Training Manual

ICAR Sponsored Winter School on

Building Climate Resilience & Sustainability through Agro-EcoTourism

03-23 February 2025 (21 days)

Sponsored by
Agricultural Education Division, ICAR, New Delhi

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About ICAR-CCARI

ICAR-Central Coastal Agricultural Research Institute (CCARI), Old Goa, Goa. ICAR - CCARI is one of the research institutes established under Indian Council of Agricultural Research (ICAR), New Delhi established in 1976 as a regional centre under ICAR Research Complex for Northeast Hill region. Considering the importance of agriculture in Goa state, ICAR upgraded the centre into an Independent Institute ICAR Research Complex for Goa from 1989. Subsequently, this Institute has been upgraded from 2014 as ICAR-Central Coastal Agricultural Research Institute. ICAR-CCARI is situated in Old Goa, the historical capital of Goa during Portuguese times. ICAR-CCARI is mainly involved in research activities, which are aimed at improving the production and productivity of field and horticulture crops, livestock, Poultry and fisheries of the coastal region through various strategies including agro-eco-tourism.

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Citation:

V Paramesha, RS Rajkumar, GR Mahajan, AR Uthappa, VA Ubarhande, and P Kumar. (2025). Building Climate Resilience and Sustainability through Agro-Ecotourism. ICAR- Central Coastal Agricultural Research Institute, Ela, Old Goa -403402, Goa, India, p270.

Published by

ICAR-Central Coastal Agricultural Research Institute, Goa-403402

Financial assistance

Agricultural Education Division, ICAR, New Delhi – 110012

Technical assistance

Shri Vishwajeet Prajapati

Preface

In the context of escalating climate challenges, the imperative for adaptive strategies that promote environmental sustainability, economic resilience, and social equity has become increasingly critical. The training "Building Climate Resilience and Sustainability through Agro-Ecotourism" presents a timely and innovative approach to addressing the complexities of climate change while concurrently leveraging the potential of agroecological systems and tourism to drive sustainable development. This comprehensive training program is designed to equip participants with the requisite knowledge, tools, and strategies to effectively integrate agro-ecotourism as a viable model for enhancing resilience within vulnerable communities. Agro-ecotourism, which combines the principles of sustainable agriculture with the biodiversity of natural ecosystems, offers a robust mechanism for conserving biodiversity, promoting sustainable livelihoods, and mitigating the impacts of climate change. By harnessing the economic potential of both the agriculture and tourism sectors, this approach facilitates the creation of synergistic solutions that benefit farmers, rural communities, and the environment simultaneously.

This training curriculum encompasses an in-depth exploration of the core principles underpinning agro-ecotourism, analysis of case studies demonstrating successful implementations, and engagement in practical exercises designed to foster a comprehensive understanding of how to position agro-ecotourism as a cornerstone of climate resilience. The primary objective of training is not only to enhance participants' capacity to manage and promote agro-ecotourism initiatives but also to promote a profound sense of responsibility for the long-term sustainability of global ecosystems. The solutions developed and implemented today will significantly influence the climate resilience and sustainability of future generations. This training program represents more than an educational opportunity; it is a platform for contributing to a transformative movement capable of revolutionizing agricultural practices, preserving ecosystems, and ensuring a more sustainable and prosperous future for global populations. Collaborative efforts, guided by a shared vision, are essential in creating a world where agriculture, tourism, and the environment coexist and thrive in harmony, thereby addressing the multifaceted challenges posed by climate change and environmental degradation.

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Glorious Journey of Indian Agriculture

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Introduction

Agriculture serves as the backbone of India's livelihood, civilization, culture, and heritage. With a population of 1.39 billion, India is the second most populous country globally and is expected to surpass China by 2027-30. It ranks as the seventh-largest country geographically, covering 328 million hectares (Mha). India boasts 160 Mha of arable land, the second-largest after the United States, and experiences all 15 major climate types, with 46 out of 60 global soil types. Around 50% of the country's geographical area is cultivated, making India one of the largest users of land for agriculture. In regions like the Indo-Gangetic Plain (IGP) and the eastern coast's deltas, the proportion of cultivated land often exceeds 90% of the total area. Indian agriculture, one of the oldest in the world, is diverse, heterogeneous, and often unstructured, subject to various uncertainties throughout the agricultural cycle from "seed to market." It is a crucial sector for the country's sustainable and inclusive economic growth, employing 49.6% of the workforce, many of whom are under-employed or underpaid, while contributing about 17% to India's Gross Domestic Product (GDP). Since its inception, Indian agriculture has made remarkable progress, but there have been periods of severe food shortages that impacted the civilization. Pre-independence, agriculture heavily relied on climate, with the southwest monsoon being the primary source of water for crops. Unfavourable monsoons often caused droughts, leading to crop failures, and sometimes these droughts occurred consecutively, resulting in famines (ICAR 1988).

The importance of agriculture was underscored by India's first Prime Minister, Pandit Jawaharlal Nehru, who famously stated, "everything can wait but agriculture," and Mahatma Gandhi's remark that "there are people in the world so hungry, that God can not appear to them except in the form of bread." This reflected the priority given to agriculture after independence, beginning with the "Grow More Food" campaign in 1947. This initiative gained momentum through scientific innovation, rigorous planning, and the tireless efforts of millions of farmers. Despite challenges like uncertain weather patterns, soil degradation, rising temperatures, and the emergence of new pests and diseases, science-driven agricultural development helped India transition from a food-deficit country to one that is food-sufficient, surplus, and even an exporter. From 1950-51, food grain production increased from 51 million tons to over 314 million tons by 2021-22, with other agricultural sectors such as horticulture, milk, and fish showing significant growth. India is now the largest producer of milk, pulses, and jute, and the second-largest producer of rice, wheat, cotton, and vegetables, as a result of contributions from agricultural scientists. The country is also a major producer of spices, fish, poultry, livestock, and plantation crops.

However, the agriculture sector faces new challenges. Increasing population and changing economies are driving the demand for more diversified and higher-quality food, while the agricultural resource base is depleting. The rising costs of inputs, machinery, and labor have put pressure on farm profitability, making agriculture less attractive as a profession. Moreover, the growth rate of productivity in many crops has plateaued, and climate change exacerbates the situation. Nearly 49% of India's cultivated land is rainfed, making it vulnerable to biotic and abiotic stresses. Even areas with irrigation systems face water shortages in the event of deficient monsoons. The increased frequency of floods, heatwaves, and cyclones has added to the sector's challenges. Despite these obstacles, agriculture remains a critical sector for India, having shown remarkable resilience over the past 75 years. This was especially evident during the COVID-19 pandemic when agriculture stood as the nation's savior, ensuring food security when other sectors struggled. In this chapter, we explore the scale, uniqueness, and diversity of Indian agriculture, the milestones achieved, the contributions of research and development, and the emerging challenges to ensure that Indian agriculture remains productive, profitable, and sustainable (Mohapatra and Raut 2021).

2. Unique, vast and diversified agriculture in India

Indian agriculture is as varied as the country itself, shaped by a wide range of agro-ecosystems that result from a combination of climatic, soil, geological, vegetational, and other natural factors. These elements have driven the development of diverse habitats, crops, and livestock over thousands of years. India is one of the earliest regions where settled agriculture began around 11,000 years ago and is one of the eight global centers of origin for crop plants. The country is home to 166 crop species and 320 wild relatives of crops. The genetic diversity within these species is extraordinary. For instance, a single species of rice has evolved into at least 50,000 distinct varieties, while a mango species has given rise to over 1,000 varieties, ranging in size from a peanut to a small pumpkin. India also boasts the largest diversity of livestock in the world, with all eight buffalo breeds found here. This diversification goes beyond physical adaptation, as economic, cultural, religious, and survival factors have all contributed to it. Numerous rice varieties and other crops, for instance, have been grown specifically for use in festivals, weddings, or other auspicious events, while others have been cultivated for their taste, color, fragrance, or even for their pesticidal or soil-enriching properties. India's climate ranges from humid and dry tropical conditions in the south to temperate alpine climates in the north. It is home to a vast agro-ecological diversity, including four of the world's 34 biodiversity hotspots and 15 of the World Wide Fund for Nature's (WWF) global 200 eco-regions. Despite accounting for just 2.4% of the world's land area, India harbors around 8% of all recorded species, including over 45,000 plant species and 91,000 animal species (ICAR 2021).

Water availability in India, like its climate, is regionally diverse and highly seasonal, primarily dependent on the southwest monsoon and, to a lesser extent, the northeast monsoon in a few southern states. Irrigation availability varies significantly across regions. In the Indo-Gangetic Plain (IGP), perennial rivers from the Himalayas and groundwater recharge ensure a steady supply of water, but rapidly depleting groundwater levels are raising concerns about long-term crop productivity and sustainability. In contrast, peninsular India faces a more irregular rainfall pattern, with a lack of perennial water streams and hard rock formations that limit groundwater recharge. India is also endowed with fertile alluvial soils in regions like the IGP, productive black soils in the Deccan Plateau, and red-to-yellow lateritic soils, though many other areas have soils that are relatively low in fertility. Overall, the organic carbon content in Indian soils is less than 0.5%, and this is on the decline.

The country's agricultural diversity is reflected in the wide range of crops grown, with approximately 60 crops cultivated in certain states. This number could be higher when localized crops are considered. Rice is the dominant crop of the kharif season, followed by wheat in the rabi season. Other significant cereals include maize, sorghum, pearl millet, and finger millet. Pulses, particularly chickpeas, are another major crop, serving as an essential source of plant-based protein for many Indians. Oilseeds, including soybean, rapeseed, mustard, and groundnut, are also important crops for edible oil production. Sugarcane, cotton, jute, mesta, tobacco, tea, and other crops are grown for industrial use. Non-staple crops like tomato, onion, potato, brinjal, okra, squashes, mango, banana, mandarin orange, papaya, and melons, along with various spices such as chilies, turmeric, and ginger, are cultivated both for domestic consumption and export. India has a long history of cultivating and exporting these crops globally.

Animal husbandry plays a crucial role in India's agricultural system. The country's livestock resources are a traditional strength and offer a sustainable and profitable approach to agriculture. India has the largest bovine population in the world, and mixed farming, which combines crops and livestock, is common across the country. India's total livestock population stands at 536 million, with cattle constituting 36% and buffaloes 20%. In 2021-22, India produced 210 million tons of milk, with a per capita availability of nearly 400 grams per day. Most of this milk comes from small and marginal farmers. The Indian Council of Agricultural Research (ICAR) has classified the country's livestock population, registering 197 breeds across various species, including 50 breeds of cattle, 17 breeds of buffaloes, 34 breeds of goats, 44 breeds of sheep, 9 breeds of camels, 7 breeds of horses, 19 breeds of chicken, and 3 breeds of dogs. Fishing is another key component of India's agricultural system, with the country's coastline and its reservoirs and lakes supporting a thriving fishing industry. The marine and inland fisheries contribute 3.8 million tons and 1.3 million tons, respectively, to total production. Major marine catches include sardine and mackerel, while carps dominate the freshwater catches. Aquaculture, especially the farming of fish and shrimp, is rapidly growing, contributing over 9.0 million tons.

3. Landmark Achievements in Indian Agriculture

In 1950-51, India's agricultural production was approximately 135 million tons (Mt). By 2021-22, the total production of food and non-food items had surged to about 1,300 million tons, marking a remarkable increase in output. Despite the net sown area remaining relatively constant at about 140 million hectares, the production of agricultural commodities has increased multi-fold. India is now one of the world's largest agricultural producers, consistently ranking among the top five countries in terms of output. This progress has not only made India self-sufficient in food but has also led to the export of agricultural commodities worth US$ 50 billion. Most agricultural commodities have seen production increases ranging from six to sixty-eight times, with only a modest increase in cultivated area. From being food-scarce until 1950, India progressed through stages of food shortage (1960), food sufficiency (2000), food security (2010), and food surplus (2010 onward). Even during the ongoing COVID-19 pandemic, India's food production systems continued to meet demand, aided by innovative interventions across the value chain. Additionally, recent data indicates a reduction in greenhouse gas (GHG) emissions intensity in agriculture and improvements in fertilizer use efficiency. The transformation of India from a food-scarce nation to a food-surplus one has been driven by a combination of science, technology, extension services, and policy.

3.1 Field crops

In the mid-1960s, Indian agriculture achieved a pivotal milestone with the onset of the Green Revolution. This was followed by successive revolutions in the production of sugar, oilseeds, pulses, and other crops, significantly enhancing the nation's food security. The term "Green Revolution" was coined by William Gaud of USAID in 1968, and that same year, the Government of India honored the achievement by issuing a postal stamp (Fig. 3). The introduction and widespread adoption of semi-dwarf, photo-insensitive, input-responsive, and high-yielding varieties of wheat and rice catalyzed an unprecedented transformation in India's agricultural landscape and food security. Technology played a central role in this revolution, with roughly 80% of the production gains attributed to improvements in crop yields. The success of the Technology Mission on Oilseeds (TMO) launched in 1986 triggered the Yellow Revolution, which led to a dramatic rise in edible oil production, from 10.8 million tons (Mt) in 1985-86 to 24.7 Mt in 1998-99. Over a decade, from 1985 to 1996, the area under oilseed cultivation grew from 19 to 26 million hectares (Mha). Similarly, pulses were incorporated into the TMO in 1991, and by the late 2010s, India achieved near self-sufficiency in pulses production (Yadav et al., 2019). Pulse production, which had been stagnant at 14-15 Mt until 0significant achievement, with sugarcane production climbing from 57.05 Mt in 1950-51 to 405.42 Mt in 2019-20. Over the years, ICAR has developed 115 improved sugarcane varieties, which have contributed to steady increases in production and sugar recovery rates. In total, ICAR has released over 6,000 varieties for cereals, oilseeds, pulses, fiber crops, forage crops, and sugarcane, including 55 varieties developed through marker-assisted selection to meet the diverse needs of farmers. Between 2014 and 2021, ICAR released 1,575 high-yielding crop varieties, over 1,300 of which are climate-resilient. These varieties incorporate traits such as drought and submergence tolerance, disease resistance, and enhanced nutritional quality, achieved through genomic techniques like marker-assisted selection. During this period, 87 bio-fortified crop varieties, enriched with higher levels of iron, zinc, protein, or pro-vitamin A, were also developed. ICAR has played a critical role in transforming India's seed sector, significantly boosting the production of breeder seeds and enhancing the varietal and seed replacement rates in pulses, oilseeds, and cereals. One of ICAR's landmark achievements is the development of internationally recognized and trade-preferred Basmati rice, which dominates global Basmati rice trade. In 2018-19, India earned Rs. 32,806 crores from Basmati rice exports. ICAR has also developed genomic resources for 16 commodities and successfully applied genome editing in major rice varieties like MUT1010, Pusa 44, & Pusa Basmati 1.

3.2 Horticulture

The development of improved varieties and hybrids of horticultural crops has been instrumental in enhancing the production of fruits and vegetables, which contributes to both nutrition and farmers' income. ICAR has released 1,596 high-yielding varieties and hybrids across various horticultural crops, including fruits, vegetables, ornamental plants, plantation crops, spices, medicinal plants, and mushrooms. These efforts have resulted in a record production of 333 million tons (Mt) from this sector in 2021-22. To further support exports, ICAR has developed good agricultural practices (GAP) and quality standards for key crops such as apple, mango, grape, banana, orange, guava, litchi, papaya, pineapple, sapota, onion, potato, tomato, pea, and cauliflower. Sea route protocols for transporting banana and mango have been standardized to reduce export costs. Additionally, advanced techniques for producing disease-free planting materials have been developed for crops like citrus, banana, guava, potato, cassava, and sweet potato. Micropropagation methods have been optimized for rapid, large-scale multiplication of several plant species. India's floral diversity, particularly in regions like Uttarakhand, Sikkim, and Arunachal Pradesh, has earned it recognition as a global center for flowering plants. Hybrids in vegetables have revolutionized production, establishing India as the second-largest vegetable producer worldwide and bolstering nutritional security. Highly productive hybrids have also been developed in coconut, mango, ber, and aonla. India remains the global leader in mango production and the development of hybrid mango varieties with enhanced productivity, fruit size, color, aroma, and quality. In vitro culture techniques have transformed banana cultivation, with 45% of banana area now planted with tissue-cultured plantlets. India is the world's largest producer of pomegranate, with 86% of the area under the Bhagwa variety, and export earnings from pomegranate have surged from Rs. 21 crores in 2003-04 to Rs. 688 crores in 2021-22. Grapes, another key export crop, have seen increased productivity and profitability through the adoption of dogridge rootstock. The growing popularity of Kamalam (dragon fruit) has also led to rapid adoption of this exotic fruit. The horticultural revolution hinges on the availability of high-quality planting materials, which have seen significant improvements in recent years.

3.3 Animal Husbandry

India's livestock sector has experienced remarkable growth since independence. In the 1950s and 1960s, India was a milk-deficit nation, importing both milk and milk powder. The launch of Operation Flood in 1970, one of the world's largest rural development programs, led to steady annual growth of 6.4% in milk production, outpacing the global growth rate of 2.2%. Today, per capita milk availability in India is approximately 400 grams per day, significantly higher than the global average of 300 grams per day. Efforts to improve livestock genetics have focused on increasing milk yield, body growth, and reproductive performance. Several breeds of cattle, goats, sheep, camels, and poultry have been conserved in their native habitats and through the preservation of embryos, semen, and DNA. Notably, India has successfully produced cloned buffalo calves using inter-species cloning from progeny-tested buffalo bulls and wild buffaloes. ICAR has developed vaccines and diagnostic tools to control livestock diseases, including vaccines for avian influenza, sheep pox, and swine fever. A key achievement was the eradication of Rinderpest in 2011, the first animal disease to be eradicated globally. The poultry sector has also grown rapidly, with India now being one of the world's largest producers of eggs and broiler meat. In 2020, 197 indigenous livestock breeds were officially registered, and in 2021, three indigenous dog breeds were also recognized.

3.4 Fisheries

The Blue Revolution has greatly expanded fish production, making India the second-largest fish producer globally. A genetically improved strain of rohu, known as 'Jayanti Rohu,' has been developed through selective breeding, achieving 17% higher growth per generation. Freshwater aquaculture has diversified to include more than two dozen important species, such as carps, catfish, and freshwater prawns, with established breeding and seed production practices. Marine cage culture has also been successfully implemented for farming high-value fish species along the Indian coasts. Several value-added fish products, as well as nutraceuticals from seaweeds, have been developed. The introduction of induced breeding techniques for carp, including hypophysation, has increased national productivity in pond-culture carp from 0.6 tons per hectare per year to 3.5 tons per hectare per year. India is now the second-largest aquaculture producer globally.

3.5 Natural resources management

The conservation and restoration of natural resources have become critical priorities in the face of increasing pressures from population growth and development, coupled with the deterioration in resource quality. To ensure sustainable development, India has recognized that science-driven management practices are essential to maximize resource use while minimizing waste. ICAR has developed comprehensive land resource inventories to guide the effective and sustainable use of natural resources. Key spatial tools for resource planning include soil resource maps at national (1:1 million scale), state (1:250,000 scale), and district levels (1:50,000 scale); soil degradation maps (1:4.4 million scale) and soil erosion maps at the state level (1:250,000 scale). In addition, geo-referenced soil fertility maps for major, micro, and secondary plant nutrients have been created to facilitate optimal nutrient usage at the farm level and guide fertilizer planning at the macro level. The data on wastelands has been standardized for better implementation of reclamation and conservation efforts. To address land degradation, ICAR developed gypsum-based technology, which has been instrumental in reclaiming over 1.3 million hectares of degraded land. Furthermore, a field kit for assessing soil sodicity in salt-affected areas has been developed to ensure ongoing monitoring and reclamation. A landmark achievement has been the preparation and distribution of soil health cards, with ICAR Institutes and Krishi Vigyan Kendras (KVKs) playing a pivotal role. ICAR also developed the Mridaparikshak, a portable soil testing kit, to supplement soil testing services nationwide.

Water Resource Management

Agriculture in India consumes more than 80% of the country's freshwater for irrigation. Water resource management thus became a priority post-independence, with the initiation of major and medium irrigation projects. Enhancing on-farm water use efficiency and promoting rainwater harvesting have been central to ICAR's initiatives. Several in-situ water conservation and management techniques have been developed over the years, and more recently, regional crop plans for efficient water management have been implemented. Additionally, ICAR has pioneered drip fertigation systems, which optimize both water and nutrient use efficiency. Integrated Farming System (IFS) models have also been developed to increase farm productivity and the income of small and marginal farmers. Over 65 multi-enterprise IFS models have been demonstrated across various agro-climatic zones. Technologies like rubber dams for water harvesting in micro-watersheds and micro-rainwater harvesting structures, such as the "Jalkund" in the Northeast region (with a 30,000-liter capacity), have also been developed.

Climate Change Mitigation and Adaptation

Global climate change is already affecting crops, soils, water, biodiversity, livestock, and fisheries in India. Agriculture contributes to global warming, primarily through methane and nitrous oxide emissions. While early estimates in 1990 suggested that Indian rice fields emitted 37.5 Mt of methane per year, indigenous research has reduced this figure to a more accurate 3.3 Mt per year. A comprehensive inventory of greenhouse gas emissions from Indian agriculture was also prepared (Pathak, 2015), strengthening the position of rice-producing countries in global climate negotiations. To mitigate climate change, ICAR developed InfoCrop, a crop simulation model tailored to tropical environments, to assess the impacts of climate change and optimize input use for higher efficiency and lower emissions. Several mitigation and adaptation technologies for climate-resilient agriculture have been created, which will help India achieve net-zero emissions and carbon neutrality in alignment with its commitments to the United Nations. Under the NICRA (National Initiative on Climate Resilient Agriculture) project, ICAR has developed a Vulnerability Atlas and established 446 climate-resilient villages in 151 clusters, with plans to expand to 300 by 2024. Technical support has been provided to states for the implementation of District Agricultural Contingency Plans across over 600 districts. ICAR has also set up facilities like high-throughput phenotyping platforms, rainout shelters, animal calorimeters, shipping vessels, flux towers, and satellite data receiving stations to support climate change research (Pathak and Ayyappan 2020).

3.6 Agricultural Engineering

Farm mechanization has been a key focus to reduce labor, save time, cut production costs, reduce post-harvest losses, and boost crop yields and farm incomes. ICAR has developed over 210 farm technologies and implements, with 23,197 prototypes of various farm machines. Notable innovations include the Happy Seeder, which has significantly reduced the burning of rice straw in north-west India, leading to improved farmer incomes. Similarly, the zero-tillage machine has enabled farmers to practice no-till farming on a commercial scale, conserving energy, water, and time while also increasing yields.

3.7 Agricultural Education

A scientific and robust agricultural education system is crucial for the long-term sustainability of Indian agriculture. The establishment of State Agricultural Universities (SAUs) since the 1960s, along with deemed universities, has played a central role in ushering in the Green Revolution, followed by the White, Yellow, and Blue Revolutions. This vision began in 1949 with Dr. S. Radhakrishnan, the first Vice President of India, who advocated for autonomous rural universities that would teach agricultural sciences alongside humanities and natural sciences. The Indo-American teams of 1955 and 1959 recommended the establishment of agricultural universities modeled on the Land Grant University system of the U.S. In 1958, the Indian Agricultural Research Institute (IARI) in New Delhi became a Deemed University, and in 1960, the first SAU was established at Pantnagar. Today, India has one of the largest agricultural education systems globally, comprising 113 ICAR Institutes, 74 SAUs, 4 Deemed Universities, 3 Central Agricultural Universities (CAUs), and 4 Central Universities with agricultural faculties. These institutions offer advanced degrees in more than 30 agricultural disciplines.

3.8 Technology Transfer and Agricultural Extension

ICAR has been at the forefront of developing efficient and effective technology transfer systems aimed at bridging the gap between technology generation and its adoption by farmers. Over time, the agricultural extension system in India has evolved from its early land-grant college-based education model, which employed a top-down approach for technology transfer (ToT), to a more decentralized, market-driven, and farmer-centric approach. This shift has led to a focus on income-enhancing, diversified technologies, on-the-job vocational training, and sustainable agricultural practices, moving from centralized funding to decentralized, bottom-up models like the ATMA (Agricultural Technology Management Agency).

The extension efforts are carried out by four major systems: (i) The Department of Agriculture and Farmers Welfare (DAFW) and related rural development ministries, along with some voluntary organizations; (ii) Frontline extension systems, such as KVKs (Krishi Vigyan Kendras), ICAR institutes, and SAUs (State Agricultural Universities); (iii) Commodity-specific extension services provided by various commodity boards; and (iv) Input-specific extension services from agri-business agencies. KVKs play a crucial role as the primary gateway for frontline innovation, generating and disseminating technology at the district level.

Starting with the first KVK in Puducherry in 1974, the network has grown to 730 KVKs by 2022, hosted by agricultural universities, state governments, NGOs, and public sector undertakings. With mobile connectivity reaching over 1.2 billion people, around 3.5 lakh rural common service centers (CSCs), and KVKs across all rural districts, Indian agriculture is poised for a digital revolution – the rise of "Smart Farmers & Farming." ICAR has developed over 80 mobile apps covering various aspects of farm and farmer-related services. KVKs provide agro-advisories and services through mobile platforms, extending their reach to rural areas. With integration into CSCs, these platforms provide demand-driven services to farmers. The Council's motto, "Agri Search with a Human Touch," reflects the importance it places on technology transfer and its commitment to empowering the farming community. Efforts are also underway to enhance the capacity of community-based organizations and farmer groups to acquire and transfer knowledge more rapidly. National and regional research-extension linkages have been institutionalized, enabling the development of participatory research and extension models such as Farmer Producer Organizations (FPOs), Climate-Smart Extension, and initiatives like Farmer FIRST, ARYA (Attracting and Retaining Youth in Agriculture), and mKisan, among others. These models and technologies are designed to address the evolving needs of farmers, enhance their income, and ensure sustainable agricultural growth.

4. National and International Collaborations

Collaborations in agricultural research, both nationally and internationally, have been pivotal in shaping India's agricultural development. Early collaborations with CIMMYT (International Maize and Wheat Improvement Center) and IRRI (International Rice Research Institute) for the exchange of dwarf wheat and rice varieties were instrumental in initiating the Green Revolution, securing food security for India. ICAR's collaboration with various international organizations has expanded across numerous commodities, leading to the development of new crop varieties, livestock breeds, and innovative approaches to managing natural resources. International and national partnerships have also focused on improving livestock health, nutrition, and hygiene standards, along with establishing protocols in the fisheries sector. India's bilateral agricultural R&D collaborations extend to 65 countries, contributing to regional agricultural cooperation in organizations like SAARC, BRICS, and BIMSTEC. India has also made significant strides in its neighbourhood, establishing institutions such as ANASTU in Afghanistan, ACARE in Myanmar, and a Deemed University for Agricultural Education in Nepal.

5. Emerging Challenges

With a projected population exceeding 1.6 billion and an anticipated annual food demand of 400 million tons by 2050, India will need to achieve a minimum of 4% annual growth in agriculture. Changing macroeconomic factors and evolving food demand patterns will likely increase the demand for quality products like fruits, vegetables, and livestock, alongside a shift towards bio-enriched food consumption. Environmental challenges, particularly climate change, will exert tremendous pressure on Indian agriculture. Rising temperatures, erratic rainfall, and extreme weather events are expected to have negative impacts on food grain production, livestock, and aquatic systems, both in terms of quantity and quality. To ensure food security for the growing population, sustainable intensification of land resources is critical. India has 121 million hectares (Mha) of degraded land, representing 36% of its geographical area, which suffers from soil erosion, salinity, alkalinity, acidity, waterlogging, and other edaphic stresses. Despite having just 4% of the world's renewable water resources, India’s irrigation infrastructure remains limited, with only 43 Mha fully irrigated, 23 Mha partially irrigated, and 74 Mha rainfed. Droughts and floods have increasingly become stress factors for farming, exacerbated by the depletion of groundwater resources, especially in regions like Punjab, Haryana, parts of Rajasthan, Gujarat, and Uttar Pradesh. In terms of soil health, deficiencies in nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) are widespread. Around 8-10 Mt of NPK is removed from Indian soils annually, and 93%, 91%, 51%, and 43% of soils are rated as deficient in N, P, K, and Zn, respectively. Fertilizers have played a crucial role in enhancing crop production; however, nearly half of the nitrogen applied in fertilizers is lost to the environment through volatilization, leaching, and emissions, causing adverse effects on terrestrial and aquatic systems and public health. Addressing these issues requires a combination of improved crop varieties, reclamation techniques, and innovative agricultural practices, supported by emerging technologies and policy interventions (Pathak and Ayyappan, 2020).

6. Way forward

India has set several ambitious national priorities, including increasing farmers' income by 200%, reducing fertilizer use by 25%, cutting water usage by 20%, increasing renewable energy adoption by 50%, reducing greenhouse gas (GHG) emission intensity by 45%, and rehabilitating 26 million hectares (Mha) of degraded land. At the same time, as a responsible member of the United Nations and other global organizations, India is committed to fulfilling international obligations such as the Panchamrit initiative (UNFCCC), achieving land degradation neutrality (UNCCD), conserving biodiversity (UNCBD), advancing regional agricultural development (SAARC), and meeting the Sustainable Development Goals (SDGs). To meet these objectives, the future of Indian agriculture must focus on precision farming, reducing the environmental impact of chemicals, promoting nature-friendly agricultural practices, and utilizing innovations like nano-fertilizers. Achieving greater synergy between crop, weather, and water cycles through ecosystem-based approaches to crop planning will also be essential. Despite the challenges, scientific advancements offer promising solutions to address these issues while fulfilling both national and international commitments. To aid in this process, ICAR has initiated a precision agriculture network program aimed at monitoring weather, plant, and soil indicators, and providing artificial intelligence-based advisories to farmers. Agricultural genomics research, already making significant strides, will also play a central role in these efforts.

ICAR, alongside the broader National Agricultural Research and Education System (NARES), is committed to leveraging scientific advances for the benefit of society. The Council aims to transform into an organization fully engaged with farmers, industry, entrepreneurs, and consumers. To realize the full potential of Indian farming, a multi-pronged strategy is necessary, encompassing integration, diversification, clustering, customized farm mechanization, value addition, and market access. Developing crop varieties that are tolerant to multiple abiotic and biotic stresses through the use of stress-tolerant quantitative trait loci (QTLs), genes, and alleles in elite cultivars will be a key strategy for achieving higher yields and long-term sustainability. Techniques to conserve, store, and enhance water use efficiency, such as low-cost micro-irrigation systems, should be scaled up for both horticultural and field crops. Practices such as applying neem-coated urea based on soil health cards and leaf color charts should become more common to improve fertilizer use efficiency. Microbe-based technologies for nitrogen fixation, nutrient recycling, bio-residue management, and alleviating both abiotic and biotic stresses have also shown significant promise. Conservation agriculture, particularly outside the irrigated ecosystem, should be widely adopted to reduce the carbon footprint of agricultural production systems. The development and deployment of small, smart machines powered by renewable energy, such as solar-powered water pumps, sprayers, and weeders, must be accelerated. In addition, enhancing agri-infrastructure, especially in the post-harvest phase, including processing and storage facilities, will be critical. The focus should also shift towards export-oriented, ecosystem-based, and sustainable food systems, with an emphasis on smart farming, post-harvest value addition, and promoting entrepreneurship, particularly among youth and women. A two-way digital communication model between farmers and scientists should become the cornerstone of the new technology delivery system.

7. Conclusion

The primary goal of agricultural development in India remains ensuring food and nutritional security, improving rural livelihoods, and securing environmental sustainability. To achieve these objectives, India will focus on developing advanced agricultural technologies and effective dissemination strategies. It is projected that food grain productivity must grow by over 1.5% annually, and horticultural crop productivity by more than 3% to meet the country's food demand by 2050. Achieving this will require the development of improved varieties of field and horticultural crops that are resilient to changing environmental conditions. Technology will also play a pivotal role in enhancing input-use efficiency, thereby reducing production costs, and enabling value addition that will make Indian agriculture profitable, competitive, and attractive to rural youth. Additionally, value addition through processing will not only help reduce significant post-harvest losses but will also increase farmers' incomes. ICAR is poised to tackle these challenges through focused research programs that account for recent scientific advancements, economic shifts, and opportunities in both the national and international arenas. This will ensure the growth of higher productivity, profitability, sustainability, and climate resilience, aligning with the evolving aspirations of Indian agriculture.

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Fundamentals of Regenerative Tourism: Exploring the Prospects of Agro-Ecotourism for Sustainability and Climate Resilience

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1. Introduction

Global tourism is facing mounting challenges, including environmental degradation, cultural erosion, and climate change. Regenerative tourism, a step beyond sustainability, aims to restore and enhance ecosystems, empower local communities, and preserve cultural heritage. Regenerative tourism offers a transformative travel approach by focusing on improving environmental, social, and cultural health. Agro-ecotourism, a niche within regenerative tourism, integrates agricultural activities and ecological conservation into tourism, fostering resilience and sustainable development. This chapter explores the intersection of regenerative tourism and agro-ecotourism as a pathway for sustainability and climate resilience. By leveraging agricultural landscapes and ecosystems, agro-ecotourism creates a symbiotic relationship among tourism, local communities, and the environment. This study outlines the fundamental principles of regenerative tourism, highlights the benefits of integrating agro-ecotourism practices, and provides actionable policy recommendations for fostering sustainable and climate-resilient tourism models.

