industries Foundation)	Rs 20.3 crore CSR project Utthan assisted in the conversion of barren lands into high-yielding assets and the creation of sustainable farm livelihoods, benefiting roughly 25,000 people in the 40 villages of coal mining districts of Angul, Jharsuguda, Sambalpur and Sundargarh. Wadi cultivation, a farming strategy that involves intercropping with seasonal vegetables and horticulture, has been embraced under this project (mango, lemon and custard apple, etc.). Utthan has benefited 6,500 farmer households by creating sustainable livelihoods through a variety of innovative farm-sector interventions in agriculture, dairy, goatery, mushroom cultivation, backyard poultry, fodder development, and other areas. Established 244 wadis, transforming 122 acres of barren ground into thriving crops. Utthan is also assisting in the development of water storage facilities (50 new ponds storing 4 million litres).To contain runoff water and prevent seepage, ponds are dug and the base is coated with polythene sheets. Utthan has installed eight solar pumps in villages, boosting irrigation potential in at least 50 acres.

Source: Compiled from various sources

Issues and Challenges

- The CSR spending in agriculture is far less in comparison to many sectors such as education, healthcare, art and culture etc.
- There is a need to put a mechanism to avoid overlap of different schemes by the Governments as well as CSR projects for the benefit of the various segments of society.
- Many companies think that corporate social responsibility is a peripheral issue for their business and customer satisfaction is more important for them. They imagine that customer satisfaction is now only about price and service, but they fail to point out essential changes that are taking place worldwide that could blow the business out of the water.
- Many corporations are also unable to conceptualize and mobilize Community participation in CSR activities due to which they fall flat on the ground.
- Corporations look for effective and well-organized Nongovernmental Organizations which can work on grass root level. Many times they fail to collaborate due to the non-availability of such dedicated and committed organizations.
- Many times government organizations and agencies, as well as corporate they, have a narrow perception of CSR initiatives which acts as a stumbling block.
- Besides, the Non-availability of Clear CSR Guidelines as well as the lack of strategic vision and consensus on CSR implementation, also acts as a hindrance.
- People have little knowledge about CSR activities, so they don't show enough interest in participating and contributing to it (Maniktala and Punjabi,2016)

Way Ahead

Many studies suggest that the CSR intervention may prove to be vital to capacity building and skilling in the agriculture sector across the globe. It would be difficult to address the bottleneck in the agriculture sector without the active participation of the government agencies, the private sector and society. The following strategies may be vital for the effective utilization and mobilization of CSR funds in sustainable agriculture development

1. The provision of mandatory CSR expenditure on the agriculture sector may be helpful in bringing the farm sector out of distress. Tax benefits to donations to entities involved in operating such agriculture projects will not only help to build such projects but increase economic activities in the rural economy. Green practices such as organic farming, rainwater harvesting, crop rotation, agroforestry, micro-irrigation, protecting native crops and reducing food miles through local sourcing of materials can enable a greener tomorrow. (Arora, 2022)
2. Department of agriculture and allied sectors will have to sensitize the companies on various agriculture related issues; and potential areas of activities which can be supported for agriculture development through CSR funds. The potential activities should address the challenges of agriculture and allied sectors such as deteriorating soil health; depleting water and other natural resources; decreasing size of farm holding; input use inefficiency; costly and scarce agriculture labour; drudgery in farming operations; information, knowledge and skill gaps; poor access to credit and investments; slow diffusion of relevant technologies; competitiveness of quality and prices in export & domestic markets; inadequate focus on processing and value addition; Low profitability of agriculture; inadequate rural infrastructure; poor access to resources and services for women in agriculture; weak institutional linkages and convergence; occurrence of extreme events of climate change, low productivity of animals etc. (Balasubramani, 2017)

3. A part of the CSR corpus must be mandatorily spent on agriculture activities to build infrastructure and skill capacity in the agriculture sector. It would prove helpful in bringing the farm sector out of distress. It can be done by pooling the CSR resources to build and operate large projects to address the problem of bottlenecks like cold-storage and logistic infrastructure in agriculture through cooperatives or social participation. To promote its government can provide tax benefits to donations to entities involved in operating such agriculture projects (Upadhaya, 2019). Also, the pooling of funds to build bigger projects would not only make monitoring easier than a large number of scattered projects but help in avoiding the overlap of government sponsored schemes also.
4. Companies should have well trained CSR department with qualified and experienced professionals for better planning, implementation and evaluation of CSR policies. Each of the company should prepare its annual CSR report which is now mandatory under new company act. Before launching the CSR project, the company must survey the area concerned to take first hand information about the need of the local people so that the involvement of the local people would enhance. The company should also conduct a social performance audit of their CSR program to judge its continuity. The Government must play the role of motivator, facilitator and persuade corporate to take into account ethical, social and environmental criteria (Maniktala and Punjabi, 2016)
5. The Government of India has to provide clear guidelines to corporate to establish CSR initiatives. There is also a need that CSR activities must be assessed by any external agencies to control and monitor that CSR activities should not impose or compel farmers to enter into contract farming. The company can make a partnership with either the Government or a Non-Profit organization for the effective implementation of the CSR activities (Mohanapriya,2015).