2. Fundamentals of Regenerative Tourism

A holistic ecosystem approach recognizes the interconnectedness of tourism, communities, and ecosystems, emphasizing local empowerment, decision-making, and equitable distribution of benefits. It prioritizes environmental restoration by actively enhancing biodiversity, ecosystems, and natural resources while protecting and celebrating cultural heritage through authentic and respectful interactions. With a long-term vision, it focuses on creating systemic and enduring changes that ensure benefits for future generations. A concept of regenerative tourism that goes beyond "not damaging" the environment and that aims to actively revitalize and regenerate it, resulting in a positive cycle of impacts on local communities and economies. The concept of regenerative tourism is illustrated in Fig 1.

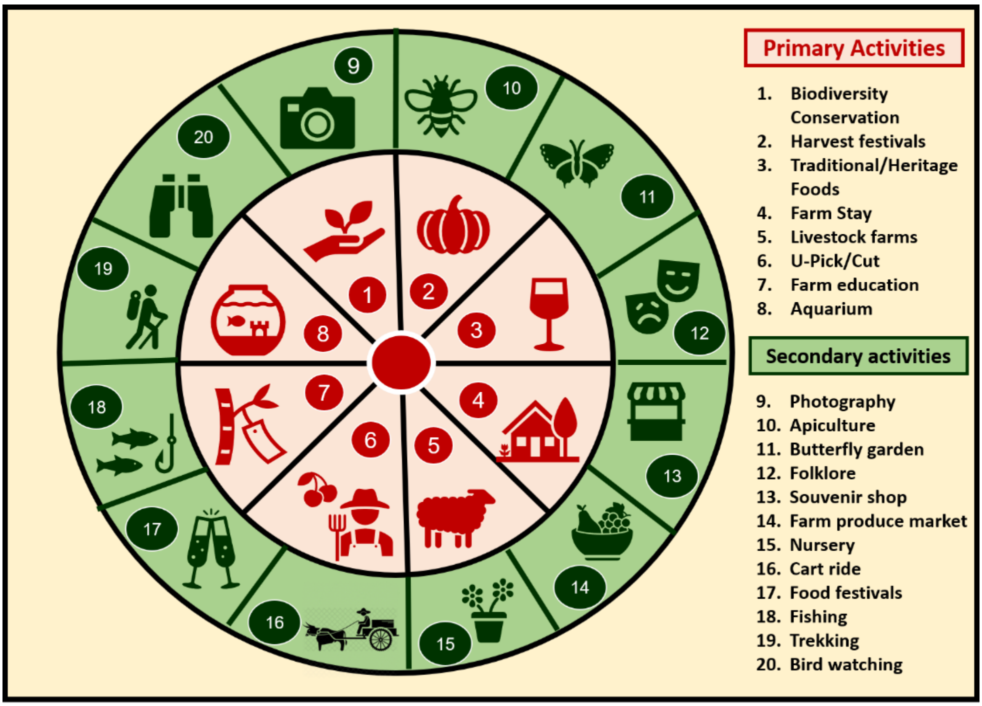
Fig 1: The concept of regenerative tourism

3. Fundamentals of Agro-Ecotourism

Agro-ecotourism is an innovative concept that combines tourism with farming, creating a unique platform where visitors can experience the charm of rural life while supporting agricultural communities. It integrates farming activities, tourism industries, and farm businesses, and provides an opportunity to link tourism with agrarian services, products, and experiences. This approach serves as a sustainable livelihood strategy for farmers while offering tourists a chance to engage with and learn about agriculture, traditional practices, local goods, and rural culture. Agro-ecotourism brings visitors closer to nature, offering an escape from the hectic pace of city life to the tranquil beauty of rural landscapes. Guests can relax and rejuvenate in natural settings, surrounded by scenic vistas and simple farm life. Beyond relaxation, it provides a hands-on learning experience, allowing tourists to immerse themselves in agricultural practices, taste traditional foods, and witness the everyday lives of farmers, fostering a deeper connection between rural communities and their cultural heritage.

This concept emphasizes sustainability and mutual benefits. Farmers generate additional income and create job opportunities for their families and rural youth, thereby contributing to economic resilience. It offers visitors a unique blend of educational, recreational, and authentic experiences, deepening their appreciation for agriculture and the environment. Agro-ecotourism not only promotes environmental awareness and cultural preservation but also strengthens the bond between urban and rural communities, making it a valuable tool for sustainable rural development and a meaningful experience for all involved.

4. Conceptual Framework for Agro-Ecotourism



Establishing a conceptual framework is essential for developing a widely accepted agro-ecotourism paradigm. In this framework, activities are classified as primary or secondary, based on location (on-farm versus off-farm) and their connection to agriculture. Primary activities occur on functioning agro-ecotourism farms and are closely tied to agricultural production or farm product marketing. These include direct farm sales of agricultural products, farm tours, farm-to-table meals, overnight farm stays, and agrarian festivals held on the farm. These activities emphasize the integration of tourism with active farming practices. By contrast, secondary activities have limited connections to agricultural production, even if they occur on a functioning agro-ecotourism farm. For instance, a farm may serve as a venue for weddings, concerts, trekking, and cycling. Additionally, while closely related to agriculture, peripheral activities, such as farmers' markets and agricultural fairs, do not necessarily occur on functioning farms. Classifying these peripheral activities as agro-ecotourism remains debatable as it significantly influences measurement, policy development, and programming within the sector. Regardless of their classification as primary or secondary, agro-ecotourism activities can be grouped into five overarching categories: direct sales, education, hospitality, outdoor recreation, and entertainment. The relationship between these activities is often illustrated as a wheel, with the inner section representing primary activity and the outer section representing secondary activity. Many activities span multiple categories; for example, farm-to-table dinners and tastings fall under direct sales, education, and hospitality. This flexible classification system underscores the diverse nature of agro-ecotourism activities and their varying degrees of connection with agriculture.

5. Agro-Ecotourism: A Regenerative Pathway

Agro-ecotourism blended farming practices, ecological preservation, and tourism experiences offer an innovative route for regenerative tourism. Key features include:

Farm-Based Tourism

Farm-based tourism offers visitors a unique opportunity to immerse themselves in the life and practices of sustainable agriculture. Guests can participate in activities such as planting, harvesting, and caring for livestock, gaining firsthand experience in farming methods that prioritize environmental health and resource efficiency. This type of tourism enhances the understanding of agricultural systems and fosters appreciation for farmers' hard work and dedication. By engaging directly with the land and its stewards, visitors develop a deeper connection to food systems and the importance of sustainable practices in ensuring food security.

Biodiversity Conservation

Eco-tourism centered on biodiversity conservation allows travelers to explore and appreciate natural landscapes while supporting the preservation of native flora and fauna. These initiatives often focus on biodiversity-rich habitats such as forests, wetlands, and grasslands, ensuring that tourism activities do not disturb the ecological balance. By promoting responsible tourism, these ventures help fund conservation efforts, create awareness of the importance of protecting biodiversity, and provide livelihoods for local communities. Visitors have a greater understanding of the intricate relationships within ecosystems and the need to protect them for future generations.

Local Economic Growth

Tourism in rural areas can contribute significantly to local economic growth by directing spending toward community businesses, including homestays, craft markets, and locally owned eateries. These activities create job opportunities and diversify income sources for rural residents, reducing dependency on traditional agriculture. By purchasing local products and services, tourists experience an authentic rural culture and empower communities to invest in infrastructure, education, and health services. This mutually beneficial exchange fosters sustainable development and strengthens the socioeconomic fabric of rural areas.

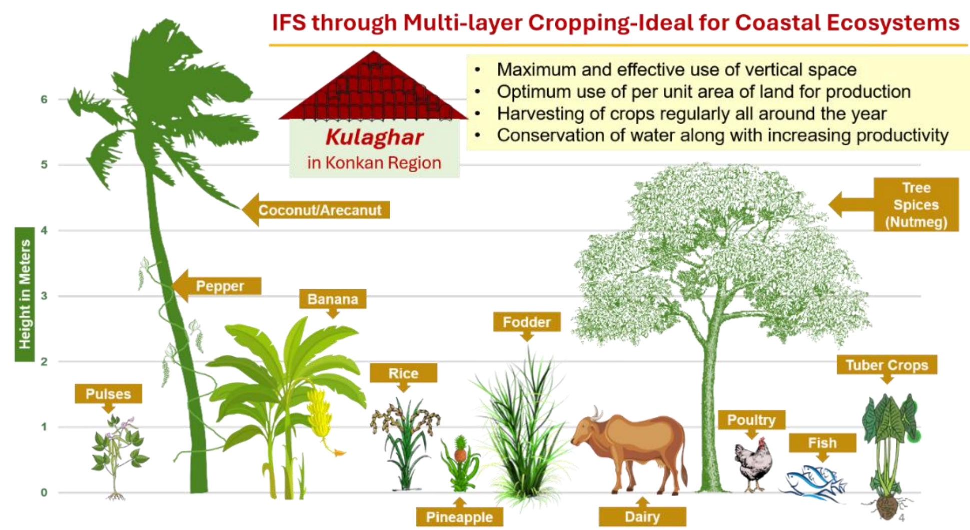


Fig 3: *Kulagar* System of Konkan region

Education and Awareness

One of the most impactful aspects of rural eco-tourism is its educational experience. Hands-on activities, such as workshops on climate-smart agriculture or guided tours of restored ecosystems, offer visitors insights into sustainable practices that enhance ecosystem health. These experiences educate tourists about the challenges of climate change, the importance of reducing carbon footprint, and the role of regenerative agriculture in building a sustainable future.

Such awareness enriches visitors' understanding and encourages them to adopt eco-friendly behaviours in their own lives.

Resilience Building

Rural tourism initiatives are crucial for building community resilience to climate change. By diversifying income streams through tourism, communities reduce their dependence on single-resource economies, making them less vulnerable to environmental or market disruptions. Additionally, tourism activities often involve ecological restoration projects such as reforestation, wetland rehabilitation, or establishing wildlife corridors, which strengthen ecosystems and enhance climate adaptability. These efforts have protected communities and created a sustainable model that has inspired other regions to pursue similar paths.

6. Conclusion

Agro-eco-tourism holds immense potential as a regenerative tourism model that aligns with sustainability and climate resilience goals. By restoring ecosystems, empowering communities, and preserving cultural heritage, agro-eco-tourism has a holistic and positive impact on the environment and society. Regenerative farming practices focus on restoring and enhancing soil health, promoting biodiversity, and creating sustainable agricultural systems. Techniques such as no-till farming reduce soil disturbance, preserve soil structure, improve water infiltration, and retain carbon. By eliminating synthetic inputs, such as pesticides and fertilizers, regenerative farming relies on natural alternatives, such as mob grazing, manure, and compost, which enrich the soil with organic matter and minimize pollution. Maximizing soil coverage through living roots and mulch helps prevent erosion and retain moisture, reducing the need for irrigation. Moving away from monocultures, regenerative practices emphasize crop rotation and cover crops, which boost soil fertility, prevent pest outbreaks, and support diverse ecosystems. Integrating livestock with crops creates a symbiotic relationship, where animals provide natural fertilizer and crops offer forage, enhancing soil fertility and ecosystem health. Cover crops enrich soil by reducing nitrogen leaching, improving water retention, and enhancing carbon sequestration. These practices work together to create resilient, diverse, and sustainable farming systems that restore degraded land, while combating climate change and fostering long-term agricultural productivity. Policymakers must adopt forward-thinking strategies to integrate regenerative principles into tourism development, ensuring a thriving future for both the people and the planet.

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Introduction to *Kulagar*-based Integrated Farming System

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Introduction

Economically and environmentally, the coastal ecosystem is the most significant of the five agro ecosystems. It has a diverse range of topographical features (mountains, valleys, and coastal plains), riverine systems, climatic conditions, soil and water sources, and vegetation, which encompasses lush tropical rain forests to coastal mangroves. The coastal zone's agro-climatic conditions are ideal for growing a variety of field and horticultural crops. In the export of horticultural produce, spices, and marine products, the region holds a commendable role. It supports the existence of more than 20 million people whose socio-economic situation remains heavily reliant on agriculture. Appropriate crop management practices and cropping systems that maximize the use of land and water resources may help boost production and boost the rural economy. The west coast of India, having several issues such as coastal salinity, less fertile lateritic soils, shortage of labor, reduced crop productivity, etc. are affecting the sustainability of small and marginal farmers. Despite all of these challenges and considering the complexity of the Konkan region, an interdisciplinary and comprehensive approach to the overall development of the state's farming system and farming communities is expected. As a result, to achieve sustainability and provide multiple ecosystem services, farmers in the region must establish or refine an indigenous farming method. One such example for biodiversity conservation, sustainability, and environment adaptation is traditional farming system (*Kulagar*), which was introduced and is still under practice.

Traditional farming systems (*kulagar*) are found in hill slope terraces of Western Ghats and are distinguished by the cultivation of a variety of crops in between areca nut and coconut plantations. *Kulagar* is a horticultural crop cultivation method used on plains, terraces, and hilltops. In every *Kulagar*, the skeletal tree species is areca nut palms. On these palms, black pepper vines (mirvel) or betel vines (panvel) trail. The interspaces are being used to grow a variety of crop plants. The *Kulagar* is being maintained as an intricately designed garden by a few groups of people. Paddy in Ponda, Kepem, Kankon, and parts of Sattari and Bicholim are among them. The upper portion of the *Kulagar* is known as visol, and it does not receive daily watering (Khedekar, 2008; Khedekar, 2013). The free flow of gravitational water is often used to irrigate them. It's classified as a apune udak in the local dialect. Plantation crops and fruit trees, which need less water for development, are grown in this region. Some of the plant species grown in this area include cashew, bamboo, pineapple, mango, and tamarind. Porsum is nearby farmland where plants such as turmeric, ginger, bread fruit, and others are cultivated. Each *Kulagar* has a different size, but most are about 1-2 hectares in size (Singh and Basavashri, 2021).

Crop diversity in *Kulagar*

Kulagar system has features of crop diversification, that majorly helps in conservation that makes it an exclusive, sustainable system for horticulture crop production. The cash crop component in a *kulagar* is areca nut, coconut, cashew nut, betel vine, etc. In Konkan region, mostly areca nut-based (rarely coconut-based) *Kulagars* are common. Local tall areca nut palms are replaced by improved cultivars like Mangala, Sumangala, and Mohit Nagar. The landraces of coconut found in Konkan region are 'Benaulim' and 'Calangute'. These palms are trailed with black pepper and betel vines. Black pepper varieties commonly grown in Konkan region are Panniyur varieties, Karimunda and Thevam. In areca nut plantations, inter culturing with pineapple, banana, shade-tolerant vegetables, and tuber crops like elephant footyam is commonly practiced. 'Mankurad' and 'Hilario' are two local Goan mango varieties with sweet relishing flavor and enormous diversity in size, shape, and quality. Apart from these two, a large number of mango varieties are available in different parts of Konkan region. Alfonsa, Babio, Baretto, Bemcorada, Bishop, Ball, Brindao, Carreira, Carreira branca, Culas, Colaco blanca, Costa, Dourado, Durbate, Fernandin, Furtad, Godgo, Japao, Jeronimo, Jose, Kapri, Madame, Malgesh, Massarrat Bardez, MussaretSalcete, Malgoa, Nicolau Afonsa, Olieveria, Papel, Papel Branco, Rebello, Reynold, Rosa, Secretin, St. Antony, Salgada, Tanque, Toranja, Chimut, Udgo and Xavierare the mango varieties grown in Konkan region (Dhandar et al.,1997). Commonly cultivated banana varieties of Konkan region are Saldatti, Savarboni, Amti, Raspali, Sakkari, Velchi, Myndoli, and Sugandi. Pineapple varieties Kew, Giant

Kew, Queen, and Red Spanish are locally grown in *Kulagars* of Goa. Spice crops like nutmeg, cinnamon, clove, and underutilized fruit crops like kokum, jack fruit, acid lime, pummelo, breadfruit, karonda, sapota, flower crops like hibiscus, jasmine, marigold, crossandra, and a large number of medicinal and aromatic plants are a part of this system. Paramesh et al. (2019) surveyed seventy *Kulagar* systems and reported different crop species (Table 1) observed in the system such as plantation crops, fruit crops, spice crops, vegetable crops, forest trees, green leaf manure plants, oornamental plants, etc.

Table 1. Different plant species present in the *Kulagar*

Plantation crops	Areca nut (*Areca catechu*), coconut (*Cocos nucifera*)
Fruit crops	Jackfruit (*Artocarpus heterophyllus*), mango (*Mangifera indica*), pineapple (*Ananas comosus*), guava (*Psidium guajava*), custard apple (*Annona reticulata*), sapota, (*Manilkara zapota*), kokum (*Garcinia indica*) and papaya (*Carica papaya*), carambola (*Averrhoa carambola*), pomelo(*Citrus maxima*), lemon (*Citrus limon*), jamun (*Syzygium cumini*), wax apple (*Syzygium samarangense*), amla (*Phyllanthus emblica*), bilimbi (*Averrhoa bilimbi*)
Spice crops	Nutmeg (*Myristica fragrans*), pepper (*Piper nigrum*), betel vine (*Piper betle*), curry leaf (*Murraya koenigii*), cinnamon (*Cinnamomum verum*), allspice (*Pimenta dioica*), clove (*Syzygium aromaticum*)
Vegetable crops	Breadfruit (*Artocarpus altilis*), chilli (*Capsicum annuum*), tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), okra (*Abelmoschus esculentus*), yardlong bean (*Vigna unguiculata ssp. sesquipedalis*), red amaranthus (*Amaranthus cruentus*), drumstick (*Moringa oleifera*), elephant foot yam (*Amorphophallus paeoniifolius*)

Forest trees	Dalbergia (*Dalbergia sissoo*), teak (*Tectona grandis*), cotton tree (*Bombax ceiba*), bamboo (*Bambuseae*), tamarind (*Tamarindus indica*)
Greenleaf manure plant	Gliricidia (*Gliricidia sepium)*
Ornamental plants	Crape jasmine (*Tabernaemontana divaricata*), hibiscus (*Hibiscus rosa-sinensis*), jasmine (*Jasminum sps.*), rose (*Rosa sps.*), ixora (*Ixora coccinea*), champa (*Magnolia champaca*), Heliconia (*Heliconia sps.*), anthurium (*Anthurium andraeanum*), aster (*Aster sps.*), gomphrena (*Gomphrena globose*), marigold (*Calendula officinalis*)
Other minor crops	Vanilla (*Vanilla planifolia*), coffee (*Coffea* sps.), cashew (*Anacardium occidentale*)

Source: Paramesh et al. (2019)

Structure and diversity of *Kulagar* system

A range of crop species is planted randomly without following recommended density/geometric pattern to maximize the production to meet the household food and nutritional requirements. Some of the areca plants in the *Kulagar* system are self-sown by fallen nuts. The farmers grow many fruit trees, spice crops, vegetable crops in the alley space of the arecanut plants. The ornamental, medicinal, and aromatic plants are planted near the home. Timber trees and gliricidia are planted near the border of the farm. The house, wells, livestock shed, and compost unit is usually located in the center of the farm.

Using cluster analysis, the *Kulagar* were classified into low, medium, and highly diversified systems (Table 2). Dominance is the relative abundance of a species in an ecological community. In the low diversified system, the dominance index was found higher (0.6) and it was lower in the highly diversified system. Simpson's Index (1-D) represents the probability that two individuals randomly selected from a sample will belong to different species was found higher (0.53) in the highly diversified system than the low diversified system (0.40). The Margalef index measures the species richness and was found to be higher in the highly diversified system (3.7) and least in the low diversified system (2.2). Species richness is a measure of the number of species found in a sample. In our study, species richness and species richness index (SRI) was found higher in the highly diversified system (28 & 3, respectively) than in the low diversified system. The number of equally common species required to give a particular value of an index is called the effective number of species (ENS) and is the true diversity of the community in question. The results indicated that highly diversified system (ENS-4) is twice diverse as that of the low diversified system (ENS-2).

Table 2. Structure, plant density, and management intensity in the arecanut agro forestry system

	Low (34)	Medium (24)	High (12)
Density of arecanut plants (Ind./ha)	852±221	1302±508	818±337
Density of coconut plants (Ind./ha)	65±78	133±154	145±170
Density of fruit plants (Ind./ha)	120±268	416±517	374±605
Density of spice crops (Ind./ha)	220±314	233±309	260±418
Density of medicinal and aromatic plants (Ind./ha)	5±6	9±9	13±10
Density of vegetable crops (Ind./ha)	2±3	5±10	10±8
Density of Flowering plants (Ind./ha)	4±4	12±7	25±13
Density of forest trees (Ind./ha)	6±11	14±18	26±23
Density of green manuring plants (Ind./ha)	20±52	61±92	161±220
Density of cashew nut (Ind./ha)	7±34	16±61	3±4
Species richness	17±9	22±8	28±8
Dominance	0.60±0.19	0.49±0.15	0.47±0.21
Simpson_1-D	0.4±0.2	0.51±0.15	0.53±0.2
Shannon_H	0.88±0.4	1.15±0.33	1.34±0.5

Margalef index	2.2±1.2	2.7±1.0	3.7±1.1
Effective number of species	2	3	4
SRI	1±1	2±0.9	3±2
MII	6.0±1.7	6.3±1.2	6.4±1.9

Provisional services from the *Kulagar* system

The different provisioning agro-products produced from the *Kulagar* system arethe production of arecanut, coconut, fruits, spices, vegetables, and greenleaf manures. The major economic products obtained from the *Kulagar* are arecanut and coconut with a mean yield of 1628 kg/ha/year and 3063 nuts/year respectively. They contribute amajor share to the gross return of the farm familydue to the higher market price.The major fruit crops present in the *Kulagar* system are banana, jackfruit, mango, pineapple, guava, custard apple, sapota, kokum, and papaya with a mean fruit yield of 530 kg/year. Carambola, pomelo, lemon, Jamun, amla, bilimbi, and wax apple are also grown by the farmers. These products provide nutrition to the farm family and the excess produce is sold in the local market to ensure year-round income as most of the fruits are seasonal. In Indian culinary preparations, spices play an important role as they add flavor and possess medicinal properties. The farmers of this region cultivated many spice crops in the *Kulagar* system. The major spice crops found are nutmeg and pepper as these were fetching high market prices with a mean spice yield of 116 kg/year. The pepper vines are trailed on the arecanut plants where as the nutmeg plants are planted in between the arecanut plants. A small number of betel vine, curry leaf, cinnamon, all spice, and clove were also planted in the backyard of the house for household consumption. The *Kulagar* system also provides vegetables for household consumption and sale in the local market. In the majority of the farms, breadfruit, chili, tomato, brinjal, and okra were common in and around the house and the yact as amajor source of vegetables to the farm family. Among leafy vegetables, red amaranths, methi and spinach were also present. The mean vegetable yield of the farms was 103 kg/year.Gliricidia is the major Greenleaf manure plant found all along the borders of the farm in most farms. Every year these plants are pruned and leaves are used for green leaf manuring purposes. The average leaf yield from the crop is1756 kg/year and is recycled efficiently as a source of nutrition to the crop plants in the system. The mean monetary returns in terms of gross return, net return, and family benefits obtained from the *Kulagar* system were Rs. 541275, Rs. 394725, and Rs. 453900, respectively. *Kulagar* was found to be very economical due to year-round income and employment generation activity to the farm families. The family benefits included the number of agroforestry products available for household consumption and net return.

Regulatory services from the *Kulagar* system

The *Kulagar* system offers various regulatory services such as maintenance of soil fertility, carbon sequestration, water purification, pest regulation, and pollination. In our study, we have quantified soil fertility and carbon stock of the *Kulagar* system. The bulk density of the soil in the arecanut agro forestry system varied between 1.36 kg/m^3 to 1.62 kg/m^3. As there was no inter-cultivation for many years, the soil may become more compact leading to high bulk density. The pH of the soil in most areca nut agro forestry systems studied was found to be 6.79 indicating the acidic nature and in some farms, it was neutral to alkaline in range (7.92). The mean soil organic carbon of the region was found to be 1.61 % and it varied from 0.52 % to 2.82 %. The higher soil organic carbon in the region is due to the high biomass addition and conservation tillage. Most of the soils in the study were found deficit to available N (114 kg/ha) and P (6.07 kg/ha) however, the availability of K was found to be higher (351 kg/ha). The mean values indicated that the availability of micronutrients such as B (1.3 ppm), Fe (70 ppm), Cu (13.5 ppm), Mn (131 ppm), and Zn (7.3 ppm) was found high in the soil. The deficiency of nutrients explains the exhaustive nature of component crops in the arecanut agroforestry system. The *Kulagar* system also can regulate the micro and macro climate through carbon sequestration. The *Kulagar* system sequestering on an average of 35.5 Mg C ha^{-1} of carbon stock and it varied between 11.7 Mg C ha^{-1} to 57.4 Mg C ha^{-1}. It shows the potential of the *Kulagar* system in climate regulation through carbon sequestration.

Economics of *Kulagar* system

Due to optimal combination of varieties of crops and trees, such system results in inbuilt genetic/bio-diversity which is an important component of sustainability. Such systems also generate a higher level of income. In our studies, a net income and employment of Rs. 23.33 lakh and 1010 man/days from 10 ha area; 3.83 lakh and 475 man/days, 3.04 lakh and 475 man/days from 2.0 ha area, and 15 lakh and 845 man/days were generated from 5 ha, which shows that *Kulagar* system is not only a sound system from ecological and climate resilience point of view, but also it has potential to generate adequate income and employment, and enhance the livelihood of small and marginal farmers. *Kulagar* system has been the age old and indigenous system of the coastal ecology more specifically in the Goa state. This system has been time tested and more climate resilient. *Kulagar* can be a best strategy for mitigation and adaptation to climate change (Paramesh et al., 2018; Paramesh et al., 2019). In the recent years, the *Kulagar* systems are linked to agro-eco tourism attracting tourist and in the process farmers are able to earn more money and employment for rural youth. This system generates new hope for the rural youth. However, such systems face various challenges, and eroding gradually.

Problems and future strategies of *Kulagar* system

The major problem which is affecting the farmers of this region is poor affordability to buy inputs, lack of knowledge on management practices, lower yield due to planting of low yielding local varieties/landraces, old and senile plantations, fruit rot problem in areca nut, crop-wildlife conflict by the monkey, wild boar, bear, etc. Due to these constraints, many of the farms are neglected and poorly managed, thereby reducing ecosystem services provided by the system. The constraints like lack of education and extension to farmers can be addressed through capacity building, information communication through mass media, exhibitions, seminars, consultancy- field visits, etc. Policy planning to manage the wild animal-crop conflict, assured price for the agro forestry products, subsidy for mechanization, and organic certification to get a premium price for the products, are some of the incentives to encourage the farmers for better management of the *Kulagar* system.

Conclusion

Farmers play an important part in genetic resource management, and they must be educated about the consequences of genetic degradation as well as the benefits of biodiversity conservation and use. By providing various inputs, they should be able and funded to continue cultivating and conserving as much plant diversity as possible. Researchers and policymakers will have a greater understanding of what farmers do and why they do so in a two-way strategy, helping them to help farmers and expand the practice to other producers. Farmers of the *Kulagars* continuously strive to save native genotypes and landraces. They would be educated on the value of protecting these natural resources in their community. To express their gratitude for plant genetic safety, awards should be granted to them. *Kulagars* can thus be seen as a very effective tool for gathering, conserving, and utilizing local genetic resources, as well as raising public awareness about these resources through their exhibition.

In order to enhance the ecosystem services provided by the *Kulagar*, management practice and plant biodiversity present in the system plays a major role. Synergies between ecosystem services, management practices, and biodiversity were not observed. This implies scope for improvement and adoption of better management practices along with productive cultivars and plant species. To redesign/improve the existing *Kulagar* systems principles of cropping system science should be considered. The full potential of the *Kulagar* system could be harnessed by revisiting several management issues. Medium to highly diversified with medium management intensity is the optimal choice to maximize the multiple ecosystem services from the *Kulagar* system. It can be concluded that the farmers of the *Kulagar* system need to strike a balance between the choice of intercrop species and their density, management practices based on both his/her needs (household and monetary needs) and crop requirements (soil, climatic, light, water, and nutrient).

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Potential of Natural Farming and Organic Farming in Agroecotourism with Special Relevance to Coastal Regions

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Introduction

Agroecotourism, an amalgamation of agriculture and ecotourism, is a growing trend that offers visitors an immersive experience of sustainable farming practices, while promoting environmental conservation and rural development. In general, across India and coastal regions in particular, the integration of natural and organic farming into agroecotourism holds immense potential because of their alignment with the principles of sustainability, biodiversity, and local cultural preservation. This chapter explores the potential of natural and organic farming to transform agroecotourism, highlighting their ecological, economic, and socio-cultural benefits.

Natural and Organic Farming: A Brief Overview

Natural farming, as highlighted by NITI Aayog, is a traditional, chemical-free agricultural method that harmonizes natural biodiversity by integrating crops, trees, and livestock. Rooted in agroecological principles, it aims to lower cultivation costs and liberate farmers from dependence on purchased inputs. This approach relies on locally available resources such as cow dung and urine to enhance soil fertility and nutrient management. By fostering biodiversity, natural farming supports a thriving ecosystem of plants and animals, thereby promoting ecological balance. Additionally, it reduces reliance on external inputs, including organic and biological inputs, thereby easing the financial burden for smallholder farmers. Through sustainable practices, natural farming offers a viable path toward resilient agriculture and improved livelihoods.

Organic farming is an environmentally friendly agricultural approach that eliminates the use of synthetic chemicals, such as pesticides and fertilizers, and relies on natural processes to enhance soil health and crop productivity. This method emphasizes the use of organic inputs, such as compost, green manure, and biological pest control, to maintain the ecological balance. Organic farming promotes biodiversity by encouraging a diverse range of plants, animals, and microorganisms, contributing to a resilient farming system. Focusing on sustainable practices helps reduce environmental degradation, improves soil fertility, and provides healthier food options, making it a crucial component of sustainable agriculture.

"Natural farming emphasizes minimal human intervention and relies on natural processes, such as biological pest control and organic matter recycling, to maintain soil fertility and crop health. Organic farming, on the other hand, adheres to certified standards that prohibit synthetic inputs, promoting the use of organic fertilizers, crop rotation, and biological diversity."

Both practices prioritize ecological balance, making them ideal for agroecotourism. By showcasing these practices, coastal farms can educate visitors on sustainable agriculture, while offering them a unique and authentic experience.

Unique Opportunities in Coastal Regions

Coastal regions have unique ecological and cultural characteristics that make them suitable for agroecotourism based on natural and organic farming.

1. **Rich Biodiversity:** Coastal ecosystems are home to diverse flora and fauna, which can be preserved and showcased through sustainable farming practices.

2. **Traditional Practices:** Many coastal communities have a heritage of organic and natural farming techniques that can be revived and integrated into tourism.

3. **Scenic Landscapes:** The natural beauty of coastal areas enhances the appeal of agroecotourism destinations.

4. **Specialized Crops:** Coastal regions often produce unique crops, such as coconuts, cashew nuts, spices, and salt-tolerant rice varieties, which can be marketed as part of the agroecotourism experience.

5. **Demand:** The demand for natural and organic farming-grown agricultural produce has increased significantly among tourists seeking authentic and eco-friendly experiences. As health-conscious travelers prioritize

sustainability and traceability in their food choices, destinations that offer organically grown fruits, vegetables, and grains have attracted attention. Tourists are increasingly drawn to farm-to-table experiences, where they can save fresh produce cultivated without synthetic chemicals, thus ensuring both health benefits and environmental preservation. Coastal and rural agroecotourism destinations that leverage natural and organic farming practices not only enhance the appeal of their offerings but also promote local biodiversity and traditional farming methods. This growing trend underscores the synergy between sustainable agriculture and tourism, which benefits both farmers and the environment.

Natural and organic farming practices align seamlessly with the principles of agroecotourism, offering a holistic experience that embodies the essence of sustainability and local culture. These practices not only provide something visually captivating to explore, through vibrant, pesticide-free landscapes and biodiversity-rich ecosystems but also create opportunities for visitors to engage in hands-on activities such as harvesting, planting, or learning about sustainable farming methods. Additionally, agroecotourism offers visitors a chance to purchase fresh, organic products such as locally grown vegetables, fruits, and artisanal goods, directly supporting the community's sustainable practices. Thus, natural and organic farming enriches the agroecotourism experience by fostering connections between people, the environment, and local economies.

"It satisfies three principles of agroecotourism something to see, something to do and something to buy."

Benefits of Integrating Natural and Organic Farming into Agroecotourism

1. **Environmental Conservation:**
   - Promotes soil health and water conservation through sustainable farming methods.
   - Encourages the preservation of coastal ecosystems and reduction of agricultural runoff.
2. **Economic Gains:**
   - Generates additional income for farmers through tourism.
   - Create opportunities for value-added products such as organic jams, oils, and herbal teas.

3. **Community Empowerment:**
    - Involves local communities in tourism activities, creating jobs and fostering cultural pride.
    - Encourages skill development in sustainable farming and hospitality management.
4. **Educational Opportunities:**
    - Provides visitors with knowledge about sustainable farming practices.
    - Creates awareness about the importance of preserving coastal ecosystems.
5. **Health and Wellness Tourism:**
    - Attracts tourists seeking organic and healthy lifestyles.
    - Facilitates activities like yoga retreats, meditation, and organic food festivals.

Case Studies and Examples

Khazan Tourism: Showcasing Unique Cultivation Practices in Coastal Salt-Affected Soils of Goa (ICAR-CCARI Goa)

Khazan tourism is emerging as a distinctive facet of agroecotourism, offering an immersive experience with the traditional methods of cultivating salt-tolerant rice in the coastal salt-affected soils of Goa. This practice, known as *Khazan* farming, thrives in the unique and fragile ecosystems of coastal regions. These areas are characterized by intricate landscapes of mangroves, salt pans, fallow lands, agricultural fields, and water bodies, which together create a serene and biodiverse setting that captivates tourists. The region is a haven for vibrant birdlife and other fauna, further enriching its scenic appeal. Cultivation in *Khazan* soils predominantly relies on traditional practices, eschewing synthetic agrochemicals in favor of organic manure and natural nutrient sources. This approach not only sustains soil health, but also aligns with environmentally friendly farming techniques.

Each small field in the *Khazan* landscape supports a thriving biodiversity of crops, microflora, fauna, and wildlife, serving as a living laboratory of nature's resilience. Visitors are provided with a unique opportunity to witness and learn about the harmonious coexistence of agriculture and biodiversity within a sustainable framework. Beyond its ecological significance, Khazan tourism offers a rich cultural experience, showcasing the heritage of coastal farming communities and their innovative methods for managing salt-affected soils. By integrating conservation, education, and recreation, Khazan tourism fosters an appreciation for sustainable agricultural practices and positions the Goa as a leader in promoting environmentally conscious tourism.


A unique *Khazan* landscape for the agroecotourism: From Barren land to a scenic beauty

Demonstrating Natural and Organic Farming Practices in Agroecotourism: Recycling Waste into Wealth

Agroecotourism (AET) combines sustainable farming practices with tourism, offering visitors a hands-on experience of eco-friendly agriculture, while generating additional income for farm operations. A critical aspect of AET is the effective management of the biodegradable waste generated during farm activities, converting this "waste into wealth" through innovative recycling and organic preparations. Demonstrations of natural and organic farming practices, including vermicomposting, Jeevamrut preparation, azolla cultivation, and green manuring, have provided valuable insights into environmentally sustainable methods and their economic benefits.

Recycling Organic Waste and Vermicomposting: A Key Component

At the Institute's AET unit, a vermicomposting unit was established to process approximately 6 tons of biodegradable waste annually. Over two cycles in a year, the unit produced 4 t of high-quality vermicompost in approximately eight months, with a conversion ratio of 0.67. This practice generated a gross income of Rs. 0.88 Lakhs and a net income of Rs. 0.52 Lakhs, achieving a benefit-cost ratio of 2.45. The nutrients recycled through vermicomposting included 57 kg nitrogen, 3 kg phosphorus, and 36 kg K, which were used to enrich the soil and support crop growth. The initiative not only reduced waste, but also served as a practical demonstration for visitors, showcasing how farm by-products can be efficiently utilized for economic and environmental gains.

Demonstration of Jeevamrut Preparation

Visitors were also introduced to the preparation of Jeevamrut, a natural liquid fertilizer. This eco-friendly bio-input was prepared by incubating a mix of cattle dung, jaggery, gram flour, cow urine, and fertile soil for seven days. Jeevamrut was applied to crops within the AET unit, offering a sustainable alternative to synthetic fertilizers. The demonstrations emphasized the simplicity, affordability, and effectiveness of Jeevamrut in promoting soil fertility.

Incorporating Azolla as a Sustainable Component

To diversify the AET activities, a small-scale azolla production unit was established. Azolla, a nutrient-rich aquatic fern, was cultivated and used as a feed for ornamental poultry birds within the system. This closed-loop approach not only reduces dependency on external feed inputs but also illustrates the versatility of azolla as a sustainable resource.

Educational and Economic Benefits

These practices, which are rooted in traditional and scientific knowledge, highlight the integration of natural and organic farming into AET. They provided visitors with practical insights into waste recycling, nutrient management, and sustainable agriculture. Additionally, they generate supplementary income, which improves the profitability of AET initiatives. By demonstrating these eco-friendly methods, the AET unit fosters awareness of sustainable farming practices and inspires stakeholders to adopt similar approaches in their agricultural systems.

Agroecotourism serves as a platform for blending conservation, education, and economic development, making it a valuable model for sustainable rural growth.

Livestock Waste Valorization System: A Sustainable Attraction in Coastal Agroecotourism

The Livestock Waste Valorization System (LWVS) established at the ICAR-CCARI, Goa, and a unique component of the agroecotourism (AET) unit exemplifies sustainable waste management while aligning with India's Swachh Bharat Mission. This innovative facility efficiently converts cattle dung and urine into biogas and phosphate-rich organic manure (PROM), offering visitors a unique attraction and educational experience for sustainable agriculture and eco-friendly practices.

To accommodate the region's specific climatic conditions, LWVS integrates a biogas plant with a daily capacity to process 200 kg of cattle dung. This system generates 7 m^3 of biogas daily, valued at Rs. 8,250 monthly and Rs. 99,000 annually. In addition, the plant produces 400 liters of nutrient-rich slurry daily, contributing Rs. 6,000 per month (Rs. 72,000 annually). PROM production, another highlight of the facility, delivers a net income of Rs. 3,880 per 100 kg of processed cattle dung, showcasing the economic viability of waste valorization.

The LWVS serves as an educational hub, offering hands-on training to farmers, particularly those from marginalized communities. Through practical demonstrations, over 60 Scheduled Caste (SC) farmers have been trained in techniques that enhance soil fertility, boost crop yields, and promote economic growth, while ensuring environmental conservation.

By showcasing these sustainable practices, LWVS enriches the agroecotourism experience, demonstrating how traditional and scientific approaches to waste management can drive ecological and economic benefits. This initiative not only supports rural livelihoods but also contributes to national missions for cleanliness, sustainability, and environmental stewardship, making it a significant attraction for tourists and stakeholders.

A photo of the LWVS unit exhibiting different components

The concept and approach of LWVS

Biomass recycling as a Model for Climate-Resilient Agroecotourism: A unique case of ICAR-CCARI, Goa

The ICAR-CCARI, Goa, serves as a unique case study of agroecotourism by showcasing climate-resilient agricultural practices through innovative waste management and resource recycling. Situated on a 51-hectare experimental farm, the institute has pioneered sustainable approaches to convert substantial biodegradable waste into valuable resources. These include vermicomposting, biogas production, use of organic fertilizers such as Phospo-Urja (PROM), composting, and eco-friendly wastewater management. This integrated system significantly enhances soil fertility and promotes water conservation, demonstrating the principles of circular agriculture.

ICAR-CCARI processes significant amounts of biodegradable waste annually, transforming it into refined products that contribute to sustainable farming systems. As part of its outreach, the institute hosts a vibrant capacity-building program that attracts over 8,000 visitors annually, including farmers, students, and stakeholders. These visitors gained practical insights into sustainable waste management and climate-resilient practices, bridging the gap between theory and application. By aligning these efforts with agroecotourism, ICAR-CCARI not only promotes environmental conservation, but also creates an educational and experiential platform for visitors. The farm's innovative practices serve as a scalable model for fostering climate resilience and integrating waste recycling, capacity building, and community engagement. This initiative highlights the potential of blending modern agricultural innovation with traditional knowledge, benefiting both the environment and farming community, while positioning ICAR-CCARI as a vital attraction in agroecotourism.

Although the initiatives and practices showcased by ICAR-CCARI are rooted in the unique context of the coastal region, their strategic planning and innovative approach makes them adaptable and scalable to other parts of the country and even the world. The principles of sustainable waste management, climate resilience, and agroecotourism can be tailored to diverse agro-climatic zones by integrating locally available resources, traditional knowledge, and modern technology. The focus on circular agriculture, including vermicomposting, biogas production, and organic fertilizer use, aligns with the global sustainable development goals, offering a model that transcends regional boundaries. By fostering capacity building and community engagement, the framework developed at ICAR-CCARI demonstrates how localized solutions can inspire broader applications, addressing the shared challenges of environmental conservation, resource optimization, and sustainable agriculture worldwide.

Vermicompost production unit as a unique education centre

Innovative Kulaghar Farmer of Goa Shri Sanjay Anant Patil Conferred with Padma Shri 2024 for his Contribution to Natural Farming

Shri Sanjay Anant Patil (59), an innovative farmer from Goa, was conferred with the coveted Padma Shri 2024 by the Government of India for his outstanding contributions to Natural Farming and zero-energy micro-irrigation systems. Shri Sanjay Patil is a green revolutionary, known to many as the 'one-man-army' because he single-handedly transformed a barren plot of land measuring ten acres, into a lush green natural farm (Kulaghar) with technical guidance from ICAR-CCARI, Goa. Even though he has had formal school education up to the 11th class, he possesses the knowledge and skills of a top engineer when it comes to water conservation and natural farming practices using Jeevamrut produced from Indian breed cow dung, which is an inspiration for small farmers in the state of Goa and also in the country. A team constituted by the Director, ICAR-CCARI, Goa visited the farmer, documented his technologies through good quality photographs, prepared the application

Shri Sanjay Patil receiving Padma Shri 2024 at the hands of Hon'ble President of India

for the nomination of Padma Awards 2024, and subsequently nominated through the Hon'ble Chief Minister of Goa.

His farm is an excellent place to educate diverse stakeholders on natural farming practices, which is an integral part of AET, that is, something to see and learn.

Challenges

Although the integration of natural and organic farming into agroecotourism holds great potential, several challenges need to be addressed.

1. **Infrastructure Development:** Coastal regions require investment in eco-friendly accommodations and transportation.
2. **Certification and Standardization:** Establishing clear standards for organic farming and agroecotourism is essential.
3. **Capacity Building:** Training farmers and local communities in sustainable farming and tourism management is crucial.
4. **Climate Change:** Coastal regions are vulnerable to climate change, necessitating adaptive farming practices.

Suggestions and Recommendations:

- Encourage public-private partnerships to fund infrastructure and marketing.
- Develop policies to support farmers transitioning to natural and organic farming.
- Promote collaboration between agricultural and tourism sectors.

Conclusion

Natural and organic farming practices have immense potential to transform agroecotourism, particularly in coastal regions, where environmental conservation and cultural heritage are paramount. By integrating these sustainable practices into tourism, coastal areas can offer unique experiences that benefit both the environment and the local communities. With strategic planning, investment, and community participation, agroecotourism can become a powerful tool to promote sustainable development in coastal regions.

Integrating Agroforestry with Agro-Ecotourism: A Sustainable Practice for Environmental and Economic Benefits

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Introduction

Agroforestry is a sustainable land-use approach that involves the incorporation of trees and shrubs into agricultural landscapes, alongside crops or livestock. This method combines the ecological advantages of forestry with the productive capacity of agriculture, fostering a mutually beneficial relationship that supports both environmental conservation and livelihood enhancement. Agroforestry is widely acknowledged as an effective solution to deforestation, soil degradation, and reduced agricultural output. Globally, agroforestry spans approximately 1 billion hectares and engages more than 900 million people. Despite its global significance, agroforestry adoption varies across regions. In 2022, India's agroforestry area was estimated to cover 28.427 million hectares, constituting approximately 8.65% of the country's total geographical area. This is significantly lower than the global average of 43% (Arunachalam *et al.,* 2022), highlighting the potential for further expansion in regions such as India to address environmental and socioeconomic challenges. A primary advantage of agroforestry is its ability to improve the soil quality and stability. Deep-rooted trees in such systems transport nutrients from the lower soil layers to the surface, making them accessible to crops. Additionally, trees play a vital role in preventing soil erosion by anchoring the soil, which is particularly beneficial in areas prone to heavy rain or strong winds. Organic matter, such as fallen leaves, further enhances soil fertility and promotes sustainable crop yields (Rudebjer et al., 2006).

Agroforestry plays a crucial role in addressing climate change. The absorption of carbon dioxide through tree growth helps reduce greenhouse gas emissions. Trees act as natural carbon sinks and moderate local climates by providing shade, reducing the adverse effects of extreme weather conditions on crops. These attributes make agroforestry a key tool for both climate adaptation and mitigation. In addition to its environmental benefits, agroforestry supports biodiversity preservation. The inclusion of trees creates habitats for diverse plant and animal species, leading to balanced and functional ecosystems. Biodiversity improves essential ecosystem services, such as pollination and pest control, which are fundamental to agricultural productivity (Parmar, 2022). From a socioeconomic perspective, agroforestry enhances livelihoods by offering farmers multiple income streams through the sale of timber, fruits, nuts, and other tree products (Prasad et al., 2022). This reduces reliance on single-crop farming, making rural communities more resilient to economic and environmental uncertainties (Market, 2016).

The growing need for sustainable agricultural practices perfectly aligns with the environmental and socioeconomic contributions of agroforestry. Furthermore, its integration with agro-eco-tourism creates a powerful synergy. Agroforestry offers the ecological and aesthetic appeal required for ecotourism, attracting visitors to experience sustainable farming, engaging in tree planting, and exploring integrated agricultural landscapes. This combination not only generates additional income for rural communities but also raises awareness about sustainable practices and environmental conservation. Amid global challenges, such as deforestation, rural poverty, and climate change, combining agroforestry with agro-eco-tourism provides a viable pathway for sustainable development (Djuwendah et al., 2023). This practice addresses environmental issues while boosting economic resilience, thus making it a compelling model for achieving holistic growth. This discussion explored the ecological, economic, and social potential of this integrated approach, highlighting its role in fostering sustainability (Soni et al., 2014).

Agroforestry Systems and Agro-Eco Tourism Integration

Agroforestry systems combine agricultural practices with forestry, offering sustainable landscapes that integrate ecological conservation and agricultural productivity. These systems provide a robust foundation for agro-eco-tourism, creating opportunities for tourists to engage in educational and immersive experiences, while contributing to environmental preservation and local livelihoods. Below are the various agroforestry systems that can enhance agro-eco-tourism (Table 1) (Migliorini et al., 2018).

Table 1: Agroforestry systems and agro-ecotourism features

Agroforestry System/ practices	Description	Agro-Eco Tourism Features
Agri-Silviculture	Integration of trees with crops to enhance soil fertility and biodiversity. Demonstrations of intercropping and sustainable irrigation practices.	Guided tours on intercropping, biodiversity, and soil conservation techniques.
Silvopastoral Systems	Combination of livestock grazing with forestry. Interactive experiences like observing livestock grazing and fodder tree planting.	Livestock grazing demonstrations, fodder production education, milking activities.
Homegardens	Intensively managed gardens near households combining trees, shrubs, and crops. Includes organic farming workshops and homegrown meals.	Species identification, organic farming workshops, fresh produce sampling.
Alley Cropping	Cultivation of crops between rows of trees to control erosion and improve soil fertility. Educational tours on agroforestry designs.	Erosion control education, nitrogen-fixing species insights, seasonal planting.
Forest Farming	Cultivation of shade-loving crops like mushrooms and medicinal plants under forest canopy. Features workshops and biodiversity tours.	Mushroom picking, herbal medicine workshops, biodiversity-focused tours.
Riparian Buffer Systems	Vegetation along waterways to prevent erosion and protect water quality. Offers canoeing, stream walks, and conservation education.	Canoeing, guided stream walks, water conservation education.

Horti-Silviculture	Combination of fruit orchards and forestry. Includes fruit-picking activities and demonstrations of sustainable forestry practices.	Fruit-picking, fresh produce sampling, sustainable forestry demonstrations.
Bambusetum (Bamboo Plantations)	Sustainable bamboo plantations showcasing ecological benefits and versatile uses. Features bamboo weaving workshops and serene groves.	Bamboo weaving, ecological education, tranquil exploration of bamboo groves.

Conceptual Framework for Integration

The integration of agroforestry into agroeco-tourism represents a sustainable model that combines ecological, economic, and social benefits. This integration is based on key principles, such as sustainability, multifunctionality, community involvement, and education. Agroforestry practices, including silvopasture, agro-silviculture, and forest farming, form the foundation for enhancing biodiversity, improving soil health, and diversifying income sources for farmers. These practices align naturally with agro-eco-tourism activities, creating opportunities for eco-conscious visitors to connect with nature, while supporting local economies. Activities such as farm stays, guided nature trails, and hands-on workshops offer immersive experiences that showcase the advantages of agroforestry, whereas cultural events highlight local traditions and foster cultural exchange and awareness.

The conceptual framework highlights the interconnected elements that drive the integration of agroforestry into agro-eco-tourism (Addinsall *et al.*, 2017). At its core, the framework emphasizes sustainability, multifunctionality, community involvement, and education as guiding factors for achieving ecological, social, and economic outcomes. Agroforestry practices such as combining trees with crops, livestock grazing, and forest farming play a pivotal role in conserving resources, enhancing biodiversity, and diversifying livelihoods (Harron et al., 2001). These practices are intricately linked to tourism activities, such as farm stays, eco-trails, workshops, and cultural events, which allow tourists to experience sustainable agricultural landscapes while promoting environmental awareness and economic development. This framework underscores the importance of community participation in decision making and implementation, fostering collaboration for shared benefits. By balancing ecological conservation with economic progress, this integrated approach ensures long-term sustainability and mutual gain for all stakeholders involved (Astarini et al., 2024).

Environmental Benefits

Integrating agroforestry into agro-ecotourism offers significant environmental benefits, creating sustainable synergy between agriculture, forestry, and tourism. Agroforestry systems enhance biodiversity by fostering habitats for various species, including pollinators and birds, by combining trees, crops, and livestock. These systems also contribute to soil conservation by reducing erosion, improving soil fertility, and stabilizing land through the roots of trees and shrubs. Agroforestry plays a critical role in carbon sequestration by absorbing and storing atmospheric carbon dioxide, which helps mitigate climate change (Hua et al., 2019). The integration of trees in agroforestry aids in water resource management by reducing water evaporation, preventing runoff, and enhancing groundwater recharge. This ensured better water availability and quality. Additionally, the presence of diverse plant species in agroforestry promotes natural pest control, reducing dependence on chemical pesticides and fertilizers, which minimizes environmental pollution. By regulating local temperatures and providing shade, agroforestry also improves the microclimate, making it favourable for crops and visitors.

Agroforestry landscapes, with their aesthetic appeal, attract ecotourists interested in sustainable practices and raise awareness about environmental conservation. Organic waste generated from tourism activities can be recycled as compost within the agroforestry system, completing the nutrient cycle and reducing waste. Furthermore, degraded lands can be restored using agroforestry practices, enhancing ecosystems and attracting more wildlife, which enriches the ecotourism experience. By demonstrating sustainable land-use practices, agroforestry integrated with agro-ecotourism promotes environmental stewardship and offers a model for achieving ecological preservation along with economic development.

In addition to these benefits, the specific tree species used in agroforestry systems contribute significantly to oxygen production. According to Keerthika and Chavan (2022), fast-growing agroforestry tree species in India exhibit a net oxygen production rate ranging from 1.03 to 34.15 tonnes per hectare per year. For instance, *Populus deltoides* and *Eucalyptus tereticornis* are widely cultivated because of their importance in pulp and paper production and sustainable wood supply, with both these fast-growing trees having a high oxygen production potential of around 33 tons per hectare per year. Bamboo, a fast-growing and highly biomass-producing species, showed an oxygen production of 27.38 million tonnes per year. This substantial oxygen output not only contributes to atmospheric oxygen levels but also enhances the overall environmental quality of agro-ecotourism destinations. Biodiversity is another key benefit, as agroforestry creates diverse habitats for flora and fauna. By mimicking natural ecosystems, agroforestry supports pollinators, birds, and beneficial insects that are essential for healthy agricultural productivity. Moreover, these systems restore degraded land, turning unproductive areas into vibrant ecosystems capable of supporting both agriculture and forestry.

Economic Opportunities

Integrating agroforestry into agro-eco tourism offers significant monetary benefits for farmers, local communities, and tourism operators, particularly in regions such as India, where sustainable agriculture and rural tourism are growing sectors (Jiwan et al., 2008). Agroforestry practices, such as silvopasture, agro-silviculture, and forest farming, produce high-value products, such as timber, fruits, nuts, medicinal plants, and biofuels. These goods can be sold in local and export markets, generating substantial income. For example, the sale of quality timber from agroforestry systems can earn ₹50,000 to ₹2,00,000 per acre annually depending on the type and maturity of trees.

Agro-eco tourism provides an additional income layer through visitor fees for experiences, such as farm stays, guided eco-trails, and workshops. Farm stays in rural India can attract domestic and international tourists, with nightly rates ranging from ₹1,500 to ₹7,000 per guest, depending on location and amenities. Guided eco-trails or nature walks can be priced at ₹500 to ₹1,500 per participant, and hands-on workshops, such as organic farming or traditional craft-making, may generate ₹1,000 to ₹3,000 per participant. Seasonal cultural events, such as harvest festivals or local fairs, provide another income stream through ticket sales, food stalls, and handmade products, potentially earning ₹50,000 to ₹5,00,000 per event, depending on attendance. Another critical economic benefit is employment generation. Agroforestry and tourism activities create jobs in areas such as tree planting, maintenance, harvesting, tour guidance, and hospitality. This translates into regular wages for rural workers ranging from ₹1,50,000 to ₹3,00,000 annually for full-time workers. Additionally, agroforestry reduces input costs for farmers by improving soil fertility and reducing dependency on chemical fertilizers, potentially saving 10,000 to 30,000 per acre annually.

Government incentives and grants for sustainable agriculture and eco-tourism development further boost monetary benefits. Programs under schemes such as the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) or the Ministry of Tourism can offer financial support ranging from ₹50,000 to ₹10,00,000 for agroforestry or eco-tourism projects. Agroforestry practices also allow farmers to earn revenue through carbon credit. These credits, valued at ₹800 to ₹2,500 per tonne of CO_2 sequestered, can be sold in both domestic and international carbon markets. Private investments and partnerships with eco-friendly organisations further enhance profitability by providing capital for infrastructure such as eco-lodges, renewable energy systems, and other tourism facilities. By diversifying income through the sale of agroforestry products, tourism fees, government incentives, and carbon credits, the integration of agroforestry into agro-eco-tourism in India ensures robust economic benefits, financial sustainability, and improved livelihood for rural communities.

Challenges and Opportunities of Agroforestry in Agro-Ecotourism

Agroforestry in agro-eco-tourism offers significant economic, social, and environmental benefits. However, its integration involves various challenges that need to be addressed for successful implementation. Understanding these challenges and opportunities is essential for optimizing the outcomes and ensuring sustainability (Addinsall *et al.*, 2017).

Opportunities

1. **Economic Growth**: Agroforestry practices, combined with agro-eco-tourism, provide multiple income streams for farmers and local communities. Revenues can be generated from farm stays, guided eco-tours, workshops, and the sale of agroforestry products, such as timber, fruits, and medicinal plants. Carbon credits from agroforestry practices further add to financial benefits.

2. **Environmental Sustainability**: Agroforestry enhances biodiversity, improves soil health, and sequesters carbon, making it a climate-resilient solution. Integration with agro-eco-tourism promotes awareness of environmental conservation among visitors while directly contributing to sustainable land management practices.

3. **Community Empowerment**: The model creates employment opportunities in areas such as hospitality, tour guidance, and agroforestry management. It also fosters inclusive growth by engaging women, youth, and marginalized groups in both tourism and farming activities.
4. **Cultural Preservation**: Agro-eco tourism highlights local traditions, customs, and farming practices, and provides a platform for cultural exchange. This promotes heritage conservation, while offering authentic experiences to tourists.
5. **Policy Support and Global Trends**: Governments and international organizations are increasingly recognizing the importance of agroforestry and sustainable tourism. Grants, subsidies, and policy frameworks support the initiatives that combine these elements.

Challenges

1. **Policy and Regulatory Barriers**: Complex or inconsistent regulations regarding land use, agroforestry practices, and tourism operations can hinder their implementation.
2. **Market Access Issues**: Farmers and communities often face difficulties in accessing markets to sell agroforestry products or attract eco-tourists. Poor infrastructure and limited marketing capabilities exacerbate this issue.
3. **Resource Limitations**: Insufficient funding, lack of technical expertise, and inadequate access to quality inputs, such as seeds and equipment, are significant barriers to scaling agroforestry and agro-eco-tourism.
4. **Lack of Awareness**: Limited understanding of the benefits of agroforestry and eco-tourism among communities and stakeholders leads to resistance or underutilization of these opportunities.
5. **Environmental Degradation Risks**: Improperly managed agroforestry or tourism activities can result in deforestation, soil erosion, and biodiversity loss, thereby defeating the purpose of sustainable development.
6. **Climate Change Impacts**: Unpredictable weather patterns and extreme climate events can affect both agroforestry productivity and the viability of tourism activities, posing risks for long-term sustainability.

Strategies to Address Challenges

To overcome these challenges, collaborative efforts among governments, NGOs, private investors, and local communities are crucial. Strategies include:

- Simplifying regulatory frameworks and providing clear guidelines for agroforestry and tourism integration.
- Strengthening market linkages through better infrastructure, e-commerce platforms, and marketing campaigns.
- Offering financial support through subsidies, grants, and microfinance for agroforestry and tourism initiatives.
- Conducting awareness campaigns and training programs to educate communities and stakeholders about the benefits and best practices.
- Implementing strict environmental guidelines and monitoring mechanisms to prevent degradation.

Policy Recommendations

To maximize the benefits of integrating agroforestry with agro-eco-tourism, the following policies are recommended.

1. Establish financial incentives and subsidies to encourage agroforestry adoption.
2. Develop training programs that equip communities with skills in sustainable tourism and agricultural management.
3. Foster public-private partnerships to provide technical and financial support for integrated projects.
4. Create comprehensive guidelines that balance environmental conservation with economic development tailored to regional contexts.

Conclusion

Agroforestry is a transformative approach to land management that integrates environmental conservation and economic resilience. By combining agricultural practices with forestry, it addresses critical global challenges such as deforestation, soil degradation, climate change, and rural poverty. The ability of agroforestry systems to enhance biodiversity, improve soil fertility, and sequester carbon underscores their environmental significance, while their capacity to diversify income streams highlights their socio-economic value. The integration of agroforestry with agro-eco-tourism further amplifies its benefits by creating opportunities for education, cultural exchanges, and sustainable economic growth. Through activities such as farm stays, guided nature trails, and hands-on workshops, agro-eco tourism not only generates income for rural communities, but also raises awareness about sustainable practices and environmental conservation. Agroforestry landscapes, enriched by their aesthetic and ecological appeal, offer unique experiences that attract eco-conscious travellers and contribute to heritage preservation. Despite its immense potential, the implementation of agroforestry and agro-eco tourism faces challenges, such as policy barriers, resource limitations, market access issues, and the need for greater awareness. Addressing these hurdles requires collaborative efforts among governments, NGOs, private investors, and local communities. Simplifying regulatory frameworks, providing financial incentives, fostering public-private partnerships, and offering training programs are essential steps to optimize the benefits of this integrated approach. As a pathway to sustainable development, agroforestry aligns with global goals such as the United Nations' Sustainable Development Goals (SDGs). Its adoption can transform degraded landscapes into productive ecosystems, enhance food security, and uplift rural economies, while contributing to climate adaptation and mitigation. Agroforestry offers a robust and inclusive model for achieving holistic growth and resilience in the face of environmental and economic uncertainties, by fostering a harmonious relationship between agriculture, forestry, and tourism.

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Policy, Market Dynamics, and Economic Perspectives in Agro-Eco-Tourism Development

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I. Agro-Eco-Tourism

Agro-eco-tourism is a modern concept that blends farming activities with the tourism industry, offering visitors an immersive experience to connect with nature and explore rural life (Parveen Kumar et al., 2021). Agro-eco-tourism has the potential to support rural economies, preserve cultural heritage, enhance environmental awareness, and create employment opportunities. India, with its rich cultural heritage and diverse biodiversity, holds immense potential to capitalize on the benefits of the tourism sector. According to the Travel & Tourism Development Index 2024 report, China, Japan, and India are among the world's largest tourism economies, with all three nations ranking near the top in terms of natural, cultural, and non-leisure assets. Further, India ranked first in South Asian countries and among lower-middle-income countries, and secured the 39th rank among 119 countries.

Table 1: Travel & Tourism Development Index 2024 overall rankings

Rank	Economy	Score
1	United States	5.24
2	Spain	5.18
3	Japan	5.09
4	France	5.07
5	Australia	5.00
South Asia		
39	India	4.25
76	Sri Lanka	3.69
101	Pakistan	3.41

105	Nepal	3.34
109	Bangladesh	3.19

Source: Travel & Tourism Development Index 2024, World Economic Forum https://www3.weforum.org/docs/WEF_Travel_and_Tourism_Development_Index_2024.pdf

Considering its rich natural and eco-tourism resources, the government launched policy initiatives aimed at developing and promoting agro-eco-tourism in the country.

II. Government Policies and Initiatives

a) National Strategy for Ecotourism 2022

The Ministry of Tourism, Government of India, formulated the National Strategy for Ecotourism in 2022 (2). This strategy paper defines and states that ecotourism is responsible for travelling to natural areas that conserve the environment and improve the well-being of local people. The strategy study identified seven pillars for the development of ecotourism in the country (Fig 1).

Fig 1: Strategic pillars for the development of Ecotourism in India
Source: National Strategy for Ecotourism-2022

The promotion and development of ecotourism requires coordination among diverse sets of stakeholders, including ministries of central and state governments, Panchayat Raj institutions, industry, non-government organizations, and local communities for convergence and synergy (Fig 2).

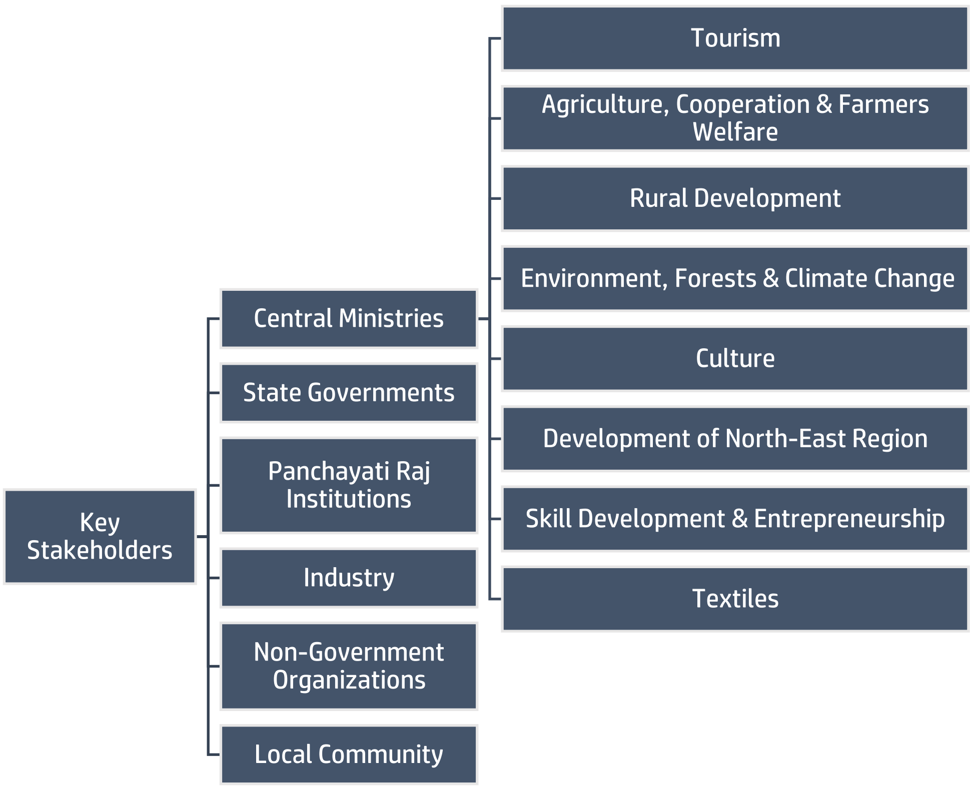

Fig 2: Key Stakeholders for promotion and development of Ecotourism in India
Source: National Strategy for Ecotourism-2022

Balancing development with conservation is crucial for sustainable development of the agro-eco-tourism sector. The Ministry of Environment, Forest, and Climate Change has established the following principles for ecotourism development (Fig. 3).

- Adopt low-impact wildlife tourism that protects the ecological integrity
- Highlight the biodiversity richness, their values and their ecological services
- Highlight the heritage value
- Build environmental and cultural awareness and respect
- Facilitate the sustainability of Ecotourism enterprises and activities
- Provide livelihood opportunities to local communities
- Use indigenous, locally produced and ecologically sustainable materials for tourism activities

Fig 3: Guiding Principles for Ecotourism by Ministry of Environment, Forest and Climate Change

Source: Ministry of Environment, Forest and Climate Change

b) Policy support for Agro-Eco-Tourism development in different states

States such as Maharashtra and Haryana have agro-tourism policies to encourage farmers to establish and register agro-tourism centers. Table 1 provides a brief comparison of the agro-tourism policies of these two states.