CONCLUSION

Corporate social responsibility (CSR) in practice entails constantly working on improving the three P's (people, planet, and profit) in a balanced manner. Even though the government frames policies and programs to support the growth of Agriculture in India, the contribution of the private sector is vital for the sustainable growth and development of agriculture. Commercial agriculture can be successful only when it is done on a sustainable footing. Developing sustainable agriculture requires an exchange of knowledge and experience among business, government and civil societal organizations. Companies also benefit as CSR is used as a power tool to maintain customer relationships and to obtain the good image in society. Agriculture is yet to attract the attention of India's CSR. If the Corporate allocates more funds under CSR in agriculture, many challenges of the farm sector can be addressed. The emphasis of CSR in the Agriculture sector needs to be in the areas of environmental sustainability, natural resource management, innovation and Technology led development, social development, entrepreneurship development, livestock development, market development, etc. In order to promote CSR activities in agriculture, it is suggested to have commitment and representation of various stakeholders, effective policy support and a proper monitoring system at various levels.

REFERENCES:

Abraham,Vincent and Balasubramani, Nanjappan (2020) Workshop on Corporate Social Responsibility (CSR) for Agricultural Development Nov 19-20, 2018. Accessed from https://www.researchgate.net/publication/ 342171286_Workshop_on_Corporate_Social_Responsibility_CSR_for_Agricultural_Development_Nov_19-_20_2018.

Arora Anant (2022) People, Planet and Hunger,Voices,TOI accessed from https://timesofindia.indiatimes.com/blogs/voices/people-planet-and-hunger/?source=app&frmapp=yes

Balasubramani N. (2017) Corporate Social Responsibility for Agricultural Development - A way forward Journal of Agricultural Extension Management Vol. XVIII No. (I) 13:28

BijoylaxmiSarmah ,JamidUlIslamb, Zillur Rahman (2015) Sustainability, social responsibility and value co-creation: A case study based approach, XVIII Annual International Conference of the Society of Operations Management (SOM-14). Procedia - Social and Behavioral Sciences 189:314 – 319.

De Olde, E.M., Valentinov, V. (2019) The Moral Complexity of Agriculture: A Challenge for Corporate Social Responsibility. *J Agric Environ Ethics* 32, 413–430.

JICA(2021) Research Report on CSR Trends in India accessed from

https://www.jica.go.jp/india/english/office/others/c8h0vm0000f9enll-att/report_01.pdf

Hency Thacker (2020) CSR Initiatives Benefitting Farmers in Indiaaccessed from https://thecsrjournal.in/csr-initiatives-benefitting-farmers-in-india/

Hick, (2000): Morals Maketh the money. Australian CPA, 70:4, pp. 72-73

Guardian Newspaper, Nov. 2001

ICAR(2022) ICAR Guidelines for Utilization of Corporate Social Responsibility (CSR) Funds

accessed from https://icar.gov.in/file/14673/download?token=DWofJjGk

KPMG (2008) Corporate Social Responsibility – Towards a Sustainable Future A White Paper

KPMG in India accessed from http://www.in.kpmg.com/pdf/csr_whitepaper.pdf

Maniktala J., Punjabi L.C. (2016) Corporate Social Responsibility: Perspectives and Challenges in Rural India, Special Issue AETM'16,IOSR Journal of Business and Management (IOSR-JBM)

Mohanapriya.T, Senthilkumar V.M., Keerthana S.(2015) An Analysis on CSR of Selected Companies Supporting Agriculture in India, International Journal of Engineering and Management Research,5(2) .344:357

Ortega MI, Sabo S, Aranda Gallegos P, De Zapien JEG, Zapien A, Portillo Abril GE and Rosales C (2016) Agribusiness, Corporate Social Responsibility, and Health of Agricultural Migrant Workers. Front. Public Health 4:54.

Parveen Kumar (2022) Strengthening agriculture through CSR accessed from https://indiacsr.in/strengthening-agriculture-through-csr/

Poetz K, Haas R, BalzarovaM.(2013) CSR schemes in agribusiness: opening the black box. *Br Food J* (2013) 115(1):47–74.

Upadhyay Rajeev(2019) Corporate Social Responsibility and Sustainable Growth in Agriculture in India.Accessed fromhttps://www.researchgate.net/publication/337756065_Corporate_Social_Responsibility_and_Sustainable_Growth_in_Agriculture_in_India

PatilVeerendra(2016) CSR for farmers' welfareaccessed fromhttps://rotarynewsonline.org/csr-farmers-welfare/Weblinks:

CSR: Government Initiatives to Bring Sustainability in India's Agriculture, The CSR Journal April 12, 2019 accessed from https://thecsrjournal.in/csr-government-initiatives-to-bring-sustainability-in-indias-agriculture/

Five Food Processing Companies that Take CSR Seriously,The CSR Journal - November 3, 2021 accessed from https://krishi.outlookindia.com/story/csr-spending-in-agriculture-far-less-than-other-sectors-study/376748

Top CSR Initiatives Aimed at Improving Farmers' Incomes in India, The CSR Journal -July 14, 2022 accessed from https://thecsrjournal.in/csr-improving-farmers-incomes-india-corporate-social-responsibility/

Strengthening agriculture through CSRaccessed from https://indiacsr.in/author/indiacsr/

L-22

Potential characteristics of nano-formulations for the management of diseases in crops

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Nanotechnology is the most significant discovery of the twentieth century which has the potential to revolutionize almost all the existing science disciplines. Green synthesis of metallic nanoparticles (MPNs) by using biological organisms or plants seems to be very rapid, simple, dependable, non-toxic and eco-friendly. Nanoparticles synthesized using physical techniques or green Technology have diverse natures, with more excellent stability and appropriate dimensions since they're synthesized using a one-step procedure. These nanoparticles are very effective against plant pathogens with low toxicity and lead to broad applicability. It is efficiently used for site-targeted delivery of important agrochemical products and for diagnosis-purpose tools. For the management of plant diseases, plant-derived nanoparticles are superior to others as they do not required the maintenance of pure culture of microbes and easy to produce in large quantities.