Table 1: Comparison of Agro-Tourism Policies of Maharashtra and Haryana

Maharashtra	Haryana
Eligible entities for Agri- Tourism Centre	
Individual farmer/Agricultural Cooperative Society of farmers/Government Recognized Agricultural Science Centre (Krishi Vigyan Kendra)/ Agricultural Colleges (Private and Government)/ Agricultural	Registration of farm houses shall be done only in those cases where the farm houses are fully developed and worth visiting from the tourism point of view

Universities/ Partnership firms or companies formed by farmers	
Requirements	
• Village: Agri tourism centre should be set up in a village and at a distance of a minimum one Kilometer from the city • A minimum of one acre agricultural land • Farmer: If a person who runs the agri tourism centre is an individual farmer, then he/she should do the farming activity • Rooms constructed for living in the agri tourism centre may possibly be eco-friendly mandatory to make available meal arrangements, clean drinking water, and amenities to tourists • Minimum one educational picnic/visit must be arranged for the students	It is mandatory to have a minimum of two lettable rooms for registration of the farm house. Well-maintained and well-equipped guest rooms with necessary amenities

Source: Maharashtra Agri tourism policy & Guidelines for Approval and Registration of Farm Tourism Scheme in Haryana

III. Market Dynamics

Tourism trends in Goa

a) Tourist Arrivals to Goa

The total number of tourists arriving at Goa has increased over the years. During the pre-covid period of 2019, the total tourist arrival was 80,64,400 (Fig 4). During the covid period, arrivals declined to 29,71,726 in 2020 and 33,30,217 in 2021. However, during the post-covid period, total tourist arrival increased to 71,87,950 in 2022 and 86,28,162 in 2023.

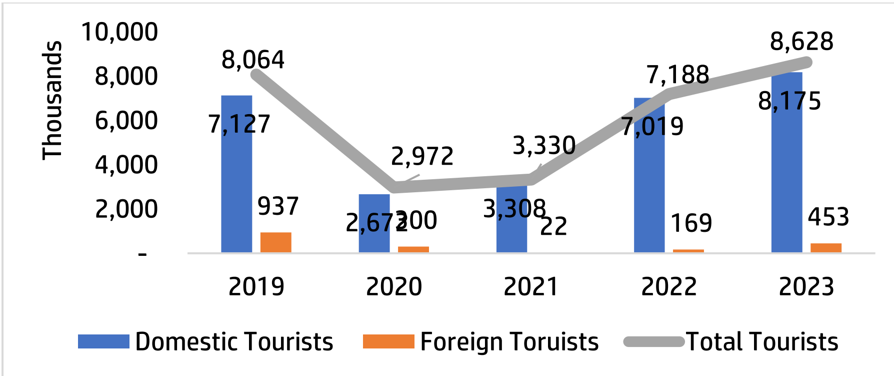

Fig 4: Tourist Arrivals to Goa over the years (2019 to 2023)

Source: Government of Goa

https://static.gladns.in/goalpub/docs/question_docs/file_0bcbde3b-fcb4-482f-a3f7-cf52acb4b86f.pdf

b) Month-wise tourist arrivals to Goa

The month-wise tourist arrival at Goa from January 2022 to May 2024 is depicted in Figure 5. The total number of tourist arrivals increased over the years. During January-2022, domestic tourist arrivals was 4,03,376 which increased to 8,90,682 in May-2024.

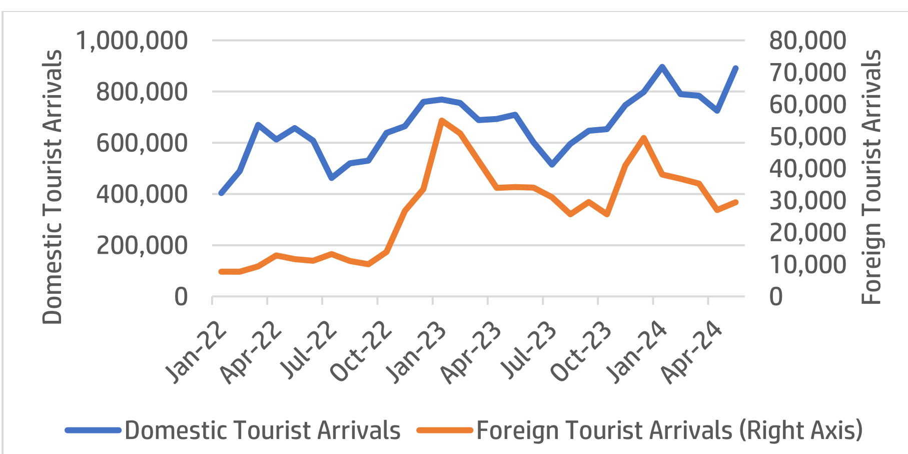

Fig 5: Tourist Arrivals over time (Jan-22 to May-24)
Source: Government of Goa

https://static.gladns.in/goalpub/docs/question_docs/file_be91131f-bdf7-4152-89fa-6f77f5c2e2b0.pdf

c) Taluka-wise Domestic Tourist Arrivals to Goa

In terms of domestic arrivals during 2021-22, Bardez (11,93,246, 35%), Salcete (9,20,504, 27%), Tiswadi (8,18,226, 24%), and Pernem Taluka (3,75,020, 11%) registered a higher share (Figure 6). The cumulative share of these four talukas is approximately 97 per cent.

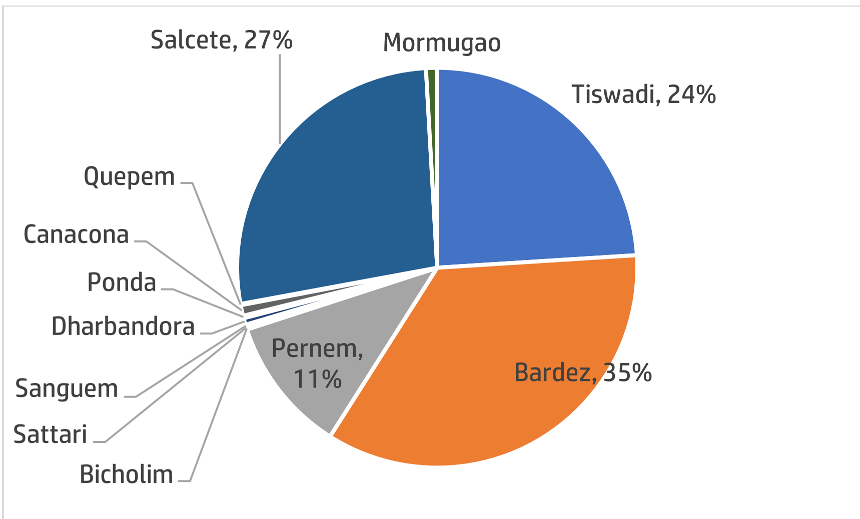

Fig 6: Taluka-wise share of Domestic Tourist Arrivals to Goa (2021-22)
Source: Government of Goa
https://www.goa.gov.in/wp-content/uploads/2023/09/Goa-at-a-Glance-2022.pdf

d) Taluka-wise Domestic Tourist Arrivals to Goa

In terms of foreign arrivals during 2021-22, Bardez (12,752, 39%), Salcete (7,194, 22%), Tiswadi (5,886, 18%), Pernem (1,962, 6%), and Canacona taluka (1,635, 5%) registered higher shares (Figure 7). The cumulative share of these five talukas is approximately 90 per cent.

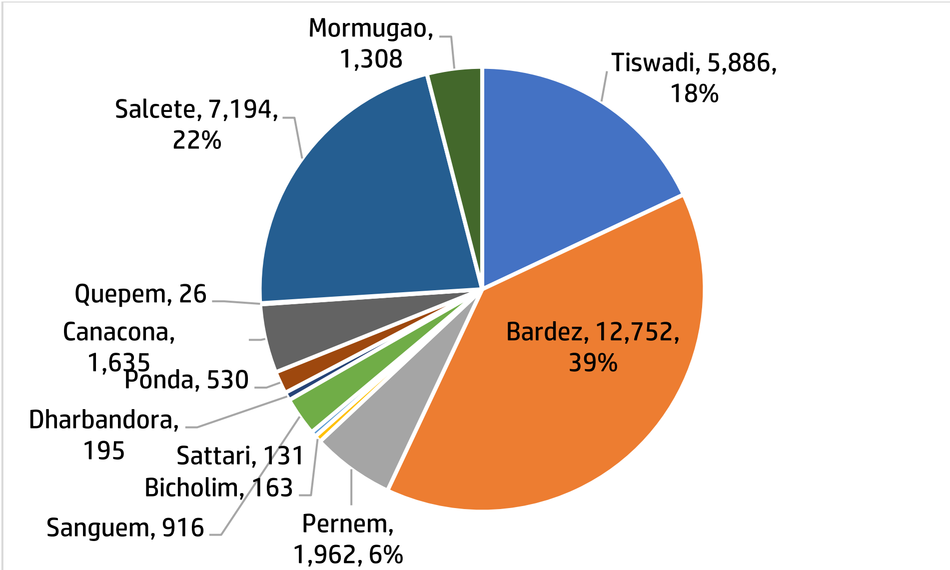

Fig 7: Taluka-wise share of Foreign Tourist Arrivals to Goa (2021-22)
Source: Government of Goa
https://www.goa.gov.in/wp-content/uploads/2023/09/Goa-at-a-Glance-2022.pdf

e) District-wise comparison of Hotels & Tourist Arrivals (2021-22)

The North Goa district, which encompasses five talukas, Tiswadi, Bardez, Pernem, Bicholim, & Sattari, had a higher share of hotels, both domestic & international tourist arrivals in Goa compared to the South Goa district (Figure 8).

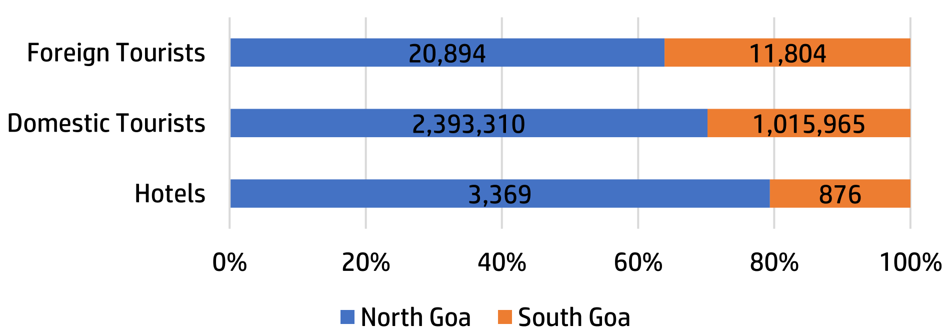

Fig 8: District-wise comparison of Hotels and Tourist Arrivals (2021-22)
Source: Government of Goa
https://www.goa.gov.in/wp-content/uploads/2023/09/Goa-at-a-Glance-2022.pdf

IV. Economic Perspectives in Agro-Eco-Tourism Development

Sustainable Agro-Eco-Tourism contributes to the development of the local economy, job creation in agriculture, tourism, and allied sectors, and provides diversified income sources. Several crop-based plantation farms in Goa and along the west coast are venturing into agro-eco-tourism and have been commercially successful. A summary of the key benefits derived from sustainable agro-eco-tourism by different stakeholders such as farmers, visitors, local communities, and governments is provided in Table 2.

Table 2: Key Benefits of Sustainable Agro-Eco-Tourism for Stakeholders

Farmers/AET entrepreneurs	**Visitors**	**Local Community**	**Government**
Diversified and sustainable income streams	Immersive and educational rural experiences	Employment opportunities and economic growth	Promotion of sustainable rural development
			Multiplier effect on the economy
Year-round revenue generation	Access to fresh farm produce	Reduced migration to urban areas through local employment	Environmental conservation
Increased transactional linkages	Opportunities to learn sustainable farming practices	Preservation of cultural traditions and rural heritage	Sustainable resource management

As agro-ecotourism is a niche and evolving market segment, targeting the right customers is crucial. An ideal ecotourist is often considered to have a low impact and high spending (Chase et al., 2018). Understanding consumer trends and preferences is therefore vital. Reports have indicated a growing interest in organic food, rural experiences, and nature-based tourism. Effective marketing and branding are also key to promoting agro-eco-tourism, and digital marketing, social media, and influencer marketing play increasingly important roles in reaching the right audience. Further, the capacity building of farmers and other stakeholders is also needed to ensure that they can provide high-quality, authentic experiences for visitors. This is essential for sustainable growth of the agro-eco-tourism sector, fostering long-term success while preserving cultural and environmental integrity.

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https://ccari.icar.gov.in/Agro%20Ecotourism/

Addressing AMR in Agriculture and Livestock Value Chains: A Strategic Tool for Enhancing Soil Health in Natural & Organic Farming Systems

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"Imagine a world where infections and diseases in humans, animals and plants are impossible to treat. This worst-case scenario could become a reality as bacteria, viruses and parasites develop resistance to the drugs we use to fight them. Antimicrobial resistance (AMR), has become one of the most pressing health issues of our time. Solutions exist and everyone has a role to play in the fight against this global threat (World Organization for Animal Health, 2024)"

Antimicrobial resistance: a global problem in animal and human

Antimicrobial resistance has led to the emergence of multidrug resistant microbes called "superbugs," that are threat for hospital workers, veterinarians, and other animal health providers due to an ineffective therapeutic option to prevent, control, and treat infectious diseases. AMR is a growing threat to animal and human health, livelihoods, and food security worldwide.

To curb the emergence of drug-resistant microbes, farmers, aquatic animal producers, animal health providers, health care workers, and citizens from every country need to take action to fight this threat to global health.

Impacts of AMR on animal, human, plant, and environmental health

The spread of new resistant strains of bacteria in terrestrial and aquatic animals has led to an increase in animal suffering and loss. This in turn affects livelihoods worldwide, as 1.3 billion people rely on livestock for their living and over 20 million people depend on aquaculture. When antibiotics spill into soil and waterways, resistant strains of bacteria can emerge in the environment. In turn, they can infect animals and humans who come into contact with them. In addition, antibiotic-resistant bacteria in treated animals can be present in manure and, therefore, can be disseminated into the environment and wildlife. The responsible use of antibiotics and proper disposal of unused and expired drugs, as well as waste from relevant industries, ensures that these precious pharmaceuticals stay out of the environment as much as possible and reduce the risk of the development of resistant bacteria.

Over the last 50 years, antimicrobial resistance has emerged mainly due to the indiscriminate use of antimicrobials in people. Currently, new resistant strains of bacteria have dangerously affected hospital patients worldwide. It is estimated that approximately 5 million human deaths were linked to antimicrobial resistance in 2019 including 1.3 million human deaths directly caused by resistant bacteria (Murray et al., 2022). It remains unclear how many human deaths are linked to AMR originating in animals, notably through foodborne infections. While the current burden of disease in animals due to AMR at the global level remains unknown, several initiatives are ongoing to estimate it, notably the Global Burden of Animal Diseases program in which WOAH is actively involved.

Causes for AMR emergence

Over the past two decades, concerns regarding antimicrobial use in farm animals have grown considerably due to the growing prevalence of antimicrobial resistance (AMR), which affects human health. AMR is a natural process that results from the ability of microorganisms to adapt quickly to changing conditions. Indeed, the appearance of rare and advantageous mutations that neutralize the effects of antimicrobials is inevitable in large and dense microbial communities, and rapid generation times allow these mutations to quickly become prevalent in growing communities (Michael et al., 2014). Additionally, bacteria can exchange mobile genetic elements, including resistance genes, via horizontal gene transfer within and between bacterial species, further enhancing their ability to adapt (Michael et al., 2014).

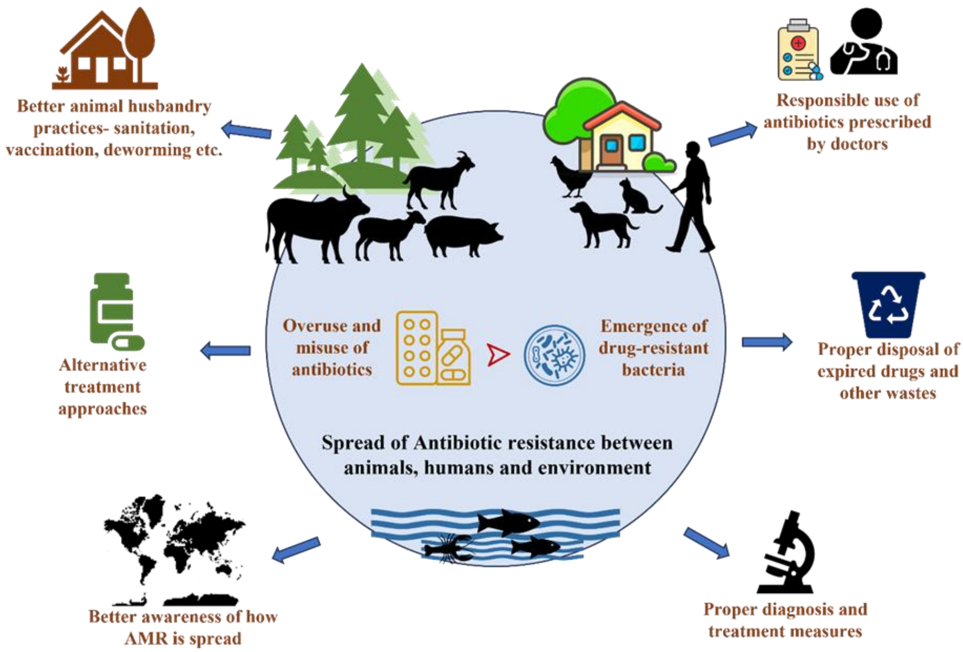

Fig : Spread of AMR and ways for its mitigation

AMR is fueled by anthropogenic factors such as the intensive clinical and agricultural use of antimicrobials worldwide, the growth of the world's human population, changes in human lifestyle (e.g., increased urbanization, migration, and travel), and misconceptions and malpractices regarding antimicrobial use (AMU) (Michael et al., 2014). Antibiotics kill or limit the growth of bacteria that make humans and animals sick. They cure animal diseases such as mastitis in dairy cows, respiratory and urinary tract infections in dogs, and streptococcal infections in fish, and are key to reducing animal suffering and death. However, bacteria are very good at adapting to their environments over time. Random genetic mutations and the transfer of antimicrobial resistance traits can lead to the acquisition of genes that enable them to survive drugs intended to kill them. Through natural selection, new resistant variants thrive and spread. Every time antibiotics are used, bacteria have a chance to develop resistance. This does not mean that we should stop using antibiotics, but it needs to be used responsibly and only when necessary. However, in many cases, especially in veterinary practice in India, antibiotics are misused, necessitating the development of conditions in which drug resistance can emerge. Using an antibiotic to treat a cow's viral infection, for instance, will be of no use to cows, as antibiotics are effective against bacteria but not viruses. Antibiotics are also sometimes overused to promote the growth of food-producing animals. Many times, it is common practice in India for livestock farmers to treat their animals with insufficient knowledge about the proper use of antibiotics. Such misuse and overuse could lead to antibiotics causing more harm. However, by using these drugs responsibly, and only when necessary, we can reduce the chances of pathogens developing resistance and protect the health of humans, animals, plants, and the environment.

The solution: prevention and responsible use of antimicrobials

In the animal health sector, several measures can be implemented by farmers, aquatic animal producers, pet owners, and relevant professionals to ensure that these precious drugs are used responsibly and remain effective. Animals are more susceptible to diseases when they live in stressful environments or when hygiene is poor. Therefore, following good animal management practices that focus on disease prevention and using antimicrobials responsibly is essential. Thus, we can limit the development of antimicrobial resistance and protect the efficacy of antimicrobials in future generations of animals and humans. A growing number of farmers and animal health professionals worldwide are changing their practices to successfully address the threat of AMR.

One Health approach in curbing the rise of AMR

Animal, human, and environmental health are intrinsically intertwined and interdependent. We share the land, resources, and pathogens. Dangerous strains of resistant bacteria can spread between and within animal, human, and plant populations and travel through waterways, soil, and air, infecting wild animals along the way. More than 60% of the pathogens that cause human diseases originate from domestic animals or wildlife, protecting the health of animals, and the environment protects human health.

To address the challenges posed by antimicrobial resistance, countries have been advised to invest in AMR containment through AMR surveillance and to curb the prevalence of antimicrobial resistance via optimal antimicrobial prescription and use in both human and veterinary medicine (WHO, 2020).

Regarding the latter, the institutionalization of AMU, as well as the reduction of antimicrobial dependence, is necessary to achieve sustainable use of antimicrobials. Antibiotics play a crucial role in livestock production because they are not only therapeutic but also economic assets. The preventive use of antimicrobials to treat at-risk herds or animals (prophylaxis) as well as clinically healthy animals sharing premises with symptomatic animals (metaphylaxis) limits economic risks and labor costs (Lekagul et al., 2019).

Fighting antimicrobial resistance is a truly global endeavour and must be addressed through a One Health approach. This is why collaboration between sectors dealing with human, animal, plant and environmental health is crucial. It is by reducing the overuse of antimicrobials in humans, animals, and plants that we will be able to achieve better global health.

How to reduce AMR in food and agriculture

AMR in food and agriculture poses risks to food systems, livelihoods, and the economy. In addition to their direct negative impact on animals, animal diseases can also significantly affect food production, food security, and farmer livelihoods. AMR increases these risks. The use of antimicrobials in agriculture contributes to the spread of AMR and undermines the effectiveness of veterinary medicine. Ensuring that these treatments remain effective and available to the agricultural sector is critical. In addition, drug-resistant infections in humans have been tracked to foodborne and animal sources. When antibiotics spill into soil and waterways, resistant strains of bacteria can emerge in the environment. In turn, they can infect animals and humans who come into contact with them. In addition, antibiotic-resistant bacteria in treated animals can be present in manure and, therefore, can be disseminated into the environment and wildlife. Additionally, the lack of new, promising antimicrobials in the market exacerbates this problem.

In conclusion, fighting antimicrobial resistance is a truly global endeavor and requires interdisciplinary systemic approaches for the development of AMR policies and strategies. This is only possible with the One Health approach through collaboration between different sectors dealing with human, animal, plant, and environmental health. In addition, increasing knowledge and awareness of antimicrobial use can positively influence the rational use of antimicrobials.

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The Role of Indigenous Livestock and Poultry Breeds in Shaping a Climate Resilient Future

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Indigenous livestock and poultry breeds

India is one of the world's mega-biodiverse countries, contributing approximately 11.6% of the global livestock population. Interestingly, more than 75% of the livestock resources in the country belong to indigenous livestock populations. Indigenous farm animals, such as cattle, buffalo, sheep, goats, pigs, and poultry, play crucial roles in regional economies, local production systems, and sustainable livelihoods. They use land unsuitable for crop production, yielding milk, meat, eggs, food products, hides, manure, and draft power, thereby contributing significantly to the region's welfare. To date, 220 indigenous breeds of livestock and poultry have been registered by ICAR-NBAGR, including 53 cattle, 20 buffalo, 39 goat, 45 sheep, 8 horses and ponies, 9 camels, 14 pigs, 3 donkeys, 3 dogs, 1 yak, 20 chickens, 3 ducks, 1 geese, and 1 synthetic cattle.

Climate resilience and adaptability

Indigenous livestock and poultry breeds are domesticated animal species that have evolved and adapted to the specific environmental conditions of a region over centuries. These breeds are well-suited to local ecosystems and climatic conditions, often thriving where exotic or commercial breeds may struggle. Indigenous livestock and poultry have developed traits such as disease resistance, heat tolerance, and the ability to efficiently utilize low-quality feed, which contribute to their survival and productivity under local environmental stresses. Climate resilience refers to the capacity of a species or breed to withstand and adapt to the negative impacts of climate change, including fluctuations in temperature, altered rainfall patterns, extreme weather events (such as droughts, floods, or heatwaves), and changes in the available feed and water. Climate-resilient breeds possess specific traits that enable them to adapt to such changing conditions, ensuring their continued productivity and sustainability of farming systems in the face of climate change. Indigenous livestock and poultry breeds are key to climate resilience, as they naturally develop traits that enable them to thrive under harsh environmental conditions. These breeds have evolved over time in specific geographic areas with selective pressures from local climates, predators, diseases, and other environmental factors.

Key traits of climate-resilient indigenous breeds

Thermotolerance

Many indigenous livestock breeds are well adapted to hot climates and can withstand high temperatures, making them particularly suited to regions that experience heat waves or high ambient temperatures. For example, the *Bos indicus* cattle breeds, such as Gir and Sahiwal in India, have developed larger surface areas for heat dissipation and sweat glands that help them regulate body temperature. Similarly, indigenous poultry breeds such as the Aseel, Naked neck, and frizzle chicken are known for their ability to tolerate heat stress, which is a key trait in regions with extreme heat.

Disease resistance

Indigenous breeds are often more resistant to disease outbreaks and pests, which are critical for ensuring the health and productivity of animals in the face of climate change-induced shifts in disease patterns. *Bos indicus* breeds are more resistant to tick infestation and tick-borne diseases. The natural resistance-associated macrophage protein 1 (NRAMP1) gene is linked with resistance to brucellosis, tuberculosis, and salmonellosis. *Major histocompatibility complex (MHC)* genes are associated with specific immunological responses. A region of chromosome 1 is associated with infectious keratoconjunctivitis (pinkeye) in cattle. Buffaloes are resistant to systemic infections in terms of febrile reactions or any type of contagious disease, particularly foot-and-mouth disease.

Feed Conversion Efficiency

Indigenous breeds are generally more efficient in converting low-quality feed, such as roughage and grasses, into meat, milk, or eggs. This is particularly important in regions where the availability of high-quality feed may decrease owing to changes in agricultural patterns, land use, and climate. Native goats, such as the Malabari from Kerala, are known for their ability to thrive on poor pastures and still produce high-quality milk and meat.

Water Efficiency

Several indigenous breeds have developed survival strategies in areas with limited water resources. For example, desert-adapted breeds, such as the Bikaneri camel in India, can survive long periods without water by efficiently conserving body fluids. Similarly, the indigenous poultry breed known as the Kadaknath chicken has developed a high tolerance to dehydration, which is critical in drought-prone regions. Indigenous livestock and poultry breeds play crucial roles in the development of climate-resilient agricultural systems. Adaptive traits, including heat tolerance, disease resistance, efficient feed conversion, and water conservation, are vital for maintaining productivity and sustainability in the face of climate change. By preserving and utilizing indigenous breeds, the agricultural sector can build more resilient and sustainable food systems capable of meeting climate change challenges.

Utility of climate-resilient Indigenous livestock and poultry

Climate-resilient indigenous livestock and poultry breeds are invaluable assets for sustaining agricultural productivity, particularly in regions that face extreme climatic challenges. These breeds have evolved unique adaptations that enable them to thrive under harsh environmental conditions, including very high and cold temperatures, water scarcity, poor quality feed, and fodder. Their utility extends beyond their ability to withstand climate extremes, contributing significantly to food security, rural livelihood, and biodiversity conservation. The following sections provide detailed insight into the utility of climate-resilient breeds.

Cattle

Bos indicus cattle breeds, including Gir, Sahiwal, Red Sindhi, Shweta Kapila, and Ongole, are known for their heat tolerance and resistance to tropical diseases, making them highly adaptable to regions with high temperatures and seasonal disease outbreaks. These breeds have evolved mechanisms, such as larger surface areas for heat dissipation and more efficient sweat glands, allowing them to thrive in hot, humid environments. Sahiwal and Gir are prized for high milk yields under such conditions, contributing to dairy industries in tropical and subtropical regions.

Buffalo

Buffaloes produce more than half of India's milk, forming the backbone of Indian dairy farming. Buffaloes are preferred by farmers because of their higher feed efficiency and higher milk and meat production. They suffer fewer fertile problems and more productive years in comparison to crossbred cows, better adaptability to harsh environmental conditions, and higher disease resistance. Buffaloes have anatomical traits such as thick skin, high concentrations of melanin in the skin, and a high density of dermal arterioles and capillaries to improve sensitivity to heat losses and protect them from heat stress. Murrah, Jaffarabadi, Surti, Chilika, Toda, and Banni are the most highly valued indigenous buffalo breeds. The Murrah buffalo originated in India and is a world-class breed.

Goats

Goats are among the most climate-resilient livestock species, particularly breeds such as Jamunapari, Barbari, Black Bengal, Malabari, and Konkan Kanyal. Jamunapari goats are known for their large size, high milk production, and high meat quality. It is particularly useful in arid and semi-arid regions because of its heat tolerance and its resistance to common livestock diseases. The Barbari goat, another indigenous breed in India, is prized for its adaptability to harsh climatic conditions, excellent meat quality, and efficient reproductive performance under resource-scarce conditions. Black Bengal, Konkan Kanyal, and Malabari also demonstrated remarkable adaptability to hot and humid climates and provided milk and meat to local communities.

Sheep

Indian Deccani sheep are crucial to pastoralists in hot and dry environments. Deccani sheep are a hardy breed from the Deccan Plateau that are adapted to hot and dry climates. It is known for its resistance to local diseases, which makes it a valuable resource for maintaining sheep populations in harsh climates. Their high reproductive efficiency and ability to produce meat and wool in resource-limited environments makes them essential for sustaining rural livelihoods.

Poultry

Indigenous poultry breeds such as the Aseel, Kadaknath, and Naked Neck offer significant utility in adverse climatic conditions. Aseel chickens are known for their heat tolerance, disease resistance, and the ability to survive in low-input farming systems. Aseel chickens are highly valued for their meat quality and are an important source of protein in rural areas. Kadaknath chicken is particularly valued for its meat, which is rich in protein and iron and is adaptable to low-quality feed. This breed has proven useful in regions where access to commercial poultry feed is limited and its heat resistance makes it a preferred option in hot climates. Naked Neck chicken originated in Africa and adapted well in India. It is highly heat-tolerant and resistant to Marek's and Newcastle disease. These breeds contribute to food security by providing eggs, meat, and income to rural communities.

Camels

Camels are among the most climate-resilient livestock species in the world. Camels are well known for their ability to survive extreme heat and drought conditions, making them invaluable in arid regions. They are capable of traveling long distances without water and can withstand high ambient temperatures where other livestock species would struggle. The Bikaneri camel, native to Rajasthan, India, is well adapted to hot desert climates and is an important source of milk, meat, and transport. Their adaptability to harsh climates, resistance to diseases, and ability to utilize marginal resources make them indispensable for climate-resilient agricultural systems worldwide. The continued conservation and promotion of these breeds is essential for sustainable food production in the era of global climate challenges.

Role of Indigenous livestock and poultry in agro-ecotourism

Agroecotourism offers a valuable opportunity to highlight the role of indigenous livestock and poultry breeds in enhancing ecosystem stability and climate resilience. By integrating agro-ecotourism into climate-resilient agricultural systems, visitors can observe firsthand how these breeds thrive in their native habitats, while supporting ecosystem balance. Indigenous breeds are integral to sustainable farming systems, promoting biodiversity conservation and reducing land degradation. Animals maintain soil health, support the local flora and fauna, and contribute to the overall stability of the ecosystem. Agro-ecotourism provides a platform for preserving traditional agricultural practices linked to the management of these breeds, offering educational experiences on their cultural significance and the traditional knowledge systems that have evolved around their care. Linking agro-ecotourism to indigenous livestock conservation also supports biodiversity and genetic preservation. Conservation of genetic resources, including endangered breeds, is essential for future agricultural resilience. Agroecotourism sites can raise awareness and funds for the conservation of these breeds through interactive tourism experiences.

Conclusion

Additionally, agro-ecotourism can demonstrate sustainable farming practices that mitigate the impacts of climate change. By showcasing drought-tolerant breeds, visitors can learn about the role of climate-resilient livestock in ecosystem services, such as water conservation, soil health, and carbon sequestration. Moreover, agro-ecotourism contributes to local economies by providing economic incentives to farmers who raise indigenous livestock, thus improving rural livelihoods and ensuring long-term sustainability.

Conservation of traditional rice varieties: A scientific approach to sustainability and nutrition

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Introduction

Landraces/traditional varieties have been nurtured and cultivated by farmers through traditional selection methods over the years. Zeeven (1998) defined landraces as a variety with a high capacity to tolerate biotic and abiotic stresses, high yield stability, and an intermediate yield level under a low-input agricultural system. They have evolved to adapt and thrive under particular environmental conditions and meet local food preferences (Lin, 1991). Farmers prefer landraces because of their good taste, cooking quality, and tolerance to various biotic and abiotic stresses. Agromorphological characterization of germplasm accessions is fundamental for providing information for plant breeding programs. Well-characterized and evaluated germplasm collections would have greater chances of contributing to the development of new varieties and, consequently, greater realization of benefits for resource-poor farmers.

The western Ghat region is a biodiversity hotspot in India and has a valuable repository of biodiversity after the Himalayas. Documentation of rice landraces from locations in the Western Ghats and information about the special traits associated with each of them have already been discussed by several researchers. Rice landraces in Kerala were studied in detail by Latha et al. (2013), Rajanna et al. (2014), and Hanamaratti et al. (2008), who discussed the landraces of Karnataka in length. The Goa state of India, located in the middle of the Western Ghats, has rich diversity with respect to landraces and traditional rice varieties. *Korgut*, a unique rice landrace, is grown extensively in coastal saline soils (*khazan* lands, local terminology for salt-affected soils) and is able to tolerate the effect of salinity stress resulting from the ingression of brackish water into paddy fields due to tidal variation (Manohara et al. 2015; Manohara and Singh 2013). Phenotyping for salinity stress at the seedling stage under a hydroponic solution showed that *Korgut* can tolerate salinity up to 12 dS/M (Manohara et al 2015). Similarly, *Shidde* is another landrace of rice grown in coastal saline soils that has the ability to tolerate water stagnation in addition to salinity.

Over time, most indigenous rice landraces and varieties have either been lost or are on the verge of extinction. The lodging nature of traditional varieties makes mechanized harvesting challenging. The non-availability of quality seeds of local varieties and the introduction of high-yielding varieties also contribute to their deliberate replacement (Manohara et al. 2019). These local genetic treasures must be conserved so that they can be used in future breeders.

Collection, conservation and characterization of rice germplasm from Goa and adjoining states

To date, we collected 20 landraces in Goa (Table 1), 104 in Karnataka, and 37 in Kerala. Each of these traditional rice varieties is unique in terms of adaptation to their habitat and other economic characteristics. Most of the collections from Karnataka are primarily from two districts: Uttara Kannada and Shivamogga.