Further, the nanoparticles synthesized by the plants do not required capping and save time and resources. The performance of the different nanoparticles is greatly affected by the other physiochemical characteristics. Size and surface area of the particles, particle shape and aspect ratio, surface charge, ccomposition and crystalline structure of the particles, aggregation and concentration of particles, surface coating and surface roughness, solvents/media, etc are some of the important aspects which regulate the efficiency of different nanoparticles and have been discussed. MNPs having all or most of the traits can be considered the best alternative for plant disease management. Eco-friendly system of MNPS seems to be simple, dependable and sage alternative of plant disease management.

INTRODUCTION

Nanotechnology is the most emerging field of science with wide application in all the sciences. Nanotechnology mainly involves the production, manipulation and use of materials ranging in size smaller than a micron to that of individual atoms. Richard Feyman firstly gave the concept of nanotechnology through his famous lecture entitled "There is a plenty of rooms at the bottom" at the American Institute of Technology. The word nanotechnology was firstly introduced by Prof. Norio Taniguchi of Tokyo Science University. The term "nano" comes from Greek word meaning "dwarf" and when it is used as prefix, it implies 10^9. A nanometre (nm) can be defined as it is one billion of a meters or roughly the length of three atoms side by side. A nanoparticle is a small microscopic particle having at least one dimension less than 100nm. The synthesis of nanoparticles with specific size, shape, composition and various important characteristics has explored the scope of their applications in various fields including agriculture, cosmetics, textiles, food, medicine and environment (Khandel and Shahi, 2018).

Nanotechnological applicability in crop disease protection offers a great promise in managing pathogens. These nanoparticles are very effective against phytopathogens with low toxicity and lead to broad range of applicability in pesticidal activity. It is efficiently used for site-targeted delivery of essential agrochemical products and for diagnosis purposes in case of prior detection of plant diseases (Chowdappa and Shivakumar, 2013). These nanoparticles have unique characteristics, which can be tailored for a specific application by modifying size, shape, and morphology.

Nanoparticles have been classified into various types according to their size, morphology, physical and chemical properties. Most of these are carbon-based, ceramic, metal, semiconductor, polymeric, and lipid-based nanoparticles.

Metallic nanoparticles (MNPs) are most frequently tested for their potential antimicrobial activities. These have a metal core composed of inorganic metal or metal oxide that is usually covered with a shell made up of organic or inorganic material or metal oxide.

Synthesis of metal nanoparticles

The synthesis of NPs is an important milestone of nanotechnology. The two different approaches to the synthesis of nanoparticles are graphically termed "top-down" and "bottom-up". Top-down (physical methods) or bottom-up (chemical and biological methods) are a measure of the level of advancement of nanotechnology. Top-down refers to making nanoscale structures by machining and etching techniques. In contrast, bottom-up or molecular nanotechnology, applies to building organic and inorganic systems atom-by-atom, or molecule-by-molecule.

Conventional approaches such as physical and chemical methods are proposed to synthesize MNPs (Iravani *et al*., 2014). However, these methods are associated with the use of heavy equipment, huge amount of energy input, and highly toxic and dangerous chemical compounds that generate biological hazards. Most of the time, these methods are not ecological and safe. Green synthesis of MPNs by using biological organisms of the plant seems to be very rapid, simple, dependable, non-toxic and eco-friendly. Nanoparticles synthesized using biological techniques or green Technology have diverse natures, with greater stability and appropriate dimensions since they're synthesized using a one-step procedure. Among the different metallic nanoparticles silver, copper, zinc, titanium, gold, etc are posses' antimicrobial properties.

Plant Mediated Synthesis of MNPs

The synthesis of metal nanoparticles using plant extracts is beneficial over other biological synthesis methods associated with complicated procedures such as maintaining microbial cultures. The low cost of cultivation, short production time, safety, and the ability to up production volumes make plants an attractive platform for nanoparticle synthesis (Dhuper *et al*., 2012). Plant-mediated MNPs are easy to recover and also exhibits a dual nature such as capping and reducing agent (Varma and Mehata, 2016). Plant materials such as leaf, fruit, bark, fruit peels, root, leaf, and callus have been used. Plant extracts involve phytochemicals like terpenoids, flavonoids, phenol derivatives, plant enzymes (hydrogenases, reductases) and their derivatives, di-hydric phenols act as a reductant in the presence of metal salt. The above evidence states the dependency of source, structure and type of phenolic phytochemical on different-sized nanoparticle formation (Ahmed *et al*., 2016).

Physicochemical Characterization of MNPs

After synthesis, MNPs, characterization of these is essential to investigate their characteristic features such as size and surface area, composition, shapes, etc (Jyoti *et al*., 2016). In general, toxicity and different characteristics have been thought to originate from nanomaterials.

Size and Surface Area of the Particles

Particle shape and size is main feature of nanoparticles and also decide their interaction in the biological system. Size and surface area are negatively correlated; therefore, apparently, decreasing the materials' size exponentially enhances its surface area relative to volume. The increased surface area leads nanoparticles more reactive than their larger size particles. The size also influences uptake and reactivities of the nanoparticles.

Effect of Particle Shape and Aspect Ratio

There has been a flurry of major advancement in the Understanding of the interplay between particle size and shape for development of more efficacious nanomaterial-based targeted delivery system; nevertheless, this also reinforces that their untoward effects should also be examined. Shape-dependent toxicity has been reported for myriads of nanoparticles including carbon nanotubes, silica, allotropies, nickel, gold, and titanium nanomaterials (Chithrani et al., 2006; Hamilton Jr, 2009; Ispas et al., 2009; Petersen and Nelson, 2010). Shape-dependent nanotoxicity influences the membrane wrapping processes *in vivo* (Verma and Stellacci, 2010). Moreover, it has also been observed that the higher the aspect ratio, the more the toxicity of particle (Fubini et al., 2011).

Effect of Surface Charge

Surface charge also plays a vital role in the toxicity of nanoparticles as it essentially defines their interactions with biological systems. Of note, positively charged nanoparticles show significant cellular uptake compared to negatively charged and neutral nanoparticles, owing to their enhanced opsonization by the plasma proteins.

Effect of Composition and Crystalline Structure

Although it has been emphasized that particle size plays a significant role in deciding the toxicity of nanoparticles, we cannot simply ignore studies exemplifying comparable toxicities for diverse nanoparticle chemistries having the exact dimensions. These studies highlight that nanoparticle composition and crystalline structure also influence their toxicity issues.

Effect of Aggregation and Concentration

The aggregation states of nanoparticles also influence their toxicities. The aggregation states of NPs depend on size, surface charge, and composition, among others. It has been observed that carbon nanotubes are mainly accumulated in the liver, spleen, and lungs without manifesting any acute toxicity but induce cytotoxic effects mostly because of the accumulation of aggregates for more extended periods (Yang et al., 2008). Agglomerated carbon nanotubes have more adverse effects than well-dispersed carbon nanotubes and enhance pulmonary interstitial fibrosis (Wick et al., 2007). Moreover, generally, it has been observed that with increase in the concentration of nanoparticles, the toxicity decreases at higher concentrations.

Effect of Surface Coating and Surface Roughness

The surface properties of particles have a significant role in the toxicity of nanoparticles as they play a critical role in determining the outcome of their interaction with the cells and other biological entities. Surface coating can affect the cytotoxic properties of nanoparticles by changing their physicochemical properties such as magnetic, electric, and optical properties and chemical reactivity. The surface coating has twofold activities. One side it reduces toxicity of the synthesized nanoparticles by coating its surface area. In contrast, another side, it enhances activities of the nanoparticles by providing site for the attachment of bioactive molecules. In general, the surface coating can mitigate or eliminate the adverse effects of nanoparticles. In particular, proper surface coating can lead to stabilization of nanoparticles as well as elude release of toxic ions from nanomaterials (Kirchner et al., 2005).

Surface modifications of NPs employing hydrophilic and flexible polyethylene glycol (e.g., pegylation) and other surfactant copolymers (e.g., poloxamers and polyethylene) have been considerably used by the research fraternity off late in this advancing field of nanotechnology to stabilize nanoparticulate systems in biological milieu (Gatoo et al., 2014).

Furthermore, as the attributes of nanoparticles such as surface roughness, hydrophobicity, and charge of nanoparticles influence the phenomena of cellular uptake of nanoparticles (Nel et al., 2009), they indeed influence the toxicity associated with nanoparticles. Surface coarseness dictates the strength of nanoparticle-cell interactions and promotes cell adhesion. Pore structure is critical in cell-nanoparticle interactions. It has been demonstrated that size dependent hemolysis effect of mesoporous silica nanoparticles is only observed when the nanoparticles have long range ordered porous structure (Lin et al., 2010; Angelis et al., 2010). Angelis et al. 2010 showed that nanoporous silicon NPs with a pore size of about 2 nm do not have any toxicity in mouse-models with no histological evidence of tissue pathology. Similarly, Park et al. 2009 observed that luminescent porous silicon nanoparticles did not show any toxicity in animal models.

Effect of Solvents/Media

Medium/solvent conditions have been known to affect particle dispersion and agglomeration state of nanoparticles, which in turn have an effect on their particle size, thereby influencing the toxicity associated with nanoparticles. It has been observed that particles of TiO2, ZnO, or carbon black have a significantly greater size in PBS than in water; moreover, it is also in general consensus that NPs display different diameters in the biological milieu (Sager et al., 2007; Jiang et al., 2009). Accordingly, the toxic effects of nanoparticles show variation depending upon the medium composition in which the nanoparticles are suspended; in another way round, the same nanoparticles exhibit different toxic manifestations when dissolved in other mediums (Colvin, 2003; Hou et al., 2013). Although the dispersing agent may improve the physicochemical and solution properties of nanomaterials formulations, they may also adversely affect the toxicity of nanomaterials.

REFERENCES

Ahmed S, Ahmad, M., Swami, B.L. and Ikram, S. (2016) A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. *Journal of Advanced Research* 7: 17-28.