Agro-morphological and molecular characterization of these collections was performed to understand the genetic diversity among these collections. We observed a wide range of values for all parameters studied. In addition to characterizing agro-morphological and yield-attributing traits, screening of these germplasm accessions for salt stress tolerance was performed using microplots to identify lines tolerant to salinity stress at the seedling stage.

Table 1: Landraces of Goa, their place of collection, and special traits attached to each of the varieties.

Sr. No.	Landraces	Place of collection (Village, Block, District)	Special traits
1	Damgo	Anconem, Pernem, North Goa	Medium land rice, good taste
2	Mudgo	Anconem, Pernem, North Goa	Medium land rice
3	Belo	Asapur, Pernem, North Goa	Medium land rice
4	Kalobelo	Asapur, Pernem, North Goa	Medium land rice
5	Walayo	Torxem, Pernem, North Goa	Medium land rice

6	Kendal	Neura, Tiswadi, North Goa	Grown on sandy soils
7	Korgut(red)	Chorao Island, Tiswadi, North Goa	Salinity tolerant, good for ganji (porridge) preparation, feeling of satiation after consumption
8	Red Kochri	Sangolda, Tiswadi North Goa	Good taste, Good for ganji preparation (porridge)
9	White Kochri	Sangolda, Tiswadi, North Goa	Good taste, Good for ganji preparation (porridge)
10	Saalsi	Gaondongrim, Canacona, South Goa	Aromatic rice, used in sweet dish preparation during festivals
11	Kolyo	Cotigao, Canacona, South Goa	Upland rice
12	Panyo	Gaodongrim, Canacona, North Goa	Water logging tolerance
13	Shidde	Amona, Tiswadi, North Goa	Salinity and water stagnation tolerant
14	Xitto	Cotigao, Canacona, South Goa	Suited for irrigated / rabi season
15	Babri	Torxem, Pernem, North Goa	Good taste
16	Patni-I	Loutulim, Salcette, South Goa	Upland rice
17	Patni-II	Loutulim, Salcette, South Goa	Upland rice
18	Korgut (brown)	Chorao Island, Tiswadi, North Goa	Salinity tolerant

a. Korgut

b. Kolyo

c. Mudgo

d. Walyo

Pictures of traditional rice varieties collected from Goa state

Landrace collections made during *kharif* 2017 from Uttara kannada district of Karnataka

Wild rice collection sites in Goa in 2013 *Kharif* season

Farmers still cultivate many local varieties in their fields because of their unique ability to adapt to the prevailing environmental conditions. Various varieties, such as *Korgut* and *Asgo* known for their tolerance to saline conditions and are grown in low-lying coastal saline soils in Goa. Similarly, *Kari kagga* and *Bili* *kagga* are popular varieties in the low-lying coastal saline soils of Karnataka state. *Pokkali* varieties are popular along the Kerala coast, whereas *Khara rata* and *Bura rata* are popular among farmers in the Maharashtra state.

Characterization of local varieties using agro-morphological and yield parameters

Systematic characterization of these traditional varieties was performed at the ICAR-CCARI farm for three consecutive years from 2020/21 to 2022/23. There is huge variation in plant height, number of tillers per plant, panicle length, grains per panicle, and many other parameters. The diversity among these germplasm lines using agro-morphological and molecular markers showed relationships among collections from different states (figure 1). The descriptive statistics for yield and its attributing traits are presented in Table 2.

Table 2: Descriptive statistics for grain yield and its attributing traits among the germplasm accessions

Variables	Min	Max	Range	PCV	GCV	H (%)	GA	Skewness	Kurtosis
DFF	83.6	152.6	69.0	13.8	13.6	98.3	27.9	0.04	-0.80
DM	118.5	177.5	59.0	10.6	10.5	99.0	21.3	0.02	-1.23
Pht	80.8	209.1	128.3	15.0	14.7	96.6	29.8	-0.44	-0.38
NPT	4.3	17.6	13.4	22.6	19.4	73.8	34.2	1.02	2.39
FLL	23.1	65.3	42.2	21.5	19.4	81.7	36.2	0.47	-0.28
FLW	1.1	2.2	1.2	14.4	11.3	61.1	18.1	0.64	0.27
PL	16.7	36.1	19.5	10.8	10.4	92.8	20.7	0.05	0.29
GPP	18.5	344.6	326.1	41.6	40.6	95.2	81.7	0.74	1.23
PF	23.2	98.1	74.9	14.8	13.1	77.7	23.7	-1.17	2.16
DGL	3.8	7.2	3.4	10.7	10.4	94.2	20.7	-0.51	0.90
DGW	1.4	3.2	1.8	12.6	12.1	92.2	24.0	-0.31	-0.07
L/B	1.3	3.4	2.1	14.6	14.2	93.7	28.2	0.51	0.99
TW(g)	1.0	4.7	3.7	24.4	24.2	98.5	49.6	-0.05	0.20
GY(g)	2.2	28.4	26.2	41.4	39.3	90.1	76.8	0.11	-0.24
SY(g)	11.6	73.5	61.9	38.4	37.9	97.2	76.9	0.49	-0.49
HI	0.0	0.5	0.5	39.1	37.8	93.4	75.2	0.01	-0.68

DFF-Days to 50% flowering; DM-Days for maturity; Pht-plant height (cm); NPT-Number of productive tillers per hill; FLL-Flag leaf length (cm); FLL-Flag leaf width (cm); PL-Panicle length (cm); GPP-Grains per panicle; DGL-Decordicated grain length (mm); DGW- Decorticated grain width (mm); L/B-Length to breadth ratio; TW-test weight (g); GY-grain yield (g); SY-Straw yield (g); HI-Harvest index.

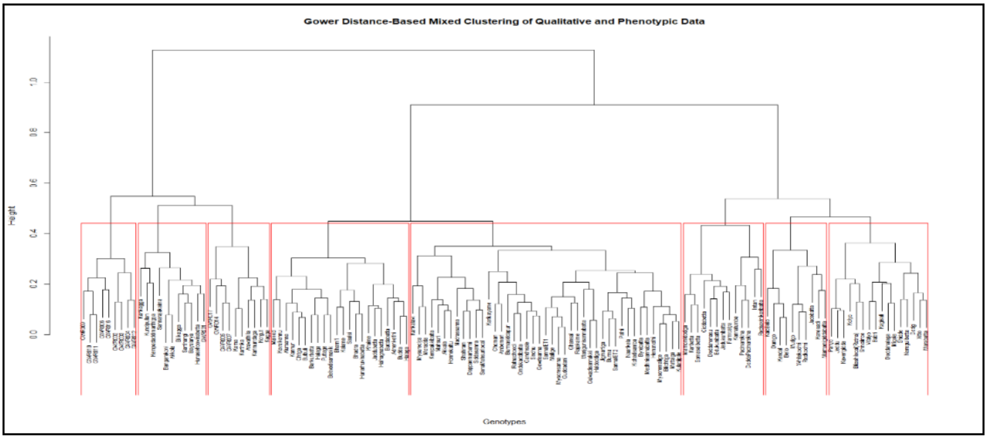
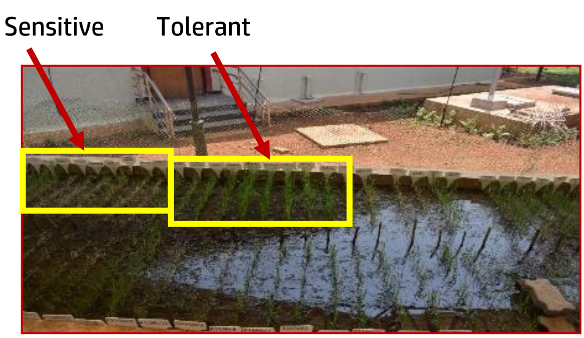


Figure 1. Dendrogram depicting the clustering among the germplasm collections based on agro-morphological and yield attributing traits

Identification of novel rice germplasm accessions tolerant to seedling stage salinity stress

Two hundred thirty-four rice germplasm accessions, including landraces, wild relatives, advanced breeding lines, and released varieties, were screened for salinity stress at the seedling stage in micro plots during the *Kharif* 2022 season under an induced salt stress level of 10 dS/M (iw). Among the genotypes tested, 13 showed a tolerant reaction with an SES score of 3, 58 exhibited a moderately tolerant reaction (SES score of 5), 99 were sensitive (SES score of 7), and 62 were highly sensitive (SES score of 9). None of the accessions displayed a highly tolerant response (SES = 1). The genotypes *Mara Batta, Sanna IET, Chitga, Dodgi, Karna, Shirali Local, Bilashi Local, Byalearya, Aravat*



Hilla, Korgut, Walayo, Barkur Bhatta, and Jeddu Batta demonstrated a tolerant reaction, with an SES score of 3. These landraces could serve as novel sources of salinity tolerance during the seedling stage. FL 478 was used as a tolerance check, while IR29 was used as a sensitivity check.

Screening of germplasm accessions under microplots at induced salt stress of 12dS/M during kharif 2022

Utilization of traditional varieties in developing salt tolerant rice varieties and genetic stocks

Korgut, a traditional rice landrace of Goa, has been registered as a unique germplasm for tolerance to salinity stress at the seedling stage by the National Bureau of Plant Genetic Resources (NBPGR), New Delhi. The Plant Germplasm Registration Committee, in its 30th meeting held on 4th September 4, 2014, approved Korgut for registration and assigned the national identity number INGR14055.

Development of high-yielding salt-tolerant rice varieties from the local salt-tolerant landrace Korgut

Keeping in view its popularity among farmers of *Khazan* land in Goa, the *Korgut* variety was purified to develop two rice varieties. As a landrace, *Korgut* faced several problems that were addressed during the selection process. Two promising selections, *Korgut* Selection 12 (KS 12) and *Korgut* Selection 17 (KS 17), are shortlisted for the final release. The State Variety Release Committee (SVRC) of the Government of Goa approved the release of these two varieties, which were later officially named Goa Dhan 1 (KS 12) and Goa Dhan 2 (KS 17). In 2019, two additional rice varieties were developed and released for the coastal salt-affected soils of Goa. Goa Dhan 3, a *Saltol* QTL introgressed line developed at IRRI, was adopted in Goa after successful testing under saline coastal conditions. The Goa Dhan 4 variety was derived from a cross between Jyothi and *Korgut* rice varieties.

Details of the four salt-tolerant rice varieties at ICAR-CCARI Goa is given below

Goa Dhan 1 (KS 12 / IET 25055 / IC629221)

A high-yielding salt-tolerant rice variety was released for cultivation in salt-affected coastal saline soils of Goa State. It is a semi-tall white-kerneled rice

variety with a short-bold grain type. The variety is medium in duration, with a grain type suitable for both raw and parboiled rice.
Year of release: 2017 (SVRC release)

Salient features

Parentage	: Pure line selection from *Korgut*
Breeding method	: Pure line selection
Plant height	: 108-110 cm
Duration	: 130-135 days
Ecology	: Coastal saline soils

Quality parameters

Short bold grain type with good HRR (60.1%), intermediate amylose content (22.67%), and optimal GC (20).

Grain yield

Under high salinity conditions, the variety can yield 30-35 q/ha, and under normal conditions, it can yield 40-45 q/ha.

Goa Dhan 2 (KS 17 / IET 27825/ IC629222)

A high-yielding salt-tolerant rice variety was released for cultivation in salt-affected coastal saline soils of Goa State. It is a tall, red-kerneled rice variety with a long bold grain type. The variety is medium in duration, with a grain type suitable for both raw rice and parboiled rice.
Year of release: 2017 (SVRC release)

Salient features

Parentage	: Pure line selection from *Korgut*
Breeding method	: Pure line selection
Plant height	: 140-150 cm
Duration	: 125-130 days
Ecology	: Coastal saline soils

Quality parameters

Long bold grain type with very good HRR (62.7 %), intermediate amylose content (24.12), and optimum GC (24).

Grain yield:

Under high salinity conditions, the variety can yield 28-30 q/ha and under normal conditions can yield 40-45 q/ha.

Goa Dhan 3 (GRS 1 / IET 25051 / IC629223)

A selection from the *Saltol* QTL introgressed rice lines was received from the International Rice Research Institute (IRRI), Philippines. It is a white-kerneled semi-tall-type variety with long-bold grains. This variety is recommended for cultivation in salt-affected coastal saline soils in the Goa state.

Year of release: 2019 (SVRC release)

Salient features

Parentage	: A 69-1/IR 55179-3B-11-3
Breeding method	: Pedigree method
Plant height	: 105-110 cm
Duration	: 120-125 days
Ecology	: Coastal saline soils

Quality parameters

Long bold grain type with very good HRR (55.7%), intermediate amylose content (21.67%), and optimum GC (22).

Grain yield:

Under high salinity conditions, the variety can yield 30-35 q/ha and under normal conditions can yield 55-60 q/ha.

Goa Dhan 4 (JK 238 / IET 27840 / IC629224)

It is a high-yielding salinity-tolerant rice variety released for cultivation in the coastal saline soils of Goa state in 2019. Because of its superior performance over locally cultivated varieties (Jyothi) and its red kernel grains, the variety is also recommended for cultivation under normal soils.

Year of release: 2019 (SVRC release)

Salient features

Parentage	: Jyothi/Korgut
Breeding method	: Pedigree method
Plant height	: 110 cm
Duration	: 125-130 days
Ecology	: Coastal saline soils

Quality parameters

long slender grain type with very good HRR (58.7%), intermediate amylose content (23.67%), and optimum GC (23).

Grain yield

Under high salinity conditions, the variety can yield 30-35 q/ha and under normal conditions can yield 50-55 q/ha.

Conclusion

Traditional rice varieties or landraces are invaluable genetic resources that have evolved through years of farmer-led selection and adaptation to local environmental and cultural needs. These landraces exhibit remarkable tolerance to biotic and abiotic stressors, including salinity and water stagnation, making them indispensable for low-input agriculture in stress-prone environments. However, their cultivation is declining owing to challenges such as lodging susceptibility, non-availability of quality seeds, and the introduction of high-yielding varieties.

Efforts to collect, conserve, and characterize landraces, particularly in biodiversity-rich regions, such as the Western Ghats, are crucial. Systematic agro-morphological and molecular studies have revealed significant genetic diversity among landraces in Goa, Karnataka, and Kerala. These studies have led to the identification and development of high-yielding, stress-tolerant rice varieties, such as Goa Dhan 1, Goa Dhan 2, Goa Dhan 3, and Goa Dhan 4. Derived from landraces such as *Korgut*, these varieties ensure the sustainability of rice cultivation in salinity-affected areas while preserving the unique traits of the traditional germplasm. The conservation and utilization of rice landraces not only safeguards biodiversity but also enhances the resilience of rice production systems, ultimately supporting resource-poor farmers and addressing future agricultural challenges.

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Seed village concept: A sustainable approach to local diversity conservation

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Introduction

Agriculture is crucial for livelihoods and food security worldwide but faces challenges such as climate change, soil degradation, and biodiversity loss, threatening sustainability. The Seed Village Concept (SVC) offers a community-based solution in which farmers collaboratively produce, process, and distribute seeds tailored to local conditions. This approach reduces reliance on commercial seed suppliers; integrates traditional and modern farming practices; and promotes biodiversity conservation, sustainable agriculture, and collective ownership. Seed villages conserve indigenous seed varieties, which are often better adapted to local conditions, enhance ecosystem health, support pollinators, and reduce chemical inputs. They foster resilience to climate change, lower farmers' dependency on external markets, and boost their economic independence. Key activities include farmer training, seed bank establishment, and eco-friendly practices to ensure reliable seed supply and biodiversity preservation. A persistent issue for small and marginal farmers is the unavailability of quality seeds at the right time and place during the cropping seasons. Current mechanisms for seed supply are inadequate, particularly for food grain crops, which still rely heavily on farmer-saved seeds, covering over 80% of the sown areas in developing countries. This practice yields 10-20% lower yields than improved seed varieties. Poor seed access contributes to stagnant yield, declining agricultural productivity, and slow economic growth. In India, the Seed Village Programme (Beej Gram Yojana), launched in 2005-2006, expanded significantly. By 2020-2021, over 65,700 seed villages benefited 3.61 million farmers, producing 2.07 million tonnes of quality seeds and supporting food security and sustainability. The programme combines traditional knowledge with modern techniques and is backed by organizations, such as Krishi Vigyan Kendras (KVKs) and the National Food Security Mission (NFSM). Seed villages offer numerous benefits such as agrobiodiversity conservation, economic savings, and community empowerment. They face challenges including limited awareness, financial constraints, and climate threats. Support through government incentives, research on resilient seeds, and knowledge-sharing platforms are essential for their success. Adopting the seed village concept principles can strengthen farming communities, conserve biodiversity, and ensure long-term food security.

Objectives of the seed village concept

The seed village program seeks to address critical agricultural challenges and enhance seed production systems through the following objectives:

Increase certified/quality seed production: Enhance the production of certified and high-quality seeds to meet the growing demand for reliable planting materials.

Improve the Seed Replacement Rate (SRR): Boost the Seed Replacement Rate in major crops, such as paddy, wheat, soybean, and gram, ensuring farmers access to improved and genetically superior seed varieties.

Enhance farm-saved seed quality: Upgrade the quality of farm-saved seeds through participatory seed production initiatives. The program aims to shift at least 10% of villages annually to adopt better seed-saving practices and produce large quantities of quality seeds.

Introduce and promote new varieties: Familiarize farmers with new and improved seed varieties to accelerate varietal replacement and enhance crop productivity.

Ensure seed availability during contingencies: Strengthen seed security by ensuring timely availability of seeds during emergencies or contingent situations, such as natural disasters or crop failures.

Features of the Seed Village Concept:

Community based seed production: Farmers within a village collaborate to produce high-quality seeds for specific crops. These seeds were then used for local cultivation or were shared with nearby communities.

Preservation of indigenous varieties: This initiative encourages the use of both traditional and locally adapted seed varieties. They are often better suited to local environmental conditions, making them more resilient to climate and pest challenges.

Capacity Building: Training programs are conducted for farmers on modern seed production techniques, quality control, and seed storage. This helps to ensure that the seeds maintain their genetic purity and viability.

Decentralised Seed Distribution: Seeds produced in seed villages are distributed within the community, reducing dependence on external suppliers. This enhances self-reliance and reduces the costs.

Economic Benefits: Farmers can sell surplus seeds, thus creating an additional source of income. It also fosters entrepreneurship among both small and marginal farmers.

Benefits of the Seed Village Concept:

Biodiversity Conservation: This supports the cultivation of diverse crop varieties, reduces genetic erosion, and maintains ecological balance.

Sustainability: Locally adapted seeds reduce the need for chemical inputs and external *interventions, promoting sustainable agricultural practices.*

Food Security: The availability of high-quality seeds ensures better crop yield and stable food supply.

Climate Resilience: Traditional seed varieties are often more resistant to local climate extremes, pests, and diseases.

Implementation Process of seed village programme

The seed village program was executed in two distinct phases to ensure systematic seed production, processing, and storage.

Phase 1: Seed Production

This phase involved identifying areas suitable for specific crops to begin seed production. Farmers grow foundations or certified seeds, which are provided at subsidized prices. To ensure uniformity and seed purity, a single crop variety was grown in a designated area using a cluster-based method.

Selection Criteria for Areas:

- Accessibility of irrigation infrastructure.
- Favorable climatic conditions conducive to multiple cropping seasons.
- Sufficient labor availability and farmers' expertise regarding the crop.
- A record of pest and disease resistance in the region.
- Regular rainfall patterns.
- Proximity to urban centers facilitates the transportation of seeds and agricultural inputs.

Phase 2: Seed Processing and Storage

This phase emphasizes the assurance of seed quality through appropriate handling and storage methods. These processes encompass cleaning, grading, treating, packaging, and storing seeds under optimal conditions. Farmers are instructed in these vital practices to improve seed durability and efficacy, thus ensuring the program's overall success.

Executing Entities

The program will be implemented by multiple organizations, including State Departments of Agriculture, State Agricultural Universities, Krishi Vigyan Kendras, State Seeds Corporations, National Seeds Corporations, State Farms Corporation of India (SFCI), and State Seed Certification Agencies. The Department of Seed Certification also has a function. Each area or locality will have one designated implementing agency authorized by the respective State Government to ensure effective coordination and management.

Programme Execution Framework

The implementation of the seed village program is coordinated by the state government and designated implementing agencies, following a systematic approach to enhance seed production while avoiding duplication of efforts.

1. Area and Farmer Selection

Compact Area Approach: Clusters of 50–150 farmers cultivating the same crop were identified in coordination with the State Department of Agriculture.

Demarcation: Project areas assigned to different implementing agencies must be clearly delineated to prevent overlap with other state-run programs, ensuring efficient resource utilization and avoiding the misuse of funds.

2. Fund Utilization and Crop Selection

Fund Restrictions: Implementing agencies, such as seed corporations involved in commercial seed production, are prohibited from using program funds for regular operations. Compliance must be certified and submitted to the initial project proposal in a prescribed format.

Crop Selection: Farmers select crop varieties in consultation with implementing agencies, with an emphasis on uniformity among participants for consistency in seed quality.

3. Project Duration and Sustainability

Assistance Period: Support is provided for a maximum of two years.

Farmer Training: Farmers are trained in seed production techniques during the assistance period, enabling them to independently manage seed production post-program.

Programme Extension: For continuation beyond two years, implementing agencies must identify new compact areas for inclusion in the scheme.

Financial Assistance and Storage Support

Subsidy on Seeds: Farmers participating in the Seed Village Programme receive financial assistance to purchase a foundation or certified seeds. The subsidy rates are as follows: Cereal Crops, 50% subsidy. Pulses, Oilseeds, Fodder, and Green Manure Crops: 60% subsidy.

Storage Bins: The program assists in acquiring or constructing seed storage bins to preserve seed viability until the subsequent sowing season. The subsidy structure is as follows: SC/ST Farmers: 33% subsidy, up to ₹3,000 for storage bins with a capacity of 20q. Other Farmers: 25% subsidy, up to ₹2,000 for storage bins with a capacity of 20 q. Each household is restricted to a single storage bin under the programme to guarantee equitable distribution.

Programme Monitoring and Implementation

The progress of the Seed Village Program is closely monitored by the **Seeds Division of the Department of Agriculture and Cooperation** to ensure that its objectives are achieved with transparency and efficiency.

Monitoring Framework

Implementing agencies are required to submit **quarterly progress reports** detailing:

- The number of farmers and areas covered under the programme.
- Types of seed varieties cultivated.
- Utilization of funds for seed distribution and farmer training.
- Outcomes of seed production and the status of storage facilities.

Regular reviews are conducted to assess program effectiveness, identify challenges, and recommend corrective measures, where necessary.

Identification of Areas and Seed Distribution

Expert Involvement: Scientists and agricultural experts identify areas suitable for seed production.

Subsidized Seed Provision: Foundation or certified seeds are provided at 50% subsidy through **Krishi Vigyan Kendras (KVKs)** and research stations. Farmers cultivate these seeds in plots of approximately one acre to produce high-quality seeds for personal use.

Programme focus and implementation details

Key Crops: The program prioritizes crops such as rice, pulses, and oilseeds to enhance agricultural productivity and food security.

Seed Distribution: Implementing agencies distribute foundation or certified seeds at **50% of their cost** to preselected farmers. Each farmer is allocated seeds for cultivation for up to **half an acre**.

Seed Procurement and Pricing

Procurement Sources: Seeds are sourced from authorized entities, including the National Seeds Corporation (NSC), State Seeds Corporations, State Farms Corporation of India (SFCI), Seed cooperatives, State Departments of Agriculture, and State Agricultural Universities (SAUs). ***Pricing***: Seed prices are determined based on the rates set by the **National Seeds Corporation**, and a 50% subsidy is calculated accordingly.

Capacity building

The program emphasizes improving farmers' ability to grow high-quality seeds and efficiently incorporating technology with community engagement. Selected farmers in seed villages engaged in a structured three-day training program focused on seed production and technology. Training seeks to provide farmers with practical expertise during the critical stages of the seed production process. The preliminary training session occurred during the sowing phase, focusing on essential topics such as isolation distance standards, suitable sowing methods, seed treatment protocols, and specific agronomic practices for the crop. The second training day occurred during the flowering phase, focusing on identifying and removing off-types and rogue plants, maintaining seed plot integrity, implementing plant protection measures, and assessing crop maturity for harvest. The final training day takes place after harvest, during which farmers are instructed on seed cleaning, grading, treatment, and storage techniques. Supplementary subjects include seed bagging, packaging, and proper methods for collecting and sending representative seed samples to laboratories for germination and quality evaluation.

The agencies that disseminate foundation and certified seeds also conduct training sessions. They ensured that farmers had the necessary skills and knowledge at each process stage. This organized training empowers farmers to adopt sophisticated methods, ensuring the generation of high-quality seeds and fostering self-sufficiency. This initiative enhances seed quality and strengthens agricultural productivity and sustainability in the seed villages.

Advantages of the seed village programme

The seed village program offers numerous benefits to farmers and the wider agricultural industry. The primary advantages encompass:

Timely availability: farmers obtain seeds directly at their residences, guaranteeing accessibility when required.

Affordability: Subsidized seeds are provided at reduced prices compared with market rates, rendering them accessible to farmers across various economic strata.

Quality assurance: This program guarantees high-quality seeds from reputable sources, fostering trust among farmers.

Rapid adoption:The program promotes extensive utilization of high-yielding crop varieties, thereby improving agricultural productivity.

Self-Reliance: Villages attain self-sufficiency in seed production, diminishing reliance on external suppliers.

Solution to isolation problems: For cross-pollinated crops, such as maize and sunflower, the challenge of isolation distance is addressed by cultivating a single variety across an extensive area.

Ease of mechanisation: The program facilitates the implementation of mechanized processes, encompassing sowing to harvesting.

Streamlined post-harvest handling: The handling and processing of seeds are rendered more efficient owing to the uniformity of the crop variety.

Minimized varietal admixture: The risk of varietal admixture is mitigated by cultivating a single crop variety in a specific location and timeframe, thereby streamlining harvesting and processing.

Efficient certification: Seed certification officials can traverse larger areas in less time, thereby augmenting efficiency.

Reduced cultivation expenses: The program's seed production expenditure is lower than that of conventional seed production techniques.

High quality seeds: This program guarantees genetically and physically pure seeds, enhancing crop yields and overall agricultural productivity.

Seed Hub

The timely availability of an adequate quantity of quality seeds is one of the most critical factors for enhancing pulse productivity. In this direction, the Department of Agriculture, Cooperation & Farmers Welfare (DAC & FW), Government of India, New Delhi has sanctioned a project on 'Creation of Seed Hubs for Increasing Indigenous Production of Pulses and Oil Seeds in India' under the National Food Security Mission (NFSM) with ICAR–Indian Institute of Oilseed Research, Hyderabad as oil seed hub and ICAR Indian Institute of Pulses Research (ICAR-IIPR), Kanpur as Nodal Agency for its implementation at 150 Seed Hub centers across the country through State Agricultural Universities/Krishi Vigyan Kendras/ ICAR Institutes. A financial outlay of Rs 150 lakhs per KVK, of which Rs 50 lakhs was meant for infrastructure development, including seed storage and processing plants, and Rs 100 lakhs was meant for revolving funds.

Impact of seed village concepts

1. Transform seed village program implementation from individual farmers to FPOs, Farmer Interest Groups, or similar collectives. Smallholders, women, and marginalized groups can produce high-quality seeds to ensure equitable access.

2. Increase Quality Seed Production Funding: Fund seeds, fertilizers, storage, marketing, and human resource development such as the NABARD seed village programme. Comprehensive funding can support implementation from start to finish.

3. Distribute Foundation Seeds: Certified seeds lose vigor over time, so distribute foundation seeds. Accessing foundation seeds improves seed quality and production reliability.

4. Strengthen Monitoring and Evaluation: Create robust M&E frameworks to track seed distribution, production, seed enterprise sustainability, and new seed entrepreneur growth.

5. Introduce Buyback plans: Establish buyback mechanisms for quality program seeds. In successful models, such as the ICAR seed hub, farmers receive incentives and support for high-quality seed production.

6. Coordinate Value Chain Actors: Improve coordination between implementation, training, monitoring, certification, and marketing agencies. Collaboration can streamline execution and target marginalized farmers, including women.

7. Map Quality Seed Sources: Map quality seed sources block-by-block and link them to the local institutions. This ensured the continuation of foundation seed access after program completion.

8. Promote Inclusive Seed Production: Add provisions for female farmers and women-led FPOs to SVP guidelines. Helping women become seed producers can boost their capacities and promote social equity.

These methods can greatly improve the seed village program. Seed systems can be strengthened by improving foundation access, market linkages, monitoring systems, and gender responsiveness. Such improvements could enhance social equity, nutrition, and economic security in agri-food systems, making the program valuable for sustainable agricultural development.

Seed villages as foundations of sustainable agricultural systems

The Seed Village Concept represents a sustainable approach to conserving local agricultural diversity through the production, preservation, and utilization of indigenous seed varieties. This concept safeguards genetic resources by promoting the cultivation of traditional crop varieties suited to local environmental conditions, thus mitigating the dominance of commercial hybrids. Conventional seeds often exhibit superior resilience to climatic variations, pests, and diseases, making them crucial for maintaining the ecological balance and fostering sustainable agricultural methods. This concept reduces dependence on external seed suppliers by facilitating community-driven seed production, allowing farmers to manage seed diversity collectively. Establishing seed banks in villages offers a reliable repository of diverse seeds, enhancing adaptability in crop selection and resilience to unforeseen challenges. The Seed Village Concept amalgamates traditional knowledge with modern methodologies, preserving biodiversity while fostering sustainable agricultural advancement, improving food security, and guaranteeing environmental sustainability.

Recommendations and way forward

Global food production must increase by 50% to satisfy the needs of a population that is expected to reach 9.7 billion by 2050 (FAO, 2018). The superior seeds of improved crop varieties are essential for food and nutritional security. Despite India's considerable advancements in the development of improved crop varieties, challenges persist in guaranteeing the prompt availability of quality seeds in adequate quantities. Central and state governments have implemented initiatives to tackle these challenges, including seed production programs, mini-kit distribution, and seed certification. The private sector and farmer producer organizations (FPOs) are crucial in seed production and marketing.

Sustainable approach for local biodiversity conservation

Biodiversity provides people with basic ecosystem services. It provides goods, such as food, fiber, and medicine, and services, such as air and water purification, climate regulation, erosion control, and nutrient cycling. Biodiversity also plays an important role in economic sectors that drive development, including agriculture, forestry, fisheries, and tourism. More than three billion people rely on marine and coastal biodiversity, and 1.6 billion people rely on forests and non-timber forest products (e.g., fruits from trees) for their livelihoods. Many people directly depend on the availability of usable land, water, plants, and animals to support their families. in fact Ecosystems are the bases of all economies. Two methods were used to conserve biodiversity. These are in situ and ex situ conservation.

In-situ Conservation

In-situ conservation involves protecting species within their natural habitats. Since preserving entire ecosystems for a few endangered species is impractical, conservation efforts focus on localized regions known as biodiversity hotspot areas with high species diversity unique to specific locations. This approach optimizes conservation by targeting smaller areas to more efficiently protect multiple species. Globally, 34 biodiversity hotspots cover a small area but house immense species diversity.

In India, legally protected areas, such as national parks, sanctuaries, and biosphere reserves, aid conservation by providing natural habitats where animals can thrive free from hunting and exploitation. However, many of these areas face challenges in safeguarding endangered species, as exemplified by tiger protection efforts in Corbett National Park.

Ex-situ Conservation

situ conservation is a human-driven approach in which endangered species are housed in enclosures outside their natural habitats, such as zoological parks and wildlife safaris. These facilities provide care and a controlled environment for these species. Advances in technology have expanded the scope of ex situ conservation, including cryopreservation techniques that store gametes of endangered species for laboratory fertilization, enabling the creation of new organisms.

Gene Banks: Long-term storage of plant materials (seeds, DNA, and pollen). The national facilities include NBPGR (New Delhi), CIMAP (Lucknow), and TBGRI (Kerala).

Field Gene Banks: For live plants in controlled settings.

Cryopreservation: Ultra-low-temperature preservation of plant tissues.

Seed Gene Banks: Seeds stored at -20°C, ensuring viability for 50–100 years, following FAO standards.

Community involvement in biodiversity conservation and sustainability

Traditions and practices: Traditional ecosystem knowledge from local communities helps sustain biodiversity use and management.

Conservation benefits of organic farming, water harvesting, and sacred grove protection.

Areas of community conservation: People create and maintain sacred groves, temple forests, and village ponds to protect biodiversity and to serve cultural and spiritual purposes.

Joint forestry management: Participatory methods, such as JFM, help communities and governments sustainably manage forests. It boosts biodiversity, restores degraded landscapes, and supports local livelihoods.

Livelihood sustainability: Agroforestry, ecotourism, and sustainable non-timber forest product (NTFP) harvesting reduce pressure on natural ecosystems and benefit communities economically.

Endangered species conservation: By reducing human-wildlife conflicts and participating in species-specific conservation programs, locals help protect endangered species.

Ecosystem service promotion: Local communities provide ecosystem services such as soil fertility, pollination, and water purification, which are essential for sustainable development, by maintaining biodiversity.

Community-conserved biodiversity reserves: Local communities protect and manage biodiversity in community-conserved biodiversity reserve areas (CCAs) using traditional knowledge, cultural practices, and sustainability methods. These areas often appear outside of government-protected areas and demonstrate community commitment to the conservation and sustainable use of natural resources.