Angelis, F. de, Pujia, A., Falcone C. et al., (2010) Water soluble nanoporous nanoparticle for in vivo targeted drug delivery and controlled release in B cells tumor context," *Nanoscale*, vol. 2, no. 10, pp. 2230–2236.

Chithrani, B. D., Ghazani, A. A. and Chan, W. C. W. (2006) Determining the size and shape dependence of gold nanoparticle uptake into mammalian cells," *Nano Letters*, vol. 6, no. 4, pp. 662–668.

Chowdappa P. and Shivakumar G. (2013) Nanotechnology in crop protection: status and cope. *Pest Manag Hortic Ecosys* 19:131–151

Colvin, V.L. (2003) The potential environmental impact of engineered nanomaterials," Nature Biotechnology, vol. 21, no. 10, pp. 1166–1170.

Dhuper, S., Panda D. and Nayak, P. (2012) Green synthesis and characterization of zero valent iron nanoparticles from the leaf extract of *Mangifera indica*. *Nano Trends: J Nanotech App* 13: 16-22.

Fubini, B., Fenoglio, I., Tomatis, M. and Turci, F. (2011) Effect of chemical composition and state of the surface on the toxic response to high aspect ratio nanomaterials," *Nanomedicine*, vol. 6, no. 5, pp. 899–920.

Gatoo, M.A., Naseem, S, Arfat, M.Y. Dar, A.M. Qasim, K., Zubair, S. (2014) Physicochemical Properties of Nanomaterials: Implication in Associated Toxic Manifestations", *BioMed Research International*, vol. 2014, Article ID 498420, 8 pages, 2014

Hamilton Jr., R. F., Porter, N.Wu, D., Buford, M. Wolfarth, M. and Holian, A. (2009) Particle length-dependent titanium dioxide nanomaterials toxicity and bioactivity," *Particle and Fibre Toxicology*, vol. 6, article 35.

Hou, W., Westerhoff, P. and Posner, J. D. (2013) Biological accumulation of engineered nanomaterials: a review of current knowledge," *Environmental Sciences: Processes and Impacts*, vol. 15, no. 1, pp. 103–122.

Iravani, S., Korbekandi, H., Mirmohammadi, S. V., and Zolfaghari, B. (2014). Synthesis of silver nanoparticles: chemical, physical and biological methods. *Research in pharmaceutical sciences*, *9*(6), 385–406.

Ispas, C., Andreescu, D. Patel, A. Goia, D. V. Andreescu, S. and Wallace, K. N. (2009) Toxicity and developmental defects of different sizes and shape nickel nanoparticles in zebrafish, *Environmental Science and Technology*, vol. 43, no. 16, pp. 6349– 6356.

Jiang, J., Oberdorster, G. and Biswas, P. (2009) Characterization of size, surface charge, and agglomeration state of nanoparticle dispersions for toxicological studies. *Journal of Nanoparticle Research*, vol. 11, no. 1, pp. 77–89.

Jyoti K., Baunthiyal M. and Singh, A. (2016) Characterization of silver nanoparticles synthesized using *Urtica dioica* Linn. leaves and their synergistic effects with antibiotics. *Journal of Radiation Research and Applied Sciences* 9: 217-227.

Khandel, P. and Shahi, S.K. (2018) Mycogenic nanoparticles and their bio-prospective applications: current status and future challenges. *J Nanostruct Chem* 8, 369–391.

Kirchner, C., Liedl, T., Kudera, S. et al. (2005), "Cytotoxicity of colloidal CdSe and CdSe/ZnS nanoparticles," *Nano Letters*, vol. 5, no. 2, pp. 331–338.

Lin, Y. S. and Haynes, C. L. (2010) Impacts of mesoporous silica nanoparticle size, pore ordering, and pore integrity on hemolytic activity," *Journal of the American Chemical Society*, vol. 132, no. 13, pp. 4834–4842.

Nel, A. E., Madler, L., Velegol, D. et al. (2009), Understanding bio-physicochemical interactions at the nano-bio interface," *Nature Materials*, vol. 8, no. 7, pp. 543–557.

Park, J. H., Gu, L. Maltzahn, G. von, et al., (2009) Biodegradable luminescent porous silicon nanoparticles for in vivo applications *Nature Materials*, vol. 8, no. 4, pp. 331–336.

Petersen, E. J. and Nelson, B. C. (2010) Mechanisms and measurements of nanomaterial-induced oxidative damage to DNA. *Analytical and Bioanalytical Chemistry*, vol. 398, no. 2, pp. 613–650.

Sager, T. M., Porter, D. W. and Robinson, V. A. (2007) Improved method to disperse nanoparticles for in vitro and in vivo investigation of toxicity," *Nanotoxicology*, vol. 1, no. 2, pp. 118–129.

Verma A, and Stellacci, F. (1010) Effect of surface properties on nanoparticle-cell interactions, *Small*, vol. 6, no. 1, pp. 12–21.

Verma, A. and Mehata, M.S. (2016) Controllable synthesis of silver nanoparticles using Neem leaves and their antimicrobial activity. *Journal of Radiation Research and Applied Sciences* 9: 109-115.

Wick, P., Manser, P., Limbach, L. K. et al. (2007) The degree and kind of agglomeration affect carbon nanotube cytotoxicity. *Toxicology Letters*, vol. 168, no. 2, pp. 121–131.