Community Conserved Biodiversity Reserved Areas (CCAs)

Community Conserved Areas are ecosystems, forests, wetlands, grasslands, or marine areas that are conserved and governed by local communities. These areas produce positive outcomes for biological and cultural diversity, while addressing local livelihoods and sustainability. India has a rich tradition of CCAs.

Gond Tribal Community, Maharashtra: Protected 1,800 ha of forest in Gadchiroli District, preventing deforestation by a paper mill, managing forest fires, and promoting sustainable NTFP extraction.

Jardhargaon Village, Uttarakhand: Regenerated 600–700 ha of forest, revived hundreds of crop varieties, and strengthened links between agricultural and wild biodiversity.

Shankar Ghola, Assam: Villagers conserve forests home to the endangered Golden Langur.

Bhaonta Kolyala, Rajasthan: Supported by an NGO, Alwar District villagers restored water systems, regenerated forests, and declared a "public wildlife sanctuary."

Community Forestry in Odisha: Thousands of villages have regenerated vast forest areas, including Dangejheri's forest, managed entirely by women. These efforts have attracted elephants in the area.

Community Conserved Areas for Individual Species Protection

Local communities play a significant role in conserving species by protecting habitats and reducing human impact. Examples of species-specific conservation efforts in India include the following.

Sea Turtle Conservation: Fisher-folk communities protect sea turtle eggs, hatchlings, and nesting sites in Kolavipaalam (Kerala), Galjibag and Morjim (Goa), and Rushikulya (Odisha). ***Olive Ridley Turtles at Rushikulya:*** Previously, local fishermen collected turtle eggs for consumption or sale. Youth from the village, learning about the Olive Ridley Turtles' threatened status and the beach's ecological significance, led to awareness campaigns. The community collectively stopped consuming and selling turtle eggs, prioritizing the protection of turtles, and educating others about conservation.

Role of local women in biodiversity conservation

Women have been central to biodiversity conservation and sustainable development in India, driving impactful, community-based initiatives.

Forest and coastal biodiversity conservation: Since 2000, women's groups across India have taken significant steps to protect the forests, natural resources, and biodiversity. Women's committees patrol forests, enforce strict rules on firewood collection, and impose fines as localized compliance mechanisms to ensure sustainable practices.

Role of tribals in conserving biodiversity: Tribal communities play a vital role in biodiversity conservation through their traditional knowledge, practices, and cultural values.

Traditional practices and beliefs: Tribes practice the sustainable use of forest resources through norms and ethics, such as restrained wood collection and ecosystem protection. In Meghalaya's Khasi Hills, the Khasi tribe protects rich biodiversity by adhering to cultural beliefs such as viewing forest disturbance as a cause of death and sacred animals like the tiger as symbols of prosperity and well-being.

Conclusions

The concept of a Seed village is a revolutionary approach to agricultural sustainability, biodiversity conservation, and food security. Empowering farmers to produce and manage high-quality seeds reduces their dependence on external suppliers, promotes ecological balance, and strengthens climate change resilience. This program preserves indigenous seed varieties using modern technology and traditional farming methods to maintain genetic diversity and boost agricultural productivity. The Seed Village Concept helps achieve long-term food and nutritional security and global sustainable development goals by empowering communities, conserving biodiversity, and building resilience.

Sustainable biodiversity conservation promotes social progress, economic growth, environmental protection and ecosystem conservation. Managing forests and natural resources with local communities helps to sustain biodiversity. Everyone, including the state and institutional support, must support wild animal and plant protection, habitat restoration, and forest conservation. Conservation has traditionally been linked to protecting nature for its spiritual value, with sacred places and landscapes shaping the culture. Flora and fauna, often national symbols, reflect the uniqueness of the habitats. Ecotourism helps preserve endangered species and reduce habitat destruction by supporting local cultures and ecosystems. They also promote conservation by raising awareness and supporting biodiversity, cultural diversity, and unique landscapes.

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Feeding Dairy Cattle under Natural Farming Conditions: Nutrient Recycling and the Role of Unconventional Feed Resources

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Introduction

Feed accounts for 60-70% of milk production costs, making feeding management crucial for farm economics (Cunningham & Rendel, 1997). Proper nutrient requirements support maintenance, milk production, fat content, and gestation (Goff, 2006). An appropriate ratio should meet these needs (NRC, 2001), with roughage dry matter making up 1%-2% of the cow's live weight for optimal intake (Roche & Berry, 2006). Cattle feed provides essential nutrients, including grains, oil cakes, brans, molasses, salt, minerals, and vitamins, which support growth, health, and milk production. Pregnant cows require extra feed to support fetal growth, improve reproduction, and increase milk yield and fat content.

Growing animals require 1-2 kg of compound feed daily. Milking cows need 2 kg for maintenance and 400 g per liter of milk, while buffaloes need 500 g per liter. Pregnant cows received 1 kg of compound feed and 1 kg of quality oil cake in the last two months of pregnancy. Appropriate nutrition is crucial for milk production, health, and reproduction. High-yielding cows require special care during lactation and advanced pregnancy, which can cause metabolic stress. Energy, proteins, and trace elements are essential for milk production and reproduction. Both the quality and quantity of nutrients are crucial for performance and reproductive efficiency.

Energy supplementation for lactating cows is essential, as milk yield peaks early postpartum; however, dry matter intake does not meet energy needs until 10-14 weeks postpartum (Roche & Berry, 2006). Cows often experience a negative energy balance when using body reserves to meet milk production demands (Butler & Smith, 1989). This can impair health and lead to metabolic disorders and delayed reproduction (Goff, 2006). Energy supplementation is vital for maintaining health, milk production, and fertility (Roche & Berry, 2006).

Strategy to Increase Energy Intake: Postpartum negative energy balance is influenced by milk production potential, dietary energy, and dry matter intake (Butler & Smith, 1989). Strategies to improve energy intake include increasing ration energy density, often through grain or fat supplementation (Goff, 2006). Excess grain can cause rumen acidosis; however, fat supplementation prevents these issues by improving fertility and nutrient absorption (Butler & Smith, 1989; Goff, 2006). Dietary Supplementation with Fat: Vegetable oils are unsuitable for ruminants because of their unsaturated fatty acids, which can harm rumen bacteria (Goff, 2006). Bypass fats that pass undigested through the rumen are preferred (Butler & Smith, 1989).

Rumen-stable and rumen-protected fat: Rumen-protected fats, such as calcium salts of long-chain fatty acids, pass the rumen undigested but can be unstable under certain conditions (Butler & Smith, 1989). Rumen-stable fats, such as palmitic acid-rich triglycerides, are more stable and provide more efficient energy (Roche & Berry, 2006).

Protein Requirements of Dairy Animals

Growth, maintenance, and production–Dairy cattle require essential amino acids that are absorbed from the small intestine, which come from microbial proteins and bypass proteins (rumen undegraded protein) (Goff, 2006).

Microbial Protein: Rumen microorganisms, especially bacteria, synthesize amino acids from non-protein nitrogen sources, such as urea and ammonia, forming microbial proteins that are digested in the small intestine (Butler & Smith, 1989). Up to one-third of ruminant protein needs may be met by microbial proteins when dietary energy is sufficient (Goff, 2006). Imbalanced diets can reduce microbial protein synthesis (Roche & Berry, 2006).

Bypass Protein: Increasing milk protein-high-yielding cows require more amino acids than rumen microbes can provide (Goff, 2006). Their diet should include bypass protein (RUP), which escapes rumen degradation and is digested in the intestine (Butler & Smith, 1989). A balanced ratio of RDP (65%) to RUP (35%) was ideal for milk protein synthesis. High-quality forages often provide adequate RDP, but may lack sufficient RUP, requiring supplementation (Roche & Berry, 2006).

Feeding Dairy Cows at Different Lactation Stages:

It can be challenging to alter roughage or concentrate mixes for dairy cows (Toghyani et al., 2012). Thus, farm managers should plan a cropping program to ensure a steady supply of both leguminous and non-leguminous forage year-round (Sánchez et al., 2016).

Table 1: Simple feeding schedule based on general guidelines

Stage of Lactation	Cow wt.	Quantity of Green Grass (kg)	Concentrate (kg)
Dry Cow	250 kg 300 kg	25 30	• No concentrate needed for non-pregnant cows. For pregnant cows, add 1.5 kg concentrate starting from the 7th month of pregnancy (Goff, 2006). • If the cow is in poor condition or the fodder is of low quality, up to 1 kg concentrate can be given to dry cows (NRC, 2001).
Milch Cow	250 kg 300 kg	25 30	Add 1.0 kg of concentrate for every 2.5 kg of milk produced (with 4% fat content). For buffaloes, add 1.0 kg for every 2.0 kg of milk produced (Roche *et al.,* 2006).

Feeding in Early Lactation

High-producing cows often struggle to meet the nutritional demands of milk production, particularly during early lactation (Grummer, 1995). During this time, cows rely on body reserves to meet energy needs, which can lead to weight loss (Butler, 2003). Adequate energy stores are essential to prevent excessive weight loss, which can cause metabolic disorders and affect milk production (Santos et al., 2009).

Challenge Feeding

Challenge feeding increases concentrate intake to help high-producing cows reach their maximum production potential (Nielsen, 2011). This process begins two weeks before calving, starting with 500 g of concentrate and increasing by 300–400 g daily until the cow consumes 500–1000 g of concentrate per 100 kg of body weight (Ballou et al., 2012). This gradual increase prepares the cow's digestive system for a higher feed intake and sets the stage for higher milk production.

Post-Calving Feeding

After calving, the concentrate allowance by 500 g per day for the first two weeks, up to a free-choice level (Mertens, 2002). Once the cow reaches the peak milk yield in the second month, the concentrate allowance is adjusted based on milk production, with daily increases until optimal levels are achieved.

Challenge Feeding Schedule

Period	Concentrate Allowance
Last 2 weeks before calving	Start with 500g, increase by 300-400g daily until the cow is eating 500-1000g per 100kg body weight.
First 2 weeks of lactation	Increase by 500g per day to free-choice level.
Second week to peak yield	Free choice.
From test day onwards	According to production, e.g., 1 kg for every 2.5 kg milk produced.
Remaining lactation	Adjust concentrate based on monthly milk production tests.
All periods	Ensure adequate green fodder and dry fodder.

Feeding in mid and late lactation

The nutrient deficit period of early lactation is followed by a relatively stable period, during which the cow can consume enough feed to meet its nutrient needs and its body weight remains stable (Santos *et al.,* 2014). During this stable period, the cow should be fed a well-balanced diet consisting of good-quality fodder and concentrate tailored to the cow's milk yield and fat percentage (Van Soest, 2006).

In the late lactation phase, the cow's feed intake exceeds its nutrient requirements. This is the period when the cow starts to need extra nutrients for the growing fetus (Ospina *et al.,* 2010). Additionally, late lactation is when cows can replenish depleted body reserves and gain weight rapidly, making it critical for future lactation cycles (Reynolds *et al.,* 2006).

From 7.5 to 10 months of lactation, cows may be fed an additional 1-2 kg of concentrate feed, beyond the nutrient requirements for maintenance and milk production, to help replenish the body condition lost during early lactation (Bertoni *et al.,* 2009). Feeding for high-yield cows: High-producing dairy cows require large amounts of nutrients to maintain high milk production (Ospina *et al.,* 2010), but bulky forages alone cannot meet this requirement because of the physical limitations of the rumen (Van Soest, 2006). Feeding high concentrate levels may disrupt rumen microbial balance, leading to metabolic issues (Gressley *et al.,* 2011). Rumen fermentation is influenced by factors such as ration composition, ingredient ratios, feed quantity, feeding frequency, and feed form (Hoffman *et al.,* 2017).

High-quality forage is essential (Bertoni *et al.,* 2009). Crude fiber is crucial for rumen fermentation, producing the acetic acid required for milk fat production (Rius *et al.,* 2014). A minimum of 20-25% crude fiber is recommended (Kohn *et al.,* 2005). Too much grain reduces cellulose digestibility, leading to reduced milk production, fat content, and potential rumen damage (Allen, 2000). Feeding multiple smaller meals daily enhances digestibility and protein use, prevents excessive acid release in the rumen, and balances Na + and K + salts for optimal function (Mertens, 2009).

Mixing of fodder and feed

Traditionally, concentrates are fed at the time of milking, while roughage is offered either before or after milking (Allen, 2000). In high-producing cows, when concentrates are fed in heavy doses during milking, their appetite is temporarily reduced and they may not consume roughage for some time (Van Soest, 2006). Consequently, this leads to four different types of fermentation: two primarily due to concentrates and two primarily from roughage (Gressley *et al.,* 2011). Feeding concentrates separately from roughage, as part of a four-time feeding schedule, reduces acetic acid production and increases propionic acid, which is beneficial for overall rumen health (Mertens, 2009).

Feeding grain on top of silage increases the fat percentage in milk production, contributing to better milk quality (Bertoni *et al.,* 2009). Furthermore, feeding concentrates either on top of forage or mixed with forage have been found to favor optimal rumen fermentation (Gressley *et al.,* 2011). This approach has led to the development of the concept of complete feeds, which incorporates both roughage and concentrates (Hoffman *et al.,* 2017).

Mixing of Concentrates and Roughages

Traditionally, concentrates are fed during milking, while roughages are offered before or after milking (Van Soest, 2006). In high-producing cows, heavy concentrate doses during milking can reduce appetite and prevent roughage intake for some time (Gressley *et al.,* 2011). This results in four types of fermentation: two from concentrates and two from roughage.

Feeding concentrates separately from roughage in a four-time feeding schedule can reduce acetic acid production and increase propionic acid (Mertens, 2009). Adding grain to silage has been found to increase milk fat percentage (Bertoni *et al.,* 2009). Feeding concentrates with or on top of forage promotes optimal rumen fermentation, leading to improved digestion (Gressley *et al.,* 2011). This approach has led to the concept of "Complete Feeds, " which combines both roughage and concentrates for better efficiency (Hoffman *et al.,* 2017).

Complete Feeding

The complete diet system combines concentrates and roughage in the desired proportion to simplify feeding (Allen, 2000). It is processed to prevent selective eating and become the sole food source for cows. This system reduces labor, ensures tighter control over nutrition, and allows for cost-effective formulation (Mertens, 2009).

Feeding cows a complete diet ad libitum improves feed intake, preserves milk quality, and enhances nitrogen utilization. It also prevents acidosis caused by overfeeding concentrates, especially in high producers (Bertoni *et al.,* 2009). Unlike traditional methods, complete feeding involves group feeding, with fewer changes in the diet based on milk yield. Research has shown that group feeding is as effective as individual rationing in improving yield and efficiency (Hoffman *et al.,* 2017).

Vitamins and minerals required for dairy animals

Recommended Nutrient Inclusions for Cattle and Buffaloes

Major Minerals	Micro Minerals	Vitamins
Calcium	Iron	Vitamin A
Phosphorus	Copper	Vitamin D
Magnesium	Zinc	Vitamin E
Sodium	Manganese	Vitamin K
Potassium	Cobalt	Vitamin C
Chlorine	Selenium	
Fluorine	Thyroid	

Feeding Allowances for Dairy Cattle and Buffalo

Type of Cattle	Stage of the Cattle	Green Fodder (kg/day/animal)	Dry Fodder (kg/day/animal)	Concentrates (kg/day/animal)
Cow (Average weight 250 kg)	Milk Yield 5 litres/day	15.0	5.0	2.0

Cow (Average weight 250 kg)	Milk Yield 5 to 10 litres/day	17.5	5.5	3.0
Cow (Average weight 250 kg)	Milk Yield 10 to 15 litres/day	20.0	6.0	4.0
Cow (Average weight 250 kg)	Cow in Gestation	15.0	5.0	1.5
Buffalo (Average weight 400 kg)	Milk Yield 5 litres/day	15.0	5.0	2.5
Buffalo (Average weight 400 kg)	Milk Yield 5 to 10 litres/day	20.0	6.0	4.0
Buffalo (Average weight 400 kg)	Milk Yield more than 10 litres/day	25.0	7.0	5.0
Bull (Average weight 300 kg)	During Days of Work	20.0	7.0	2.0
Bull (Average weight 300 kg)	During Days of No Work	15.0	5.5	1.0

Commonly Available Feed Ingredients for Dairy Animals

Cereal Grains	Vegetable Protein	Milling By-Products	Animal Fat	Vegetable Fat
Maize	Groundnut oil cake	De-oiled Rice Bran	Lard	Corn oil
Bajra	Soybean meal	Wheat bran	Tallow	Groundnut oil
Sorghum	Sunflower oil cake	Rice Polish		Sunflower oil
Broken Rice	Cotton seed meal	Molasses		
Oats	Coconut meal			
Barley	Linseed meal			
Wheat	Mustard cake			
	Sesame seed meal			

Inclusion of Unconventional Feeds in Dairy Cattle Nutrition

India, with 20% of the world's cattle and only 4% of its arable land dedicated to livestock feed, faces significant pressure on its resources (IGFRI, 2020). The country is experiencing a shortage of both green fodder (11.24% to 32%) and dry fodder (23%), especially during droughts, along with a 44% deficit in concentrate feed. This situation poses a challenge to livestock health and productivity.

Traditionally, cattle feed in India relies on crop residues, such as straw from jowar, bajra, ragi, and wheat, but limited land for fodder crops makes this unsustainable. Non-conventional feed resources (NCFR), such as agro-industrial by-products, food waste, and underutilized plants, are emerging as viable alternatives (Meena et al., 2021). The NCFR can help alleviate feed shortages, reduce reliance on resource-intensive crops, and mitigate urbanization pressures (Bhat et al., 2019). Many NCFR originate from agricultural or industrial waste, promoting resource efficiency and reducing food waste (Mohan et al., 2020).

However, NCFR often has a lower nutritional value and may contain antinutritional factors, such as tannins and saponins, which can affect digestion or cause toxicity (Singh et al., 2022; Kumar et al., 2018). Processing methods, such as drying, fermentation, and detoxification, can improve digestibility and nutritional value (Reddy et al., 2021). Although unconventional feeds present a solution to feed shortages, they require careful management, processing, and supplementation to optimize their benefits for livestock health and productivity.

Classification of Unconventional Feedstuffs for Cattle Nutrition

Unconventional feedstuffs such as by-products and plant-based materials are essential for sustaining livestock productivity, especially in regions with limited conventional feed options. Proper handling and inclusion of these feeds, with attention paid to their nutritional value and potential risks, are crucial for safe and effective use in cattle diets.

Unconventional Feedstuffs - Protein Sources from Plant Origin

1. **Neem Cake:** Neem cake, a by-product of neem seed oil extraction, provides 20-30% protein. It can be a valuable supplement but contains toxic compounds such as azadirachtin, which requires heat treatment to reduce toxicity. It should make up no more than 5-10% of ruminant diets (Singh et al., 2019).

2. **Niger Cake:** Niger cake, extracted from Niger seed oil, is rich in protein (30-40%) and essential fatty acids. It supports cattle health, but contains saponins and cyanogenic compounds. Safe inclusion is 10-20%, with processing like fermentation, to mitigate toxicity (Ranjan et al., 2018).

3. **Sunflower Meal:** Sunflower meal, a by-product of sunflower oil extraction, offers 30-40% protein and fiber. It aids in muscle development and milk production, but may reduce digestibility if overfed. Typically, it should be included in 10-30% of the diet (Kumar et al., 2020).

4. **Safflower Meal:** Safflower meal, with 30-40% protein supports growth and milk production. However, its lower oil content compared to that of other oilseeds makes it less energy dense. Inclusion should be 10-20% to avoid excess fiber intake (Patel et al., 2019).

5. **Karanj Cake:** Karanj cake, from the Karanj tree, is rich in protein (25-30%) and fiber but contains toxic compounds like karanjin. It should make up 5-10% of the diet and may require heat treatment (Rajendran et al., 2017).

6. **Corn Gluten Meal:** corn gluten meal), a by-product of corn milling, contains 60-70% protein and essential amino acids. It supports growth,

but is low in lysine, requiring supplementation. Typically included at 10-20% (Reddy et al., 2021).

7. **Sunhemp Seeds:** Sunhemp seeds provide 25-30% protein and fiber. They support digestion and growth, but contain alkaloids that require processing to reduce toxicity. best used at 5-10% of the diet (Chaudhary et al., 2020).

8. **Salseed Cake:** Salseed cake, rich in protein (25-30%) and fiber, aids growth and digestion, but contains antinutritional factors like alkaloids. Inclusion should be 5-10%, during processing to reduce toxicity.

Unconventional feedstuffs such as neem cake, niger cake, and sunflower meal offer valuable alternatives to conventional protein sources. These feedstuffs require careful management owing to antinutritional factors and should be processed and included in moderation for safe and effective use in cattle diets.

Unconventional Feedstuffs - Protein Sources from Animal Origin

1. **Dried Poultry Droppings:** Rich in protein (20-30%) and minerals, and poultry droppings promote cattle growth and health. However, their high nitrogen content requires careful management and processing, typically included at 5-10% of the diet.

2. **Frog Meal Feed:** Frog meal, with 50-60% protein supports growth and milk production. It contains chitin, which can affect digestibility; therefore, appropriate processing is required. Use of 5-10% of the diet.

3. **Cow Dung Meal:** Cow dung meal provides fiber but is low in protein and energy. It should be processed to reduce pathogens and toxins and used at 5-10% of the diet.

4. **Crab Meal:** Crab meal offers 40-50% protein and essential minerals, supporting growth and bone health. However, it contains a high sodium content, requiring careful processing and inclusion at 5-10%.

5. **Tamarind Seed Powder:** Tamarind seed powder is an energy source but is low in protein and may contain tannins. It should be processed and used at 5-10% of the diet for optimal health benefits.

6. **Mango Seed Kernel:** Mango seed kernels provide energy and fiber, but are low in protein and may contain antinutritional compounds. Processing helps to mitigate these issues, and inclusion should be limited to 5-10%.

Miscellaneous Feedstuffs for Cattle

1. **Babul Pods:** Babul pods are carbohydrate-rich energy sources, which are particularly useful in dry areas. They should be processed for better digestibility and used along with other feeds.

2. **Sugarcane Bagasse:** Sugarcane bagasse, a fibrous by-product, contributes to rumen health, but is low in protein and energy. Therefore, protein-rich ingredients should be supplemented to improve their nutritional value.

3. **Sugarcane Tops:** Sugarcane tops are rich in fiber, providing energy and supporting rumen function. However, they are low in protein and should be mixed with high-protein feeds for a balanced diet.

4. **Sugarbeet Pulp:** Sugarbeet pulp is a fiber-rich by-product that contains energy and some proteins and minerals. It requires minimal processing and is often used as a supplement for other feeds.

5. **Seaweed Meal:** Seaweed meal provides essential minerals, particularly iodine and calcium, to support digestion and immunity. It also offers some protein and fiber but requires careful monitoring to prevent iodine toxicity.

6. **Jackfruit Waste:** Jackfruit waste, including pulp, seeds, and rind, serves as an energy source and provides fiber. Its low protein content means that it should be used in moderation and may require processing to improve digestibility.

7. **Tomato Pomace:** Tomato pomace is high in fiber, providing modest amounts of protein and minerals. It supports rumen health, but should be supplemented with higher-energy feed for a balanced diet.

8. **Brewer's Grains:** Brewer's grains are a cost-effective, sustainable feed with high protein and fiber content, supporting rumen health and productivity. However, they require drying, supplementation with high-

energy feeds, and care because of antinutritional factors, such as phytates (Kumar et al., 2021; Bhat et al., 2019; Singh et al., 2020).

Unconventional Dried Leaves as Cattle Fodder

1. **Neem Leaves:** Neem leaves are rich in fiber, calcium, potassium, and antioxidants. They have antimicrobial and anti-inflammatory properties but may be bitter and require drying and grinding to reduce bitterness.

2. **Moringa Leaves:** Moringa leaves are nutrient-dense and rich in protein, vitamins, and minerals, supporting growth and milk production. However, overfeeding can lead to imbalance. Drying helps to prevent spoilage.

3. **Acacia Leaves:** Acacia leaves are high in fiber and moderate in protein. They support digestion, but contain tannins, which reduce protein digestibility. Drying or fermenting can reduce the tannin content.

4. **Mulberry Leaves:** Mulberry leaves are rich in fiber, protein, and vitamins, which promote growth and milk production. Overfeeding can reduce the intake of other feeds. Drying prevents mold growth.

5. **Guava Leaves:** Guava leaves are high in fiber and antioxidants. They aid digestion and boost immunity but contain tannins that affect digestibility. Drying and grinding can help to mitigate this problem.

6. **Cassia Leaves:** Cassia leaves are rich in fiber and moderate in protein. They improve digestion but contain purgative compounds; therefore, they should be used in moderation. Drying and mixing with other feed can balance these effects.

7. **Tamarind Leaves:** Tamarind leaves support digestive health but contain oxalates that can harm cattle if overfed. Drying helps to reduce oxalate levels.

8. **Banana Leaves:** Banana leaves are low in protein but high in fiber, providing roughage that improves rumen function. Therefore, they should be supplemented with a balanced diet. Drying and chopping improved digestibility.

9. **Papaya Leaves:** Papaya leaves contain fiber, protein, and digestive enzymes such as papain. They aid digestion, but should be fed sparingly. Drying reduces the enzyme activity.

10. **Arecanut Dried Leaves:** Arecanut leaves are rich in fiber, which promotes rumen function, but low in protein. They require supplementation with a protein-rich feed. Processing methods such as drying or fermentation can improve digestibility and reduce antinutritional factors such as tannins (Reddy et al., 2021; Kumar et al., 2023).

Unconventional dry leaves and alternative feedstuffs, such as sugarcane tops, brewer's grains, and arecanut leaves, offer sustainable and cost-effective options for cattle feeding. While these feeds provide essential nutrients, such as fiber, protein, and minerals, they may require processing to improve digestibility and reduce antinutritional factors. When used in moderation with proper supplementation, these feed resources contribute to optimal livestock productivity and sustainability.

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CONSERVATION OF LOCAL VEGETABLE CROPS: ENHANCING BIODIVERSITY, LOCAL CULINARY TRADITIONS, AND AGRO-ECO-TOURISM

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Status of vegetable production in goa

The characteristic coastal conditions of Goa offer rich horticulture options, and the main horticulture crops grown in the state include cashews, coconuts, arecanuts, spice crops, and garden crops such as mangoes, pineapples, jackfruits, and bananas, *etc*. Oil palm cultivation was undertaken earlier in this state. However, the richness of choices was realized through comparatively less land allotment under vegetable cultivation. For the reference year 2021-22, the data show that out of 1,44,498 ha the total cropped area in Goa only 8,362 ha (2943 ha during *kharif* season and 5419 ha during *rabi* season) was under vegetable cultivation, only 5.8% of the total cropped area(Directorate of Agriculture, Goa 2021-22). The Taluka-wise area under vegetable cultivation for the year 2021-22 in the state of Goa is listed in **Table 1.**

Table 1. Estimated area under vegetable crops in Goa (2021-2022)

State/ District/Taluka	Area under vegetable crops (ha)		
	Kharif	*Rabi*	Total
Tiswadi	401	570	971
Bardez	194	357	551

Pernem	45	888	933
Bicholim	246	393	639
Sattari	158	251	409
NORTH GOA	**1044**	**2459**	**3503**
Ponda	410	195	605
Sanguem	104	101	205
Dharbandora	90	67	157
Canacona	334	410	744
Quepem	111	167	278
Salcete	820	1820	2640
Mormugoa	30	200	230
SOUTH GOA	**1899**	**2960**	**4859**
GOA STATE	**2943**	**5419**	**8362**

Source: Directorate of Agriculture, Goa 2021-22

During the year 2021-22 from an area of 8,362 ha, 82,604 tons of vegetables were harvested reflecting 9.8 an average state vegetable productivity of Goa (Directorate of Agriculture, Goa 2021-22) which is half of the national average productivity of vegetables.

Local vegetables conservation for its use

Although there is very limited productivity and area under vegetable cultivation, the state has distinguished contributions, notably in *Capsicum annum*. Chillies are believed to have originated in tropical America and were brought from South America to India by the Portuguese trading colony of the Goa during the 16th century (Mehta, 2017). The introduction of chillies, a crop of multi-faceted culinary uses, to India *via* the coast, therefore, is a contribution of the coast to the vegetable basket of India and Indian food customs. The noteworthy thing is that geographically the state of Goa covers an area of 3,702 square kilometers merely, however, introduction of chillies in India through coast of Goa, further adaptation, conservation, of this crop in local Coastal-Tropical niches and afterwards selection by the farmers to the existing types led to the development of "two unique special Local chillies from Goa that received Geographical Identifications (GI) *viz*., '*Khola*'

GI no. 618, dated 06.08.2018 and '*Harmal*' **GI no. 642, dated 14.01.2019** (Geographical Indications Registry, Govt. of India)

Farmers from Goa also traditionally conserved other GI tags (**Figure 1.**) as well as non-GI tagged local vegetable types like '*Sat-Shiro Bheno*' also called as '*Sat Shirancho Bhendo*' (Local seven-ridged Okra), which has been acknowledged with **GI no. 790, dated 31.07.2023**. Local Brinjal types '*Agsechi Vayingim*' or '*Agassaim Brinial*' an oblong-shaped dark purple fruited brinjal with **GI no. 763, dated 31.07.2023** (Geographical. of India). '*Taleigao Vayingim*' or '*Taliegao Brinjal*' (in Examination stage for GI Registry), Sweet potato (red and white local types) and Red amaranth, *etc*. There are two kinds of traditional vegetable cultivation customs, '*Porso*' where most of the vegetable growers cultivate different vegetables on a small piece of land during *rabi* season with assured water supply of irrigation. Chillies, Vegetable cowpea/yard long bean (*wal*), onion (local onion), cluster bean, gourds, roots, and tuberous crops can also be seen growing. While, in the *kharif* season on hilly slops i.e. '*molo*' farmers cultivate different kinds of Gourds from cucurbitaceous family like '*Tovshi Cucumber*,' *etc*.

Registered logos with GI Registry of Local Vegetables from Goa	GI details with weblinks that includes uses in local culinary traditions
	HARMAL chilli GI no. 642, dated 14.01.2019 GI certificate no. 387 https://search.ipindia.gov.in/GIRPublic/Application/Details/642
	KHOLA chilli GI no. 618, dated 06.08.2018 GI certificate no. 356 https://search.ipindia.gov.in/GIRPublic/Application/Details/618

SAT-SHIRO BHENO okra
GI no. 790, dated 31.07.2023
GI certificate no. 494
https://search.ipindia.gov.in/GIRPublic/Application/Details/790

AGSECHI VAYINGIM / AGASSAIM brinial
GI no. 763, dated 31.07.2023
GI certificate no. 492
https://search.ipindia.gov.in/GIRPublic/Application/Details/763

Fig 1. Registered GIs for Local vegetables from Goa with Geographical Indications Registry, Govt. of India
Source web: https://search.ipindia.gov.in/GIRPublic/

Enhancing local vegetable biodiversity for its use

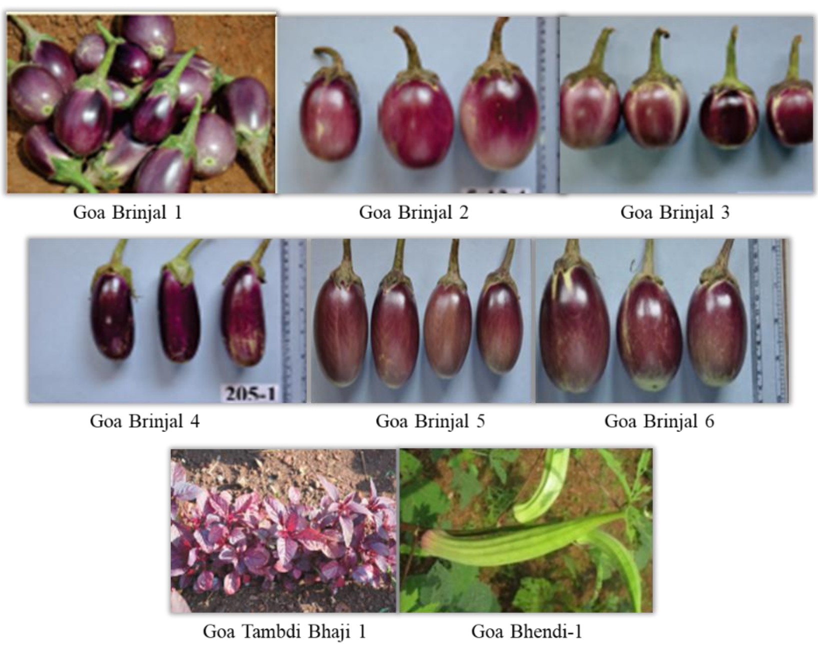

Fig 2. Vegetable varieties bred by ICAR-CCARI

The ICAR-Central Coastal Agricultural Research Institute was established in April 1976 as a regional center under the ICAR Research Complex for Northeast Hill region, Umiam (Barapani), Shillong, Meghalaya. Later in the year 1976, it was linked as 'ICAR Research Complex for Goa,' to Central Plantation Crops Research Institute, Kasargod, Kerala. Considering the importance of agriculture in the state, the Indian Council of Agricultural Research (ICAR), New Delhi, from April 1989, created the ICAR Research Complex for Goa as an Independent Institute for the state of Goa. Subsequently, the Institute has been upgraded from 1st April 1, 2014, as 'ICAR-Central Coastal Agricultural Research Institute' (ICAR-CCARI) under the Natural Resource Management division of ICAR.

The Institute contributed to generating a scientific backup for helping the mentioned local vegetables in the Geographical Indications registry. Similarly, enhancing biodiversity for its use, building on the local vegetable biodiversity strength, during the course of the period, the Institute has developed improved vegetable varieties in Brinjal, namely, Goa Brinjal 1, Goa Brinjal 2, Goa Brinjal 3, Goa Brinjal 4, Goa Brinjal 5, and Goa Brinjal 6'. A leafy Amaranth variety 'Goa Tambdi Bhaji 1' and an Okra variety 'Goa Bhendi1' (https://ccari.icar.gov.in/Varietiesreleased.html, https://ccari.icar.gov.in/annrep2019.pdf) were also contributed by the institute to help improve vegetable production in the state (**Figure 2**).

The Institute has initiated work on the underutilized, local vegetable species *Momordica sahyadrica* wherein conservation through awareness of the scientific community approach was followed. The importance of this less-known yet potential local vegetable species, along with its culinary uses, has been documented in a national scientific journal (Chaudhari et. al., 2023[a]) and the Institute's attempt to enhance its variation through breeding technique research was appreciated in an international event (Chaudhari et. al., 2023[b]; https://hortsem.iihr.res.in/wp-content/uploads/2023/10/Final-Programme-Schedule-Book-15-10-2023.pdf).

Conclusion

Conservation, systematic study, improvement with local vegetable types and creating awareness have been a part of vegetable research at ICAR-Central Coastal Agricultural Research Institute and local 'Underutilized Vegetables species' are realized as 'Potential Vegetables. ' Recognizing local vegetable types through the Geographical Indications Registry and using them to develop improved varieties will help in deriving commercial gains. Agro-eco-tourism may accommodate these local vegetables and potential vegetable species, which show resilience to local agro-climatic niches, to fit into their models, as they provide a way to communicate, disseminate, and celebrate local vegetable diversity as well as local culinary traditions with other parts of the world.

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Combating human-wildlife conflict in Agro-ecology: Strategies for coexistence and sustainable agriculture

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Introduction

Human-Wildlife Conflict (HWC) is defined as 'interaction between humans and wildlife where negative consequences, whether perceived or real, exists for one or both the parties when action of one has an adverse effect on the other party' (Conover, 2001; Decker et al., 2002). HWC occurs when the needs of wildlife encroach upon those of human populations, negatively impacting the development goals of human societies and vice versa (cited from FAO, 2015; Manral et al., 2016; Pradhan & Choudhury, 2024). More broadly, interactions between wildlife and humans can cause damage or costs to both and further, can lead to conflicts between different groups of people (human-human conflicts) over wildlife and how it should be managed. HWC has been in existence since the time when wildlife and humans have co-existed and shared the same resources (cited from FAO, 2015). Wild animals require large habitats for their sustenance which are found to be overlapping with human settlements and agriculture lands near Protected Areas (Pradhan & Choudhury, 2024). However, in many regions, these conflicts have intensified over recent decades because of the expansion of human population, conversion of land area, land-use patterns, encroachment on wildlife habitat, the expansion of agricultural and industrial activities and developmental activities in and around the Protected Areas, among others, are the fundamental causes or instigators of HWC (cited from FAO, 2015; Pradhan & Choudhury, 2024). Conflicts have also arisen due to the growth of some wildlife populations and the presence of certain species (e.g., wild boar) in urban environments (cited from FAO, 2015). A wide range of species are responsible for HWC in India including primates, rodents, antelopes, wild boars, elephants, tigers, lions and leopards. Impacts of HWC can range from injury and death, loss of crops and livestock, damaged infrastructure, disease transmission (to humans and also to wildlife), and other intangible social costs such as restrictions on movement, competition for water sources, the need to guard property (which may lead to loss of sleep), poor employment opportunities and psychological stress (cited from FAO, 2015). Those living on the outskirts of settlements and near community or state-managed wildlife areas tend to suffer the most (Pradhan & Choudhury, 2024). As a result of these negative impacts, wildlife species may be killed in retaliation, with a risk of population declines. In certain cases, indiscriminate killing of non-problematic wildlife or habitat destruction may also take place as an expression of resentment or hostility toward conservation and wildlife management authorities (cited from FAO, 2015 and Agarwal et al., 2016). Considerable human-animal conflict may cause some wildlife populations to dwindle or even go extinct locally (Pradhan & Choudhury, 2024).

Key issues of HWC

Safety and security of humans

Any wild animal can attack a human being for their self-defense or for food (Agarwal et al., 2016). Large wild mammals (carnivores and herbivores: tiger, leopard, lion, sloth bear, elephant, Indian gaur) are responsible for most of the attacks on humans, often leading to injury or death (cited from FAO, 2015 and Agarwal et al., 2016). Road accidents caused by wildlife and bird–aircraft collisions occur worldwide and can also result in human death and injury (cited from FAO, 2015).

Damage to property

Some wildlife (e.g., elephants, macaques/langurs) can cause significant damage to property by invading human settlements in search of food and/or water (FAO, 2015 and Agarwal et al., 2016). Elephants may end up breaking fences/walls and causing damage to buildings due to their enormous size and strength. Macaques and langurs often raid homes, stealing food and causing structural damage to roofs or windows. This can lead to financial losses, safety risks, and increased human-wildlife conflicts.

Loss of livestock

For rural populations, domestic animals often are an important source of income. Attack and predation by wild carnivores (e.g., tigers, leopards, wild dogs) on livestock often forces rural communities to adopt mechanisms to protect livestock by building enclosures or introducing guard dogs (cited from FAO, 2015 and Agarwal et al., 2016).

Damage to crops

Due to unavailability of preferred diet in their habitat, wildlife (e.g. elephants, wild boar, deer, antelope, macaques/langurs, peafowls) are compelled to depend on agricultural crops for food, resulting in enormous damage to the crops. Crop damage can have a negative impact on economies and livelihoods of farmers (cited from FAO, 2015 and Agarwal et al., 2016).

Dimensions of man-wild animal conflict in agriculture

Among the various facets of wild animal-human conflict the most important manifestation is the impact of various wild animals on agriculture and allied practices world over. Various wild animals contribute in different ways to precipitate conflict in agricultural systems globally as well as in India. Many such conflicts are precipitated by native animals whose populations have mushroomed in local niches or by introduced animal 'vermin' which utilize the favourable environment created by a fractured ecosystem to their benefit and thus thrive. These animals ultimately contribute to conflict by targeting agricultural and allied practices, causing conflict situations. As the causes are multivarious, the process to mitigate each conflict would involve drastically different approaches. The commonly encountered wild animal conflicts involving agriculture as are follows

Wild boars:

Improved conservation policies and heir implementation in India has resulted in a burgeoning of wild boar populations in India. Though the exact estimation of the numbers is sketchy, it is an undeniable fact that lack of predators and effective control of poaching and hunting have resulted in an explosion of wild boar populations, especially in buffer areas of protected forest.

A recent study (Senthilkumar et al., 2020) in Krishnagiri district in Tamil Nadu, found that the common reasons for the intrusion of wild pig into cultivable land are the changing cropping pattern and increased wild pig population (Fig. 1).

Fig. 1: The high fecundity of wild boars can cause a spurt in their populations under favourable circumstances

These animals have easy access to agricultural fields, especially those bordering the protected areas and thus turn out to be the primary cause of conflict. Wild boar may destroy to agricultural crops by They cause damage by their activity of digging (or rooting) for planted seeds and also by crushing or eating of plants. Likewise, these may harm crops while wallowing and rooting (Sarwar, 2019) which injure the plant roots, and form holes and grooves that harm farm equipment and endanger operations. Wild boars harshly influence trees and timber resources in many ways like disturbance of planted seedlings, girdling and rubbing of matured trees, chewing and rooting of sideway roots of fully-fledged trees, and tusking or scent marking with the tusk glands that injuries to tree bark.

The mitigation practices followed world over includes the use of strong fences to prevent entry, employing permanent guard, especially at nights, maintaining guard dogs, and unconventional techniques like using videos tapes drawn around the fence which create a buzzing sound in wind and keep the animals away. In other countries, more aggressive techniques like direct trapping of entire herd or hunting of raiding animals are permitted.

Elephants:

Elephants impact agriculture in whichever regions of India they are present. Indiscriminate development practices have resulted in fragmentation of the natural forests and blocking of 'corridors' of migration for these animals. Drastic changes in agricultural practices like increased area of cultivation of crops favoured by these animals (like banana, sugarcane, etc.) have contributed to precipitation of the crisis. One of the classical differences between conflict by other animals and those by elephants is the accompanying loss of property (houses, godowns, etc.) as well as human-lives in such conflicts. Between 2013 and 2024, 6,000 acres of croplands were damaged, 26 people and 21 elephants were killed due to elephant movements in Karnataka (Shekhar, 2024). The bitter interaction in such instances have resulted in creation of a negative image of these otherwise revered animals in the minds of the suffering population. The classical example is of naming the carcass of a popular crop-raider, which was killed by poisoning, as 'Osama Bin Laden' by people who otherwise look up to these animal as Lord Ganesha (Fig. 2).

Fig. 2: 'Ganesha to Bin Laden'. The carcass of a crop-raider named as 'Bin Laden' in Assam

Elephants can cause substantial damage to cash crops, leading to extensive loss to farmers precipitating conflict. Elephants raiding carrot fields can cause extensive loss to farmers (Fig, 3). Affected farmers then resort to extreme measures like poisoning or using illegal electric fences to combat the raid.

Fig. 3: Carcass of an electrocuted elephant in a carrot field in Emerald, Nilgiris (right). The stomach is completely filled with carrots (left)

Mitigation measures include erection of elephant proof trenches, installation of rail barricades and solar fences, increased the network of forest department officials through base camps and is relying on drones to identify herds (Shekhar, 2024). Wildlife SOS has installed Early Warning System to alert villagers about elephant movement (Gupta, 2023).

Wild ungulates:

A wide range of ungulates cause substantial damage to agriculture depending on the regions. The most commonly involved (other than wild boars) are the deer (sambhar, chital, etc.), antelopes (Nilghais), bovis (gaur), etc. While each type of conflict may be locally significant, the conflicts caused by Nilghai are widespread and well studied. Due to prolonged breeding activity and lack of potential predators have led locally overabundant populations in Gujarat, Uttar Pradesh, Haryana, Punjab, Rajasthan, Madhya Pradesh and Delhi. These cause extensive damage to most agricultural crops, not only by foraging but also through trampling, resting in field and daily movement of the animals (Chauhan, 2011).

The magnitude of conflicts due to gaur is very intense in certain regions of India. The key drivers of this conflict include the human population increase, greater local dependency on the biomass in forest-fringe areas, land use changes, linear infrastructure, mining, urban development and habitat loss, fragmentation and degradation (Report, 2023).

Monkeys:

Monkeys, both macaques and langurs are responsible for significant crop damage in selected localities of India. Rhesus and bonnet macaques as well as the common (Hanuman) langurs are responsible for the conflict. In some areas like the Nilgiris, the endangered Nilgiri langur can cause considerable loss to commercial crops (Fig. 4).

Fig.4: A bonnet macaque in the pear orchard of Sheep Breeding Research Station, Sandynallah (Left). A pair of Nilgiri langurs in a carrot field.

A study in 250 villages in Jammu (Sharma and Andrabi, 2018) reported loss of farm produce worth Rs. 33 crores because of invasion by wild monkeys. Sometimes in severe attack, they cause damage up to 90% in agriculture and horticulture. The authors stated that there was no centralised data bank on monkey raids in the country. According to the official and media reports, crop damages due to monkey attacks have been reported from 20 States/UTs. In 2018, about They raid crops and utilize the agro-ecosystems for food resource and shelter. Hence monkeys are considered pests in the areas of massive agriculture, horticulture and other plantations since they damage the crops and orchards.

Mitigation measures depend on forcible trans-locate monkeys to a reserve. However, this method is cumbersome and does not guarantee freedom from conflict on the long run. Many state government forest departments have resorted to castration of animals before relocation. The other techniques suggested include guarding the plantations, biophysical barriers, use of crackers and other repellants like toy snakes, pepper spray, smoke, shrill noises, etc.

Indian peafowl:

Indian peafowl are emerging as one of the major 'vermin' causing agriculture related conflict all over India. India's national bird often damage crops by feeding on grains, fruits, and seedlings in farmlands, causing substantial losses to farmers, particularly in regions with large peacock populations. They can also damage plants, attack their reflections breaking glass and mirrors, perch and scratch automobiles or leave their droppings (Veeramani et sl., 2022)

Among the various strategies discussed for the control and management of peacock conflict, the use of foxes as control agents (Thanvir, 2025) and a specialized 'Peacock Monitoring and Repellent System' are unconventional approaches. The latter uses a Support vector Machine (SVM) with among other high-tech devices, passive infrared (PIR) sensors, GPS and GSM equipped drones is used to detect the presence of peacocks. Once detected, intrusion ultrasonic sound wave of frequency KHz is generated to chase-off the peacock (Maniraj et al., 2019).

Large felids:

Livestock depredation, which leads to significant economic losses for farmers, is the primary cause of human-large felids (e.g., leopards, tigers) conflict and additionally, have been linked to attacks on humans (cited from Athreya et al., 2020). Growing evidence suggests that inadequate livestock protection practices, often combined with low wild prey availability, contribute to livestock depredation by large carnivores, particularly felids (Athreya et al., 2016; Kshettry et al., 2018 and Athreya et al., 2020). Indian wildlife laws prohibit the killing of wild carnivores like leopards and hyenas, and rural communities generally are tolerant to their presence. However, there are numerous instances where locals either kill large carnivores involved in conflicts illegally or pressure wildlife authorities to relocate these animals from their areas (Athreya et al., 2011 and Athreya et al., 2020).

Leopards (*Panthera pardus*) are classified as vulnerable on the IUCN Red List due to declining populations in many parts of their range (Stein et al., 2016; Mahanti and Kumar, 2017). India's leopard population is estimated at 13,874 (Range: 12,616 – 15,132) individuals (MoEF, 2024). In recent years, leopard attacks have increased in India as agricultural and residential development encroaches on their habitats. Leopards have adapted to living on the outskirts of human settlements, and their behavioral flexibility, diverse prey preferences, and ability to thrive in human-modified environments make them more prone to attacking humans and livestock (Mahanti and Kumar, 2017). Livestock are typically killed by a throat bite, strangulation, and then dragged to a concealed area before feeding, starting from the abdomen (Govind and Jayson, 2021). Sheep, goats, cows, and buffalo are the common targets, with the preferred time for these attacks being late night (8:00 PM – 12:15 AM) when prey is taken from cages (Govind and Jayson, 2021). Athreya et al. (2020) found that poor nighttime protection and domestic dogs increased leopard attacks on livestock. This could easily occur when cages were poorly maintained, highlighting the need for secure, well-maintained barns (Govind and Jayson, 2021).

Tigers (*Panthera tigris*) are also significantly impacted by human-wildlife conflict. India has a minimum of 3,167 tigers and is home to more than 70% of the world's wild tiger population (PIB 2022). Livestock predation and attacks on humans by tigers foster negative attitudes toward their conservation (Kartika and Koopmans, 2016). The fear and anger caused by livestock losses or human injuries and fatalities often drive people to kill tigers in retaliation (Goodrich, 2010). This negative attitude also reduces support from local people for tiger conservation (Löe and Röskaft, 2004; Karanth and Gopal, 2005). Mortality of tigers due to HTC is usually the major cause of decline in numbers; reducing the number of HTC is critical to successful tiger conservation (Goodrich 2010).

Efforts to reduce and mitigate human-large felid conflict often face various challenges. Preventive measures such as improved livestock management, protection of wildlife habitat, and zoning though crucial, often require significant resources and co-operation from the locals, making it hard to achieve. HWC mitigation strategies such as compensation and insurance programs for the loss aims to alleviate the adverse effects. But in various instances, these efforts are hindered by issues like long-term sustainability, corruption, and inadequate funding. Reactive measures like lethal control or translocation are commonly used, but they can be controversial, costly, and ineffective in the long term, especially for endangered species. Integrated programs involving education and community engagement are key to fostering tolerance and cooperation, but their impact is often slow to materialize and difficult to measure (e.g., tigers: Goodrich, 2010; Kartika and Koopmans, 2016, leopards: Athreya et al, 2020).

Conclusion

No single strategy can fully resolve the issue of human-wildlife conflict (HWC), nor should it be expected to completely eliminate it. Instead, the focus should be on effectively reducing or mitigating these conflicts to a level where communities are more inclined to accept long-term coexistence with wildlife.

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One health approach for sustainable tourism: Addressing zoonoses for global health and environmental protection

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Introduction

Tourism is a vibrant force that stimulates travel to explore nature, adventures, wonders, and societies; discover cultures; meet people; interact with values; and experience new traditions and events (Baloch *et al.,* 2022). Tourism offers significant economic, cultural, and social benefits. It can help a nation increase its export revenues since international tourists often spend money on goods and services while they are abroad. This could enhance trade balance and strengthen the nation's economy (Bal *et. al.,* 2016). However, the rapid expansion of tourism has led to environmental degradation, biodiversity loss, and public health risks, including the spread of zoonotic diseases. Addressing these challenges requires an integrated and holistic approach, such as One Health, which links human, animal, and environmental health. The One Health approach can be pivotal in fostering sustainable tourism by promoting health, environmental conservation, and socioeconomic equity.

Understanding the One Health Approach

One Health is an integrated, unifying approach that aims to sustainably balance and optimize the Health of people, animals, and ecosystems (Mettenleiter *et al.,* 2023). The One Health approach emphasizes the interconnectedness of human, animal, and environmental health (Mettenleiter *et al.,* 2023). This framework aims to address complex issues, such as zoonoses, antimicrobial resistance, and ecosystem health, by strengthening cross-sectoral collaboration among public health professionals, veterinarians, environmental scientists, and policymakers. In the context of tourism, this approach provides a comprehensive strategy for mitigating the negative impacts of tourism while maximizing its benefits.

Challenges of Unregulated tourism

According to the World Tourism Organization (UNWTO), tourism is one of the fastest-growing industries. Twenty-five million international tourists in 1950 grew to 166 million in 1970, reaching 1.442 billion in 2018, and projected to be 1.8 billion by 2030. Mobilizing such a substantial human tourist mass is likely to cause environmental pollution (Mikayilov *et al.,* 2019). The environmental footprint of tourism includes habitat destruction, pollution, and the overuse of natural resources. Wildlife tourism, if not managed responsibly, can disrupt ecosystems and increase human-wildlife interactions, increasing the risk of zoonotic disease transmission. Unregulated tourism has a direct effect on food safety and biodiversity conservation. They also exacerbate climate change, which in turn impacts the biodiversity and health of communities dependent on natural resources. South Asian countries, more specifically Sri Lanka and Pakistan, are on the verge of tourism growth and environmental pollution compared to other countries (Tiwari *et al.,* 2021).

Addressing challenges through One Health approach for Sustainable Tourism

1. Biodiversity Conservation:

Biodiversity, the variety of life on Earth, underpins the health of ecosystems that sustain human and animal lives. It provides critical services, such as clean air and water, pollination of crops, disease regulation, and cultural and recreational opportunities that form the backbone of tourism. However, tourism may threaten biodiversity through habitat destruction, pollution, resource overexploitation, and increased human-wildlife interactions. Tourism often occurs in biodiversity-rich areas, such as national parks and coastal ecosystems. The One Health approach advocates for sustainable practices that protect habitats and wildlife populations, ensuring the longevity of these natural attractions while reducing human-wildlife conflict and disease risks.

Biodiversity-rich areas, such as coral reefs, rainforests, and wildlife sanctuaries, are major tourist attractions. They offer unique experiences such as wildlife safaris, trekking, diving, and cultural interactions with indigenous communities. Protecting biodiversity is essential for sustaining these attractions and the livelihoods of communities that are dependent on them.

The construction of hotels, roads, and other infrastructure can fragment or destroy habitats, thereby threatening the survival of plant and animal species. Pollution from tourist activities, including plastic waste and untreated sewage, further degrades ecosystems, particularly aquatic ecosystems. Additionally, the overexploitation of natural resources, such as overfishing, collection of souvenirs, or excessive foot traffic in fragile areas, can exhaust resources and disrupt the ecological balance. Moreover, increased human presence in wildlife habitats often leads to conflicts that disturb animal behavior and increase the risk of zoonotic disease transmission.

Role of One Health: By implementing collaborative One Health strategies, conservation efforts can be strengthened conservation efforts **(**Guo *et al.,* 2019**).** Integrating biodiversity conservation into tourism through a one-health approach emphasizes the preservation and restoration of natural habitats to maintain ecological balance. Sustainable tourism operators can collaborate with conservationists to create protected areas, reforestation projects, and buffer zones that limit human impacts. Wildlife surveillance and management are also crucial because monitoring animal health helps prevent zoonotic disease outbreaks and ensures population stability. By working with veterinary and ecological experts, tourism activities can include controlled access to sensitive areas and the implementation of wildlife monitoring systems. Furthermore, eco-friendly infrastructure, such as green buildings, renewable energy, and sustainable water and waste management, minimizes ecological disruption while supporting sustainable tourism practices. For instance, community-based ecotourism projects often allocate funds for conservation, while empowering locals as custodians of their environment. Educating tourists about the significance of biodiversity encourages responsible behavior, such as avoiding littering, respecting wildlife boundaries, and supporting conservation initiatives through interpretative tours and informational campaigns. Governments and industry bodies can reinforce these efforts by implementing regulations that mandate environmental impact assessments for tourism projects and introducing certification systems for eco-friendly tourism operators.

Conservation of biodiversity is integral to sustainable tourism and human well-being. Healthy ecosystems act as natural buffers against climate impacts, such as coastal mangroves, and protect against storm surges. By aligning tourism practices with biodiversity conservation, stakeholders can ensure a future in which tourism thrives in harmony with nature, fostering mutual benefits for people, wildlife, and the planet.

2. Zoonotic Disease Prevention:

Tourism often involves interactions between people, animals, and the environment, particularly in biodiversity-rich destinations, such as wildlife sanctuaries, national parks, and rural areas. Although these interactions provide cultural, recreational, and educational value, they also pose a risk of zoonotic disease transmission. Zoonotic diseases, which make up approximately 70% of all new and existing diseases, are increasingly interconnected with factors such as the environment, society, and economics (Rodriguez, 2024).

Increased human-animal interactions in tourism hotspots can amplify the risk of zoonotic diseases. Through One health strategy, tourism stakeholders can implement measures such as wildlife surveillance, visitor education, and hygiene practices to prevent disease outbreaks and safeguard both tourists and local communities.

Tourism increases the risk of zoonotic diseases through various pathways, including increased human-wildlife interactions in activities such as safaris, petting zoos, and unregulated wildlife encounters, which increases the chances of disease transmission. Habitat encroachment, caused by infrastructure development, fragments natural habitats, pushing wildlife closer to humans and domestic animals. Additionally, poor waste management and unsanitary food handling in tourist areas create ideal conditions for disease vectors, such as rodents and insects. The global mobility of tourists further amplifies this risk, as travellers can unknowingly transport pathogens across regions, thereby facilitating the spread of zoonotic diseases worldwide.

Role of One Health: Preventing zoonotic diseases through the One Health approach involves comprehensive measures that integrate wildlife monitoring, controlled interactions, hygiene practices, education, community engagement, and policy enforcement. Regular surveillance and health monitoring of wildlife can detect zoonotic outbreaks early, while guidelines for safe human-wildlife interactions, such as maintaining distance and limiting visitor numbers, can reduce disease risks. Ensuring clean facilities, proper waste disposal, and handwashing stations further minimizes pathogen spread in tourist areas. Educating tourists about zoonotic risks and responsible practices, such as avoiding feeding or handling wildlife, fosters safer behaviors. Engaging local communities by offering sustainable livelihoods reduces reliance on practices such as bushmeat hunting, which often harbors zoonotic diseases.

The One Health approach to zoonotic disease prevention is essential for sustainable tourism. By addressing health risks at the intersection of humans, animals, and the environment, stakeholders can create safer tourism experiences to protect public health, preserve ecosystems, and foster economic resilience. Mitigating zoonotic disease risks reduces the likelihood of tourism disruptions due to pandemics. Integrating these strategies ensures that tourism positively contributes to global health and sustainability.

3. Environmental Protection:

Environmental protection is a cornerstone of sustainable tourism. However, the development of tourism infrastructure has implications for environmental degradation, reduction in green spaces, deforestation, solid waste and sewage, overutilization of air and water, emission of CO_2 and other gases contributing to air and water pollution, climate change, loss and displacement of biodiversity, and degradation of ecosystems (Baloch *et al.*, 2023). Sustainable tourism practices, guided by One Health principle, prioritize pollution reduction, waste management, and resource conservation. This helps to maintain ecosystem health, which is intrinsically linked to the well-being of humans and animals. Natural environments, such as beaches, forests, and mountains, are often primary attractions for tourists. These ecosystems not only support diverse flora and fauna but also provide critical ecosystem services such as clean air and water, climate regulation, and recreational spaces. Without proactive environmental protection, the degradation of these resources undermines both tourism and the well-being of the communities that depend on them. In China, more than fifty-eight major Chinese tourism destinations are inviting immediate policy measures to mitigate air pollution and improve environmental sustainability (Zhang *et al.,* 2020).

The tourism industry has become one of the main sources of global carbon dioxide emissions, accounting for 5% of total global carbon emissions (Zhao *et al.*, 2024). Climate change has a significant impact on tourism, including ecosystem degradation through coral bleaching, deforestation, and biodiversity loss, which can diminish natural attractions. Extreme weather events, such as hurricanes, droughts, and floods, disrupt tourist activities and damage infrastructure, thereby affecting the overall experience. Additionally, climate change exacerbates health risks, including heat stress, spread of vector-borne diseases, and water scarcity, posing threats to both tourists and host communities. Balancing tourism industry development with carbon emissions reduction is a major challenge for the tourism industry (Zhao *et al.*, 2024).

Pollution from tourist activities, including plastics, sewage, and chemicals, contaminates ecosystems, particularly waterbodies. Additionally, the overuse of local resources such as water, energy, and natural materials strains both communities and wildlife. Tourism also contributes to climate change through high-carbon activities, such as air travel and energy-intensive accommodations, intensifying global warming, and putting ecosystems at greater risk.

Role of One Health: Applying the One Health approach to environmental protection involves integrating eco-friendly practices, community engagement, and education into tourism activities. Promoting sustainable tourism infrastructure with renewable energy, low-impact construction, and sustainable materials minimizes ecological disruptions. Protect natural habitats and biodiversity to maintain the ecological balance that supports tourism. For example, reforestation programs can restore ecosystems while also capturing carbon emissions.

Ecotourism practices reconnect citizens with nature (Tauro *et al.,* 2021). One Health-aligned eco-tourism initiative minimizes environmental impacts and enhances awareness about the importance of conserving natural resources and biodiversity. Tools based on the One Health concept are available for assessing the potential risks of severe zoonotic diseases associated with wildlife trade (Wikramanayake *et al*., 2021).

Comprehensive waste management practices, such as recycling and the use of biodegradable materials, reduce pollution at tourist destinations. Habitat restoration projects, including reforestation, wetland recovery, and marine conservation, enable tourism operators to offset their ecological footprint. Encouraging the responsible use of resources such as water, energy, and food through initiatives such as rainwater harvesting and solar energy can further alleviate environmental strain. Encouraging green architecture and waste management systems in tourist facilities reduces environmental impact.

Empowering local communities to actively participate in environmental protection fosters conservation, while providing economic benefits through community-based tourism models. Educating tourists about responsible behaviors, such as avoiding littering, respecting wildlife, and supporting eco-friendly services, enhances their contribution to sustainability. To reinforce these efforts, governments and tourism boards can implement regulations mandating environmental impact assessments and offer certifications, such as green tourism or eco-tourism certification, to reward environmentally responsible operators. Encourage low-carbon travel options, such as biking, walking tours, and electric transport, to reduce tourism's carbon footprint

By integrating environmental protection into tourism through the One Health approach, stakeholders can ensure a balance between economic development and ecological sustainability. This approach benefits the planet, promotes healthier communities, and ensures long-term viability of the tourism industry. It represents a shared responsibility for preserving the natural world for future generations while enjoying its beauty and resources responsibly today.

4. Food safety

Food safety is a critical aspect of sustainable tourism, as it ensures the health and well-being of tourists and local communities, while supporting the long-term viability of food systems. The One Health approach provides a comprehensive framework for addressing food safety challenges in the tourism industry. By applying this approach, stakeholders can create safer dining experiences, promote sustainable food production and support public health.

Destinations that prioritize safe, high-quality food can enhance their reputation, attract more tourists, and build trust. Additionally, ensuring food safety allows for authentic presentation of local cuisines, fostering cultural preservation and appreciation. Moreover, safe food practices contribute to economic sustainability by supporting local producers and promoting farm-to-table systems, which in turn boosts local economies.

Food safety in tourism faces several challenges, including the complexity of diverse food supply chains, which increase the risk of contamination and spoilage. Street food, a popular cultural attraction, often lacks proper regulations and raises hygiene concerns. Inconsistent food safety standards across regions further complicate efforts to ensure uniform practices at tourist destinations. Environmental factors such as pollution, pesticide use, and poor waste management can contaminate food and water sources. Additionally, the high demand for local resources through tourism can lead to shortcuts in food safety practices to meet this pressure.

Role of One Health: Applying the One Health approach to food safety involves creating integrated systems in which the Food Safety Department, health departments, agricultural agencies, and environmental authorities collaborate to monitor and ensure safe food practices. Sustainable farming practices such as reduced pesticide use, organic farming, and sustainable aquaculture should be encouraged to help local producers adopt eco-friendly and safe methods. Hygiene training for food handlers, including street vendors and restaurant staff, is essential to maintain proper food safety standards. Additionally, promoting traceability within the food supply chain and certifying food businesses that adhere to safety and sustainability standards will ensure transparency and accountability.

Tourists should also be educated about safe food choices, such as avoiding raw or undercooked foods in high-risk areas and choosing locally certified products. Managing water quality is crucial for reducing foodborne illnesses, as clean water is necessary for cooking, drinking, and sanitation. Finally, implementing waste reduction strategies and properly managing organic waste can help prevent environmental contamination and ensure a safer and more sustainable food system for tourism destinations.

Integrating food safety into sustainable tourism through the One Health approach ensures that tourism supports public health, protects local resources, and celebrates culinary heritage. By prioritizing safe, sustainable, and culturally rich food experiences, destinations can build trust, foster long-term economic growth, and contribute to global health and sustainability efforts.

Conclusion

Tourism exerts various influences on health, impacting both consumers and providers (Igueiredo *et al.,* 2024). The One Health approach offers a transformative path for achieving sustainable tourism by addressing the interconnected challenges of health, environment, and society. By integrating these principles, tourism can evolve into a sector that not only generates economic value, but also preserves ecosystems, protects public health, and uplifts local communities. Adopting the One Health framework is not just an option, but a necessity for ensuring a sustainable and resilient future for global tourism.

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Mangroves and Climate Change: Integrating Ecology and Sustainable Tourism for Resilient Coastal Ecosystems

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Introduction

Mangroves are among the most vital ecosystems on Earth, serving as natural guardians for coastal regions and providing critical services for biodiversity, human communities, and global climate. Mangroves act as a unique buffer between land and sea, mitigating the effects of rising sea levels, storm surges, and coastal erosion. Mangroves are a diverse group of salt-tolerant arboreal flowering plants that thrive in tropical and subtropical regions (Ellison and Stoddart 1991). These ecosystems play an essential role in maintaining ecological balance. A mangrove is generally defined as a tree, shrub, palm, or ground fern that grows above mean sea level in the intertidal zones of coastal marine environments or estuarine edges (Duke 1992). The term "mangrove" can refer to either the ecosystem as a whole or the individual plant species within it (Tomlinson 1986). Mangrove species exhibit varying tolerance to changes in sea level, salinity, and storm intensity. By studying which mangrove populations can adapt to rising sea levels and other environmental changes, natural resource managers can identify and protect areas that act as refuges and sources for future mangrove regeneration. Their dense root systems stabilize shorelines, trap sediments, and sequester significant amounts of carbon, making them invaluable for the fight against climate change. These ecosystems, characterized by salt-tolerant trees and shrubs, serve as natural barriers against coastal erosion, storms, and sea-level rise. Mangroves are increasingly valued for their role in carbon sequestration, commonly referred to as "blue carbon" (Chow, 2018). However, these ecosystems are under increasing threat owing to deforestation, urban development, and pollution, all of which undermine their ability to perform these critical functions.

Climate change poses significant challenges to ecosystems worldwide, with mangroves being no exception. While geological records indicate that climatic shifts have occurred throughout history, the current pace of global warming threatens the survival of ecosystems. Greenhouse gas emissions from human activities are now higher than ever before, leading to widespread effects throughout the climate system. These emissions have been the primary drivers of observed warming since the mid-20th century. Climate change has caused observable impacts on ecosystems and human societies worldwide. Even if greenhouse gas emissions are halted today, many aspects of climate change and its associated effects would persist for centuries. This underscores the sensitivity of natural and human systems to shifting climatic conditions (Hernández-Delgado, 2015). Human activities have significantly impacted the climate system, with greenhouse gas emissions reaching unprecedented levels in recent decades owing to economic growth and population expansion. This has led to increased atmospheric concentrations of carbon dioxide, methane, and nitrous oxide, causing widespread changes in the natural and human systems. Since the 1950s, the atmosphere and oceans have warmed, snow and ice have diminished, and sea levels have risen—changes unparalleled for millennia. Projections for the 21st century predict further temperature increases, more frequent heat waves, intensified extreme precipitation, ocean warming and acidification, and rising sea levels. These shifts exacerbate risks, disproportionately affecting disadvantaged communities and heightening the urgency to address climate change to prevent sudden or irreversible impacts on ecosystems and human well-being (IPCC, 2014; Hernández-Delgado, 2015).