Yang, S., Wang, X., Jia G. et al., (2008) Long-term accumulation and low toxicity of single-walled carbon nanotubes in intravenously exposed mice, *Toxicology Letters*, vol. 181, no. 3, pp. 182–189.

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૦૩.	ઉત્પાદન શરૂ થયાનું વર્ષ	:	૧૯૫૬-૫૭
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- વર્ષ: ૨૦૦૭-૦૮, ૨૦૦૮-૦૯, ૨૦૦૯-૧૦, ૨૦૧૦-૧૧, ૨૦૧૫-૧૬, ૨૦૧૬-૧૭ અને ૨૦૧૯-૨૦ નો "*હાઈએસ્ટ સુગર કેઈન ક્રશિંગ ઈન ઈન્ડીયા*" એવોર્ડ.
- વર્ષ: ૨૦૦૭-૨૦૦૮, ૨૦૦૯-૨૦૧૦ અને ૨૦૧૩-૧૪ દરમ્યાન સેન્ટ્રલ એકસાઈઝ એન્ડ કસ્ટમ્સ તરફથી નોન એસ.એસ.આઈ. કેટેગરીમાં "*બેસ્ટ એસેસી*" એવોર્ડ.
- ઈન્ડીયન ઓર્ગેનાઈઝેશન ફોર કોમર્સ એન્ડ ઈન્ડસ્ટ્રી-દિલ્હી તરફથી "*ઈન્ડીયન એચીવર્સ એવોર્ડ ફોર ઈન્ડસ્ટ્રીઝ ડેવલપમેન્ટ-૨૦૦૮*"
- ઈન્ડીયન ઈન્ડસ્ટ્રીઝ ઈકોનોમીક ડેવલપમેન્ટ તરફથી "*ઈન્ડીયન લીડરશીપ એવોર્ડ ફોર ઈન્ડસ્ટ્રીઝ ડેવલપમેન્ટ-૨૦૧૧*"
- સધર્ન ગુજરાત ચેમ્બર્સ ઓફ કોમર્સ તરફથી તેના ગોલ્ડન જયુબીલી વર્ષ: ૨૦૧૨-૧૩ નિમિત્તે "*ફેરડીલ ફીલામેન્ટસ એવોર્ડસ ફોર આઉટસ્ટેન્ડીંગ વર્કસ ડન ફોર ટ્રેડ એન્ડ ઈન્ડસ્ટ્રી બાય એસોસીયેટસ*"
- ભારતીય સુગર-પૂને તરફથી "બેસ્ટ ઓવરઓલ પર્ફોર્મન્સ કો.ઓપરેટીવ સુગરમીલ એવોર્ડ"-૨૦૧૫
- બારડોલી પ્રદેશની શૈક્ષણિક તેમજ વૈદકીય સંસ્થાનાં વિકાસમાં બહુમુલ્ય ફાળો.

ઉત્તમ પ્રકારની સફેદ દાણાદાર ખાંડ બનાવનાર

વિશિષ્ટતાઓ

- બારડોલી પ્રદેશની સહકારી ક્ષેત્રે ગૌરવ અને પ્રતિષ્ઠા પ્રાપ્ત કરનારી સંસ્થા
- બારડોલી પ્રદેશ અને આજુબાજુનાં વિસ્તારમાં શેરડી ઉગાડનાર ખેડૂતોની આર્થિક, શૈક્ષણિક અને સામાજીક વિકાસ કરનારી સંસ્થા.
- આધુનિક યાંત્રિકરણ દ્વારા સફેદ પાસાદાર અને ઉત્તમ કવોલીટીની ખાંડનું ઉત્પાદન કરનારી સંસ્થા.
- ગ્રામ્ય વિસ્તારમાં ઉત્તરોત્તર મહત્વનો ફાળો આપનારી ખેડૂતોની સહકારી સંસ્થા

રસીકલાલ સુખાભાઈ પટેલ	*ભાવેશભાઈ નગીનભાઈ પટેલ*	*હેમ પ્રકાશ સિંહ*
પ્રમુખ	ઉપપ્રમુખ	ઈ.ચા.મેનેજીંગ ડીરેકટર

તથા
વ્યવસ્થાપક સમિતિના સભ્યો અને સભાસદ પરિવાર

સહકારી ખાંડ ઉદ્યોગ મંડળ લિ., ગણદેવી

વાયા. બીલીમોરા, જી. નવસારી
પીનકોડ-૩૯૬ ૩૬૦
* * * * *

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૨૦૨૧-૨૦૨૨ ના વર્ષની સિધ્ધિઓ

શેરડી પીલાણ	ખાંડની રીકવરી	ખાંડ ઉત્પાદન ગુણી
૧૨,૦૦,૯૬૩	૧૧.૬૦ ટકા	૧૩,૯૧,૫૩૦

ઈથેનોલ - ૯૯,૧૬,૮૧૮ લીટર   રેકટીફાઈડ સ્પીરીટ-૧,૩૦,૮૪,૬૭૯ લીટર
દૈનિક પીલાણ ક્ષમતા ૫૦૦૦ ટી.સી.ડી.
૪૫ કે.એલ.પી.ડી.ડીસ્ટીલરી પ્લાન્ટ
૪૦ કે.એલ.પી.ડી. ઈથેનોલ પ્લાન્ટ
બાયો કંમ્પોસ્ટ પ્લાન્ટ

ગણદેવીની સફેદ પાસાદાર
ખાંડ
વાપરવાનો આગ્રહ રાખો

શ્રી રતિલાલ છગનલાલ પટેલ	- કાર્યકારી ચેરમેનશ્રી	શ્રી અલ્પેશભાઈ ચંદુભાઈ દેસાઈ	-ડીરેકટરશ્રી
શ્રી જયંતિલાલ બાપજીભાઈ પટેલ	- ડીરેકટરશ્રી	શ્રી ગણપતસિંહ વલ્લભભાઈ ચૌહાણ	-ડીરેકટરશ્રી
શ્રી રાજેશકુમાર ભીખુભાઈ પટેલ	- ડીરેકટરશ્રી	શ્રીમતી કામિનીબેન અનિલભાઈ નાયક	-ડીરેકટરશ્રી
શ્રી અભિષેક નટવરલાલ પટેલ	- ડીરેકટરશ્રી	શ્રીમતી પુનમ અનિરૂધ્ધ દેસાઈ	-ડીરેકટરશ્રી
શ્રી રણજીતભાઈ નાથુભાઈ પટેલ	- ડીરેકટરશ્રી	શ્રી વિરેન્દ્રભાઈ રમણભાઈ પટેલ	-ડીરેકટરશ્રી
શ્રી અરૂણભાઈ ગોવિંદભાઈ પટેલ	- ડીરેકટરશ્રી	શ્રી અમૃતભાઈ ખંડુભાઈ નાયક	-ડીરેકટરશ્રી
શ્રી સન્મુખભાઈ લલ્લુભાઈ પટેલ	- ડીરેકટરશ્રી	શ્રી ગોવિંદભાઈ ટી. પટેલ-વલસાડ ડી.સે.કો-ઓ.બેન્ક લિ., વલસાડના પ્રતિનિધીશ્રી	
શ્રી મેહુલકુમાર ગિરીશભાઈ પટેલ	- ડીરેકટરશ્રી	શ્રી ખાંડ નિયામક રજિસ્ટ્રારશ્રીના પ્રતિનિધી-ગાંધીનગર	
શ્રી નટુભાઈ દીકુભાઈ પટેલ	- ડીરેકટરશ્રી	શ્રી અમૃતભાઈ એચ. પટેલ-રાજ્ય સંઘ પ્રતિનિધી-ગાંધીનગર	
શ્રી કાંતિલાલ દયાળજી પટેલ	- ડીરેકટરશ્રી	શ્રી બાલાજી ડી. પબસેત્વાર -મેનેજીંગ ડીરેકટર	

બાલાજી ડી. પબસેત્વાર	રતિલાલ સી. પટેલ
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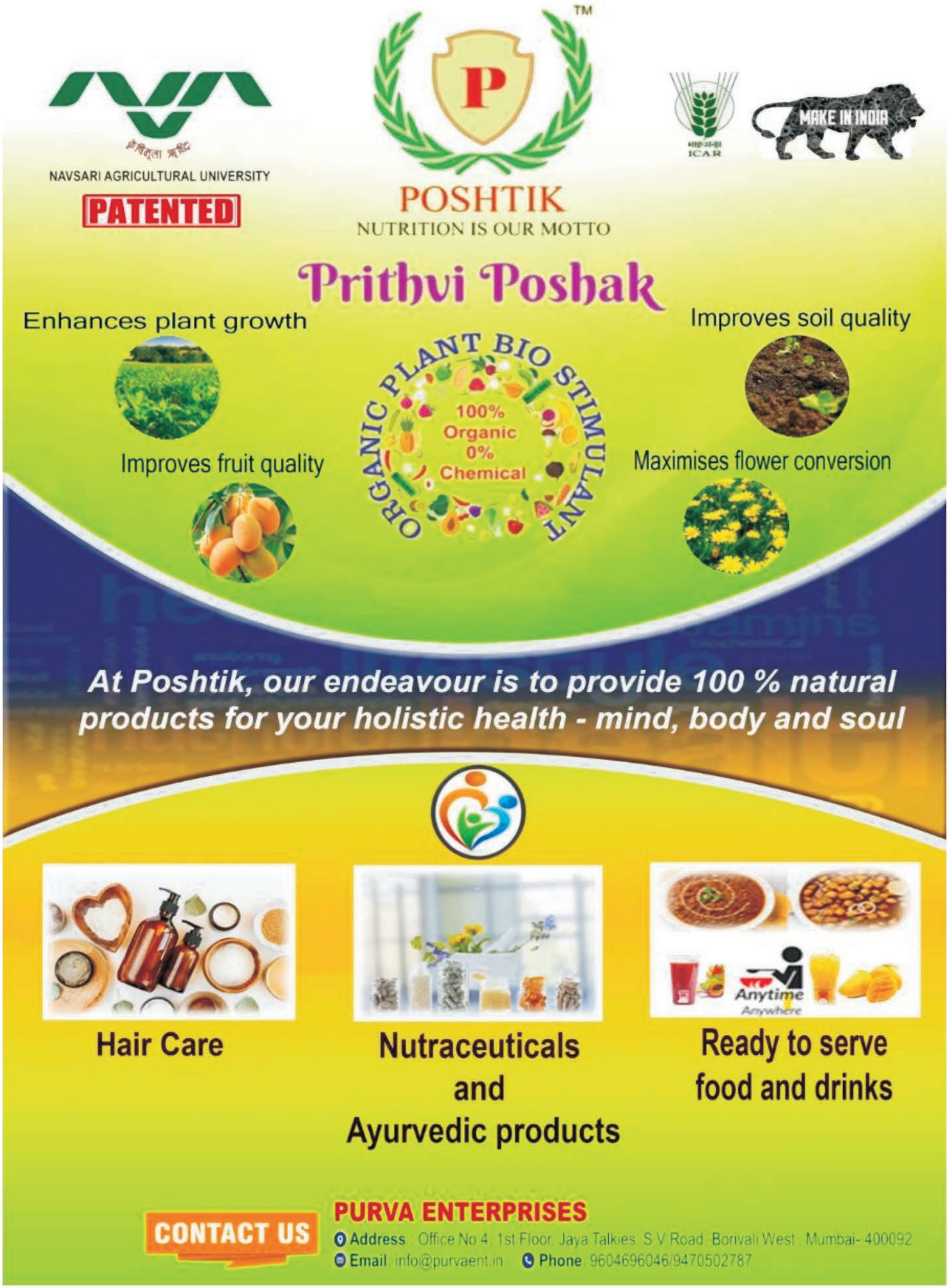
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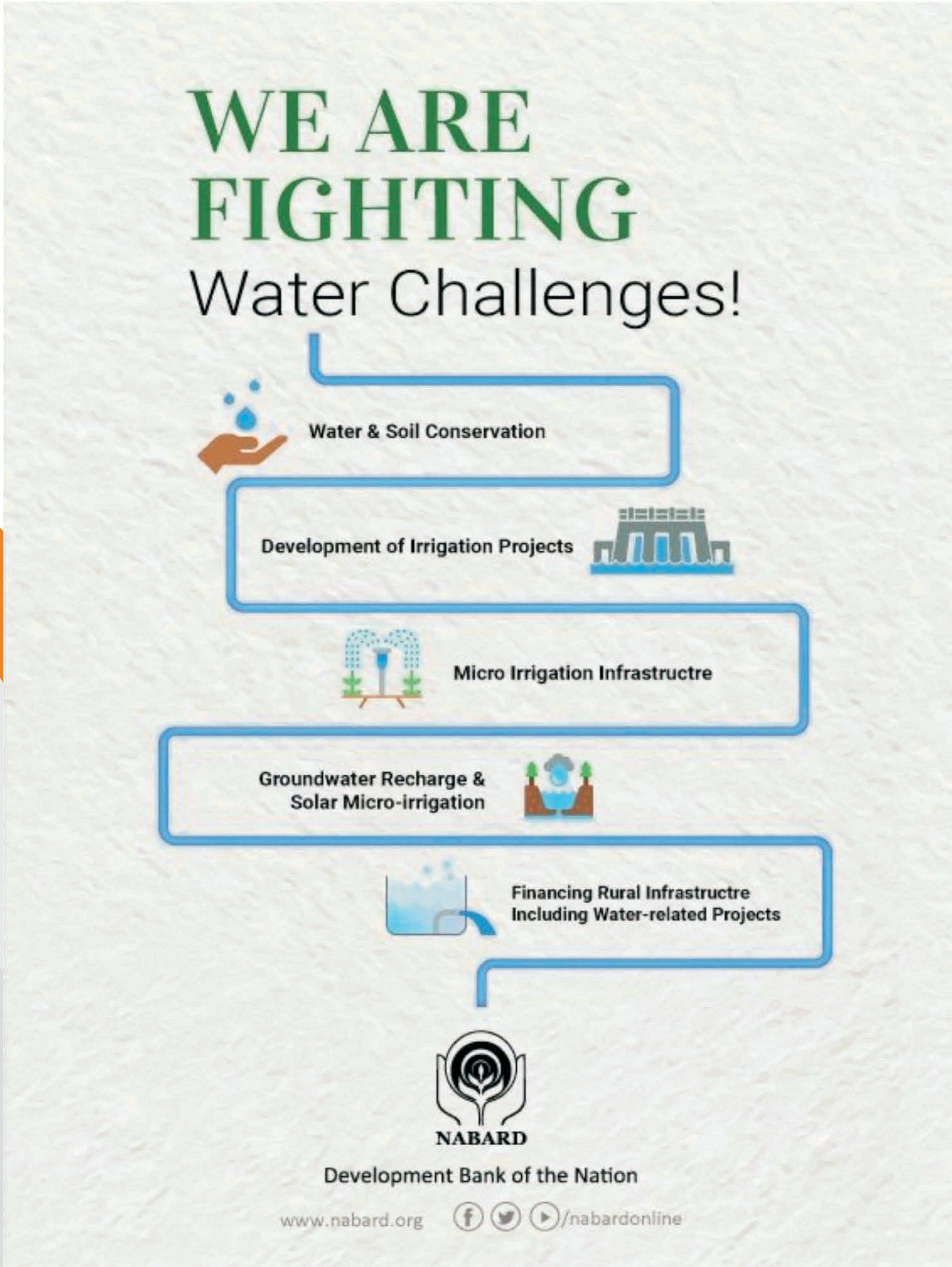
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