Sustainable tourism within mangrove areas is a growing sector that, when managed responsibly, can simultaneously support conservation efforts and local economies. This chapter delves into the dual role of mangroves as ecological powerhouses and hubs for sustainable tourism. The ecological significance of mangroves cannot be overstated: they are home to diverse flora and fauna, including endangered species, and play a pivotal role in the livelihoods of millions of people worldwide. However, these unique ecosystems offer unparalleled opportunities for eco-tourism, providing visitors with a chance to connect with nature while fostering a deeper understanding of the need for conservation.

Mangrove Ecosystems in India: Distribution, Diversity, and Conservation

India, with a vast coastline of approximately 7,516.6 km, including island territories, supports a mangrove cover of approximately 6,749 sq. km, ranking as the fourth-largest mangrove area globally (Naskar & Mandal, 1999). Indian mangroves are distributed across three distinct zones: the east coast facing the Bay of Bengal with a coastline of approximately 2,700 km, the west coast along the Arabian Sea at 3,000 km, and island territories encompassing 1,816.6 km. The major states with extensive mangrove coverage include West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Goa, Maharashtra, Gujarat, and the Andaman and Nicobar Islands. Gujarat has the second largest mangrove cover in India after the Sundarbans, contributing 23% of the nation's total mangrove area. Kachchh district alone accounts for nearly 90% of Gujarat's mangroves. Indian mangroves constitute approximately 3% of the global mangrove cover, and 8% of the mangroves in Asia (SFR, 2009; FAO, 2007). The distribution is primarily along the east coast (60%), followed by the west coast (27%) and the Andaman and Nicobar Islands (13%). Mangrove density was categorized as very dense (canopy density >70%), moderately dense (40–70%), or open mangrove cover (10–40%). The east coast, owing to its gradual topography and the extensive river deltas of the Ganges, Brahmaputra, Mahanadi, Godavari, Krishna, and Cauvery, supports 80% of India's mangroves, with 20% located on the west coast. These nutrient-rich deltas create favorable conditions for mangrove formation (Jagtap & Komarpant, 2003). Approximately 60 mangrove species grow in abundance across India (Untavale, 1986). Sundarbans, located on the east coast of West Bengal, represent the largest mangrove forest, covering approximately 9,600 sq. km of forest and water. This region is characterized by islands formed from sediment deposits of the Ganga, Brahmaputra, and Meghna Rivers and a dense network of smaller rivers and creeks. Sundarbans host around 30 true mangrove species, with Debnath and Naskar (1999) identifying 36 species in total. The mangrove area in Odisha spans nearly 200 sq. km, although it has faced degradation at a rate of approximately 20 sq. km over the last decade. Andhra Pradesh hosts approximately 582 sq. km of mangroves, while Tamil Nadu, with the second-longest coastline of 1,076 km, has an estimated mangrove cover of 225 sq. km. The key mangrove wetlands in Tamil Nadu include the Pichavaram and Muthupet mangroves, which are nourished by freshwater from the Cauvery River. The Pichavaram mangrove forest, spanning 1,100 ha in the Cuddalore district, is among the largest and most pristine forests in Tamil Nadu (Venkataraman, 2007).

In Goa, mangroves are confined to narrow intertidal mudflats along estuarine banks, covering 67.3 sq. km. These areas are often reclaimed for urbanization and agriculture. Odisha has a mangrove sanctuary of 130 sq. km, nourished by three major rivers, with dense and tall trees similar to Sundarbans (Selvam, 2003). Mangrove ecosystems in India are classified into three types: deltaic mangroves (53% of the total mangrove cover, including Sundarbans, which alone accounts for 78% of this category), coastal mangroves (12%, located along intertidal coastlines, bays, and backwaters), and island mangroves (16%, found in protected zones such as the Andaman, Nicobar, and Lakshadweep Islands) (Ingole, 2005). These mangroves are vital not only for their ecological benefits but also for their role in sustaining local livelihoods and biodiversity. However, continued urbanization, pollution, and habitat loss threaten their existence. Effective conservation measures, sustainable management, and community participation are crucial to ensure the long-term resilience of mangroves in India.

The Role of Mangroves in Climate Resilience

Mangroves are vital coastal ecosystems uniquely adapted to survive in saline and waterlogged conditions and play a crucial role in enhancing climate resilience. Mangroves protect coastlines from storm surges, tsunamis, and flooding by absorbing wave energy and stabilizing sediments, thereby reducing damage to infrastructure and safeguarding communities (De Groot et al., 2002; Ren et al., 2009). Their dense root systems prevent coastal erosion, maintain shoreline integrity, and adapt coastlines to rising sea levels by trapping sediments and contributing to soil buildup. One of the most significant contributions of this process is carbon sequestration. Mangroves are highly efficient at capturing and storing carbon dioxide (CO_2), sequestering up to four times more carbon than terrestrial forests. For example, a 20-year-old *Rhizophora* mangrove plantation can store 11.6 kilograms of carbon per square meter, with a carbon burial rate of 580 grams per square meter annually (Fujimoto, 2000). Global estimates place mangrove carbon storage between 5.23 and 8.63 Pg C (Alongi, 2022), with long-term storage occurring in waterlogged soils that can extend to depths of over 3 meters. Studies have also revealed that mangroves generally fix more carbon than their ecosystem requires, with approximately 40% of net primary production stored as excess carbon, further emphasizing their critical role in mitigating global warming (Duarte and Cebrian, 1996; Clough et al., 1998).

Mangroves are globally recognized as biodiversity hotspots, offering unique and critical habitats for a vast array of marine and terrestrial species. These ecosystems are ecological powerhouses that foster rich biodiversity and support numerous life cycles, particularly in the coastal regions. Their dense and intricate root systems serve as nurseries for commercially and ecologically significant species such as fish, crustaceans, mollusks, and migratory birds. This biodiversity underpins food security and sustains the livelihoods of millions of coastal communities. In addition to their role in climate mitigation, mangroves support biodiversity by serving as habitats and breeding grounds for diverse species, including fishes, crustaceans, and migratory birds. Their ecological benefits extend to adjacent ecosystems, such as coral reefs and seagrass meadows, thereby enhancing ecosystem resilience and stability. The connectivity between mangroves and these ecosystems highlights their importance in maintaining the ecological balance and fostering biodiversity at local and global scales.

Beyond their ecological functions, mangroves provide various ecosystem services that are essential to human communities. These include direct benefits, such as timber, firewood, honey, food, and traditional medicines, as well as opportunities for aquaculture and eco-tourism. Mangroves indirectly regulate atmospheric gases, maintain water quality, stabilize sediments, and support fisheries, which are vital for food security and the livelihoods of millions of coastal residents (Osland et al., 2022). The economic value of these services underscores their immense value. For instance, Pearce and Moran (1994) and Costanza and Folke (1997) highlighted the significant contribution of mangroves to global ecosystem services, including reducing infrastructure repair costs and supporting sustainable economic activities.

Despite their ecological and economic importance, mangroves face significant threats from deforestation, pollution, and land use changes. The degradation of these habitats not only jeopardizes biodiversity, but also undermines the critical ecosystem services they provide. Conservation and restoration efforts are imperative to safeguard mangroves as biodiversity hotspots and ecological powerhouses. By protecting mangroves, we can ensure the preservation of countless species, the health of coastal ecosystems, and the well-being of millions of people who depend on them. Mangroves are indispensable in addressing the dual challenges of climate change and biodiversity loss. Their ability to sequester carbon, protect coastlines, support livelihoods, and foster biodiversity underscores their importance. Restoring and conserving mangroves is essential to securing their ecological and economic benefits. By prioritizing mangrove conservation, humanity invests in long-term climate resilience, ensuring that these ecosystems continue to play a vital role in mitigating global warming and sustaining coastal communities.

Challenges

The impact of climate change on mangroves is profound and multifaceted. Rising sea levels, increasing temperatures, and changes in precipitation patterns have posed significant threats to these ecosystems.

1. **Sea Level Rise**: Mangroves are highly sensitive to sea-level changes. Excessive submergence can lead to the drowning of mangrove forests, especially in areas where the sediment supply is insufficient to support vertical accretion.

2. **Temperature Changes**: Increasing temperature affects mangrove physiology, altering growth rates and species composition. Prolonged exposure to high temperatures can reduce productivity and resilience.

3. **Storm Intensity**: Climate change has led to more frequent and intense storms, which can damage mangrove ecosystems by uprooting trees and altering sediment dynamics.

4. **Salinity Variations**: Changes in rainfall and freshwater flow can disrupt the salinity balance of mangrove ecosystems, affecting species distribution and ecosystem functions.

5. **Deforestation**: The conversion of mangrove forests for aquaculture, agriculture, and urban development has led to a significant loss of mangrove cover worldwide.

6. **Pollution**: Industrial discharge, oil spills, and untreated domestic waste degrade mangrove ecosystems, thereby reducing their capacity to provide ecosystem services.

7. **Overharvesting**: The unsustainable extraction of mangrove wood for fuel and construction materials threatens the sustainability of these ecosystems.

Sustainable Tourism: An Emerging Opportunity

Mangroves are widely recognized as one of the world's most important ecosystems, offering numerous environmental, social, and economic benefits (Spalding and Parrett 2019). Mangrove forests have become popular attractions for nature-based tourism, a trend that has grown significantly in recent years. This is not a new development as mangrove tourism has existed for decades. For example, the Caribbean has been a hub for mangrove tourism since the 1970s (Bacon 1987). Over time, mangrove-related tourism has aligned with the broader ecotourism movement (Balmford et al. 2009; Cisneros-Montemayor and Sumaila 2010). Spalding and Parrett (2019) found that mangrove forests are a tourist attraction in many countries worldwide. Their research, based on an analysis of 3,985 mangrove attractions across 93 countries and territories, revealed that millions of visitors engage in mangrove tourism annually, making it a multibillion-dollar industry. These attractions often combine facilities, activities, and wildlife experience. Common facilities include boardwalks, viewing towers, information centers, and educational boards, while activities range from boating (e.g., canoeing, kayaking, and paddle boarding) to fishing and hiking. Wildlife associated with mangrove ecosystems, such as fireflies, bioluminescence, monkeys, crocodiles, and diverse bird species, further enhances their appeal (Spalding and Parrett 2019). The tourism industry leverages these features to support community development and to stimulate local economies.

However, the rapid expansion of mangrove tourism poses a significant challenge. Intensification of tourism can lead to long-term environmental degradation and habitat loss. Despite the benefits to mangrove ecosystems, unsustainable exploitation has caused considerable global damage globally (Webber et al. 2016). Since the 1980s, the world has experienced alarming rates of mangrove forest loss due to economic development pressures (FAO 2007; Polidoro et al. 2010). Reports indicate that nearly half of all mangroves have disappeared since the mid-20th century, with annual loss rates averaging 1-2% (Duke et al. 2007; FAO 2007). Additionally, mangroves have been lost at rates to 3-5 times higher than those of terrestrial forests (WWF International 2017). The rate of mangrove loss has declined over the last three decades, suggesting either increased ecosystem resilience or the impact of conservation and restoration efforts (Spalding et al. 2010; Webber et al. 2016). The high value of mangrove ecosystems derived from their diverse services underscores the critical need for protection and restoration initiatives (Salem and Mercer 2012; Spalding and Parrett 2019). Using mangroves as attractions can support powerful arguments for their conservation and sustainable management, ensuring their preservation for future generations (The Economist 2018).

Mangroves and SDGs

Countries worldwide share the responsibility of enhancing the planet's sustainability and improving the quality of life of their citizens to secure a better future. The Sustainable Development Goals (SDGs) aim to address global challenges through 17 interconnected goals, ensuring that no one is left behind (United Nations 2020). Goal 14, which seeks to "conserve and sustainably use the oceans, seas, and marine resources for sustainable development," is particularly relevant to sustainable mangrove tourism development. Oceans play a vital role in regulating the Earth's systems, including temperature, chemistry, and biodiversity, which are essential for human habitation (UNDP 2020). Mangrove forests, as part of marine ecosystems, require protection, conservation, and effective management to benefit communities, society, and future generations.

Beyond Goal 14, sustainable development of mangrove tourism contributes to other SDGs including Goal 1 ("No Poverty"), Goal 2 ("Zero Hunger"), Goal 8 ("Decent Work and Economic Growth"), Goal 13 ("Climate Action"), and Goal 15 ("Life on Land") (Blum and Herr 2017). To achieve genuine sustainability in mangrove tourism while balancing economic demand and environmental protection, four critical strategies are essential. These strategies are interconnected and focus on the following.

1. **Conservation and Restoration of Mangroves:** Establishing robust conservation efforts alongside the rehabilitation of degraded mangrove ecosystems.

2. **Clear Policy and Legislation:** Developing policies and regulatory frameworks to ensure the effective and sustainable management of mangrove tourism.

3. **Infrastructure and Facilities Development:** Enhancing infrastructure and facilities to support sustainable tourism without harming mangrove ecosystems.

4. **Community Participation and Engagement:** Actively involving local communities in conservation efforts and sustainable tourism initiatives to promote stewardship and equitable benefits.

Collectively, these strategies support the broader agenda of achieving sustainable mangrove tourism development in a holistic and balanced manner. They aim to align economic growth with the preservation of mangrove ecosystems for the benefit of the current and future generations.

The Role of Blue Carbon in Climate Mitigation

Blue carbon ecosystems play a critical role in mitigating climate change by capturing and storing excess atmospheric carbon from the atmosphere (Bandh et al., 2023). As defined by the Intergovernmental Panel on Climate Change (IPCC), blue carbon refers to all biologically driven carbon fluxes and storage within marine systems that can be effectively managed. The primary focus has been on examining coastal vegetation such as tidal marshes, mangroves, and seagrasses, which are integral components of these ecosystems (Ouyang et al., 2023). Blue carbon sequestration is considered a nature-based solution for addressing ongoing climate crises. Vegetated marine habitats provide essential services, including enabling society to adapt to climate change by protecting coastal areas from increased storm activity, rising sea levels, and coastal erosion. However, it is essential to acknowledge that the effectiveness of restoring blue carbon habitats for carbon sequestration remains uncertain (Macreadie et al., 2021). The link between the benefits of conserving blue carbon ecosystems and the need to prevent their degradation is strengthened through economic incentives, multi-regulatory frameworks, and financial support for conservation and restoration initiatives (Bandh et al., 2023).

Osland et al. (2022) identified carbon sequestration as the most significant benefit offered by tropical coastal ecosystems. Mangroves, in particular, play a key role in sequestering organic carbon stocks in aboveground components (leaves and branches) and belowground components (sediment and roots) within the soil. This carbon storage occurs across a range of depths from 30 cm to more than 3 m, providing a mechanism for long-term carbon retention (Suello et al., 2022). Current assessments of carbon accumulation in mangroves rely on radiometric analysis. According to Lamont et al. (2020), these analyses estimate carbon accumulation in mangroves at 0.17 to 4.3 Mg C per hectare annually. Soil carbon measurements fall within this range, varying from 1.74 to 2.5 Mg C per hectare annually (Suprayogi et al., 2022).

However, carbon acquisition through root systems shows higher rates, ranging from 5.06 to 6.63 Mg C per hectare annually, surpassing estimates from radiometric analyses or soil mass carbon determination (Lamont et al., 2020). These discrepancies arise because radiometric analyses and soil measurements often exclude root contributions. Recent research has highlighted that carbon sequestration through mangrove litterfall exceeds estimates obtained using radiometric or mass analysis methods. Chen et al. (2021) predicted that mangrove litterfall contributes 3–5 Mg C per hectare annually to carbon sequestration. When including the carbon stored in the upper layers of sediments, the total forest stock amounts to 693 Mg C per hectare, with the soil forest stock contributing 516 Mg C per hectare (Alongi, 2022).

The potential for carbon storage in soils increases significantly when deeper sediment layers are considered, reaching up to 2,792 Mg C per hectare. Using a median value of 627.8 Mg C per hectare and global mangrove area estimates ranging from 83,495 to 137,760 km², Alongi (2022) calculated the global carbon storage in mangroves to range between 5.23 and 8.63 Pg C. These findings underscore the significant role of mangroves and other blue carbon ecosystems in the capture and storage of atmospheric carbon. Conservation and restoration of these ecosystems are essential strategies for combating climate change as they provide long-term carbon storage, protect biodiversity, and enhance the resilience of coastal communities to environmental challenges.

Policy and Global Collaboration for Mangrove Preservation

Mangrove ecosystems are invaluable, providing habitats for numerous threatened species, supporting fisheries, and offering billions of dollars in ecosystem services, including coastal protection and carbon sequestration (Global Mangrove Alliance, 2023). Recognizing their significance, global initiatives have set ambitious goals for mangrove conservation. For instance, the *Global Mangrove Alliance (GMA)* aims to halt net mangrove loss, restore half of the recently lost areas, and double the protection of existing mangroves by 2030. These objectives align with international frameworks such as the *UN Decade on Ecosystem Restoration* and resolutions from the *United Nations Environment Assembly*, which emphasize the sustainable management of mangroves through ecosystem-based approaches, policy development, and resource mobilization (UNEP, 2023).

National legal and policy frameworks are central to the achievement of these goals. As of 2023, at least 75 jurisdictions have incorporated mangrove considerations into their national laws, with 64 implementing regulations on mangrove cutting or clearing and 19 enforcing complete bans, with certain exceptions (GMA, 2023). Effective policy measures include financial mechanisms, such as taxes and direct payments, and market-based approaches, such as carbon credits, to incentivize conservation and sustainable use. For example, Costa Rica's *National Blue Carbon Strategy, 2023*, leverages economic incentives to reverse the loss of blue carbon ecosystems, benefiting both the environment and dependent communities (GMA, 2023). In addition, community management frameworks empower local populations to engage in mangrove conservation, ensuring that traditional knowledge and sustainable practices are integrated into national strategies.

Case studies have highlighted the effectiveness of tailored legal and policy approaches. Belize, for instance, is developing a *National Mangrove Restoration Action Plan* that uses land tenure analysis to identify priority restoration areas while aligning with national climate commitments (Belize National Mangrove Restoration Action Plan, 2023). Ecuador has embedded mangrove protection into its constitution, balancing conservation with sustainable use by local communities (Ecuador's Constitutional Protections for Mangroves, 2023). These examples demonstrate that policies that consider ecological, social, and economic factors can lead to effective mangrove conservation outcomes.

Science-based approaches play a critical role in mangrove preservation. Satellite imagery, GIS technology, and field surveys were used to monitor mangrove health, track deforestation trends, and identify restoration priorities. Research on mangrove ecology and restoration techniques informs evidence-based policymaking, ensuring targeted and adaptive management strategies (Ramsar Convention on Wetlands, 2022). Integrated coastal and marine spatial planning further supports these efforts by embedding mangrove ecosystems in broader environmental and developmental agendas.

Community engagement is essential for the successful conservation of mangroves. Capacity-building programs empower local communities through education and training in sustainable livelihoods such as eco-tourism and aquaculture. Participatory management models, in which communities are involved in decision-making, ensure long-term commitment to conservation (Global Mangrove Alliance, 2023). Public awareness campaigns further highlight the ecological and economic value of mangroves, fostering grassroots support for conservation.

The preservation of mangrove ecosystems requires a multifaceted approach that integrates global collaboration, national policy development, science-based strategies, and community engagement. By aligning international goals with effective legal frameworks and local participation, initiatives such as the Global Mangrove Alliance and Costa Rica's Blue Carbon Strategy have demonstrated how collective action can restore mangrove ecosystems, protect biodiversity, and support sustainable livelihoods. These efforts have ensured that mangroves remain vital ecological and economic assets for future generations.

The Future of Coastal Ecosystems: Building Resilience

Coastal ecosystems including mangroves, coral reefs, seagrass meadows, and estuaries are vital for sustaining biodiversity, protecting coastlines, and supporting millions of livelihoods. However, these ecosystems are facing mounting challenges due to climate change, pollution, overexploitation, and urbanization. To ensure their future survival and functionality, it is imperative to build resilience in these ecosystems. This requires addressing climate change, which is one of the most significant threats. Rising sea levels, increasing temperatures, and extreme weather events have resulted in widespread habitat degradation. Resilience can be enhanced by prioritizing adaptive restoration strategies and promoting species that thrive under changing environmental conditions. Mangroves, for example, not only act as carbon sinks, but also shield coastlines from storm surges, emphasizing their importance in climate adaptation plans. Nature-based solutions, such as restoring mangroves, coral reefs, and seagrass beds, are also critical, as they provide natural protection against coastal erosion and flooding. By integrating these solutions into urban planning and disaster risk management, coastal regions can mitigate the impact of climate extremes. Strengthening policy frameworks that emphasize ecosystem-based management and foster collaboration among governments, communities, and private stakeholders is an essential step forward. Ultimately, the future of coastal ecosystems depends on proactive, science-driven actions that align conservation with sustainable development goals, ensuring that these ecosystems remain functional and resilient for generations to come (Sutton-Grier et al., 2015, Singh, 2020).

Conclusion

Mangroves and their ecosystems provide significant benefits to the environment, local communities, and global economy. As mangrove forests increasingly serve as popular tourist destinations, they present opportunities for economic growth owing to their natural beauty and biodiversity. Achieving sustainable tourism development requires balancing economic activities with the preservation, conservation, and restoration of vital ecosystems. While mangrove tourism can boost national economies and promote cultural heritage, it also presents challenges, such as deforestation, resource depletion, pollution, and habitat degradation. Overemphasizing economic gains, urbanization, and unregulated development can disrupt the equilibrium needed for sustainability. Ineffective conservation efforts, unclear policies, poor management, and inadequate infrastructure exacerbate these issues. Moreover, the limited community involvement in managing mangroves and promoting sustainable tourism hinders the effectiveness of such initiatives.

To address these challenges, a model of sustainable tourism development that balances economic pressure with environmental protection is required. Key strategies to achieve this include continuous conservation and restoration efforts tailored to local ecological conditions, supported by clear policies, and robust legislation to ensure sustainable use and management. Infrastructure and facilities should be developed with minimal environmental impact by leveraging advanced technologies to optimize resource efficiency and reduce pollution. It is equally important to foster community participation and engagement by actively involving local populations in mangrove tourism management and conservation. Education and capacity-building initiatives can empower communities and encourage a sense of stewardship of these ecosystems. By integrating these strategies, mangrove tourism can support economic development, while ensuring the preservation of these critical ecosystems. Balancing economic, environmental, and social priorities is crucial for fostering resilient coastal ecosystems that can withstand the challenges of climate change and benefit future generations.

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Effective water and land management strategies for sustainable agroecotourism

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Introduction

The west coast region of India is characterized by high rainfall; therefore, the application of soil and water conservation measures such as bench terraces, contour trenches, rainwater harvesting structures such as farm ponds, *jalkunds*, bunds, and other structures is necessary for reducing soil erosion, which also adds beauty to the agricultural farm and agro-ecotourism unit. Several soil and water conservation practices are in place in coastal areas to maintain soil moisture and prevent runoff and soil erosion. Coastal regions have a rich tradition of soil conservation and rainwater harvesting. The farmers here have followed some of the traditional methods for cultivating crops on sloping lands by converting the slope into terraces using locally available lateritic stones to reduce runoff and soil loss. For irrigating the crops, farmers use the sunken ponds and temporary check dams for harvesting sub-surface flow and use of coconut husk as the mulching material for moisture conservation during non-monsoon season (Chakurkar et al., 2018). Such indigenous technical knowledge (ITK) on water and land management can be a good attraction for tourists or visitors, as it highlights the traditional wisdom of farmers, which is being followed by age. Tourists can visit such facilities, and farmers can explain the technologies, ideas, and methods to visitors. Watershed management also promotes agroecotourism, emphasizing its relevance and utility as a prerequisite for long-term natural resource management (Kumar et al., 2021). Watershed models can serve as agro-technology parks, as they lead to the development of water resources and soil conservation, which ultimately conserves biodiversity, flora, and fauna.

Traditional knowledge on land and water management

Soil and water conservation is an ancient practice. It is part of the *Kulagar* system or integrated farming system practice followed by farmers (Maneesha et al. 2019) in the Goa and west coast regions. Crops such as cashew, mango, arecanut, and coconut predominantly occupy the steep slopes of lower coastal ghats and central undulating uplands of Goa (Manivannan et al., 2010). In the steeply sloping regions of Goa, the cultivation of plantation crops, such as arecanuts, is taken up by converting the slopes into terraces using locally available lateritic stones to reduce runoff and soil loss. Loose boulder check dams across the gully slope have been adopted at regular intervals to reduce the flow velocity and sediment load. Water percolating from the uphill is collected at the bottom of the slope in a pond, and the excess flow is allowed to flow downstream. Sunken ponds for surface water harvesting and springs for subsurface water harvesting were used to provide supplemental irrigation for crops.

Percolation pond

Bench terraces

Loose boulder check dam **Rainwater harvesting pond**

Runoff diversion channel **Temporary check dam (Baand)**

Runoff diversion channels are also used in the *Kulagar* system to divert excess runoff flow with safe velocity. Temporary check dams made of sand and bamboo sticks were constructed across the gully to store water for supplemental irrigation during the non-monsoon season and removed in the monsoon season to allow excess water to flow. Contour bunds are sometimes provided to reduce runoff and soil erosion (Khedekar 2013). Water percolating from the uphill is collected at the bottom of the slope in a pond, locally known as *tallem*. Water from *tallem* was used for irrigation during the day and stopped during the night. The baand is usually constructed in the middle part of *Kulagar* to supply water to both sides. Sometimes, mud tanks are also made to store water for irrigation, which is known as Ushen. (Khedekar 2013).

Approximately 80% of the soils in the west coast region, including Goa, are lateritic with gravelly texture, and thus have poor water-holding capacity. After the monsoon season, no moisture is available in the soil. However, farmers in the Goa and west coast regions follow some of the traditional methods of moisture conservation and water management. Coconut husks are used as a mulch material to conserve soil moisture after the monsoon season. Mulching is effective in reducing soil evaporation and maintaining a high soil moisture content. Mulching with coconut husk can retain 35-40% extra soil moisture in the root zone compared to non-mulched trees. This practice reduces the cost of cultivation, leads to water saving, and improves soil structure, water-holding capacity, and crop productivity (Subramanian et al. 2019).

Mulching with coconut husk to conserve soil moisture

In the hilly region of western ghats, farmers usually divert the sub-surface flow/spring water from the hills locally known as *Jhara* to their fields through a network of small unlined channels and sometimes by using the trunk of areca nut and palm trees with semi-circular shapes. The water collected is either stored in a small pond and used for irrigation through gravity on hill slopes, or diverted into the fields directly in the plain lands.

Water collection from springs for irrigation in non-monsoon season

Although traditional systems of water and land management are sustainable, there are limitations associated with these methods, such as seepage of water from unlined channels, low discharge, lack of storage facilities, and poor distribution of water throughout the field. To address these issues, traditional knowledge must be integrated with advanced scientific methods for water and land management.

Effective water and land management techniques

Soil and water loss are major problems in sloping lands on the west coast region of India due to heavy rainfall. The majority of the soil series in the *Konkan* region, including the Goa state, are coarse to medium textured and well drained with low water holding capacity (Desai et al., 2021). The major horticultural crops in the west coast region, such as cashew, mango, coconut, and arecanut, are mainly cultivated on the steep slopes of lower coastal ghats and undulating uplands (Manivannan et al. 2010). Although the coastal region receives very high rainfall, many locations experience severe water scarcity during summer, as the maximum amount of rainfall is received only during the southwest monsoon (June to September). Therefore, moisture stress negatively affects the productivity of important horticultural crops, such as mango, cashew, coconut, and arecanut. In the absence of proper soil and water management practices on slopes, runoff and soil erosion lead to a substantial loss of soil and nutrients, resulting in land degradation (Mahajan et al. 2021). Therefore, it is necessary to adopt soil and water conservation measures to reduce land degradation and maintain the ecological balance (Manivannan and Sikka 2013).

Soil and water conservation measures

The long-term impact of soil and water conservation (SWC) measures under mango cultivation in laterite soil on 19% slope land in Goa was studied (Desai et al., 2019). The results revealed that CCT+VB and SCT + VB could reduce runoff to 22.3% and 26.8%, respectively, compared to the control (42.1%). Soil loss was reduced from 12.6 t/ha/yr in control to 2.15 t/ha/yr and 4.00 t/ha/yr in CCT+VB and SCT+VB treatments respectively. The N, P, K and SOC loss in the soil was found to be 8.4, 1.22 4.88 and 80.1 kg/ha in CCT+VB as compared to 76.4, 13.8 33.6 and 581 kg/ha respectively in control (Desai et el., 2021). Analysis of soil moisture content at different depths revealed that CCT+VB had the highest soil moisture content, followed by SCT+VB. The long-term adoption of soil and water conservation measures in lateritic soils on sloping land improves the physical, chemical, and biological properties (Desai et al., 2019).

Continuous contour trenches with vegetative barriers in mango

Circular trenching and circular terraces in coconuts could reduce runoff by 34.8% and 21.7%, respectively, on 14% slope land in laterite soils. Soil loss from circular trenching and circular terraces were 53.09 kg/ha and 56.72 kg/ha as compared to control treatment (82.47 kg/ha). Circular trenching and terraces reduced soil loss by 35.6% and 31.2%, respectively. Circular trenching in coconuts recorded the highest soil moisture content during December, January, and February, which resulted in a reduction in nutrient loss, increased yield, and plant growth parameters. The efficiency of the different SWC measures in conserving soil and water was observed in the order of circular trenching > circular terraces > control.

Circular trenching in coconut

A long-term experiment was conducted to evaluate the impact of five soil and water conservation measures on soil carbon sequestration and soil quality under cashew nut cultivation with a 19% slope (Mahajan et al., 2020). Soil and water conservation measures significantly improved the soil organic carbon, soil organic carbon stock, carbon sequestration rate, and microbial activity compared to the control condition (without any measures). Among the measures tested, continuous contour trenches with vegetative barriers (CCT + VB) outperformed the others with respect to soil organic carbon stock, sequestration rate, and microbial activity. The lower metabolic quotient with the measures compared to the control indicated the alleviation of environmental stress on the microbes. The soil and water conservation measures improved the soil organic carbon stock and carbon sequestration rate significantly over the control and it was highest 186.3 Mg C/ha and 0.84 Mg C/ha/year, with the CCT+VB measure. The highest value of the soil quality index (0.98 was achieved with CCT + VB. The results of the study indicate that soil and water conservation measures for cashews are a potential strategy to improve soil carbon sequestration and soil quality, along with improving crop productivity and reducing erosion losses.

Continuous contour trenches in cashew

Rain water harvesting ponds/ Farm ponds

The west coast region of India receives abundant rainfall; however, the utility of rainwater is limited. The methodology for establishing rainwater harvesting ponds in laterite soils has been standardized with low-cost interventions to increase durability and reduce cost (Desai and Mahajan, 2022). After excavation of the pond, a high-concentration herbicide was sprayed to kill weeds and unwanted plants. Smoothening of the side slopes and bottom was performed using plaster prepared from fine garden soil and a 10-15 cm thick layer of paddy straw was laid along the sides and bottom of the pond to provide a smooth surface. Both materials are locally available, thus reducing the cost and protecting the lining material from the damage caused by sharp stones. A silica polyfilm with a thickness of 300 GSM was used as lining material. After laying the polyfilm, it was properly set and fixed in a trench dugout around the pond and covered with soil. The total cost involved in establishing large size (3500 m^3 with 3 m depth), medium size (1400 m^3 with 2.5 m depth), and small-sized ponds (300 m^3 with 1.5 m depth) in laterite soils is approximately Rs. 6.6, 4.7 lakhs and 2.5 lakhs respectively (https://ccari.icar.gov.in/agni/natural-resource). The direct water harvesting pits/jalkunds will cost upto Rs. 60000. Rainwater harvesting ponds can be used for protective irrigation of crops during the non-monsoon season, rearing of livestock, piggery, poultry, duckery, etc. Such farms can be a good attraction for tourists, as they highlight the traditional practices of farmers coupled with modern techniques of in-situ water conservation, such as farm ponds, and these fields can serve as the centers of agro-ecotourism units for visitors.

Large size pond (V=3500 m^3, D=3 m)

Medium size pond (V=1400 m^3, D= 2.5 m)

Small size pond (V=300 m^3 D= 1.5 m)

Direct water harvesting pits (Jalkund)

Land and water management strategies for sustainable agroecotourism

- Soil and water conservation measures include contour trenching, bench terracing, check dams, and vegetative barriers to control soil erosion and runoff losses.
- Rainwater-harvesting ponds, artificial groundwater recharge structures, and integrated watershed management for augmenting water resources and crop intensification
- Adoption of zero-energy (gravity) and solar-energy-powered micro-irrigation systems with mulching techniques to improve water-use efficiency
- Adoption of Integrated farming system (IFS) models for year-round income and livelihood security
- Land shaping techniques such as farm ponds, ridges, and furrows and 3-tier systems for multi-enterprise in the salt-affected soils of the coastal region
- Crop diversification and adoption of low water requiring and climate-resilient crops like millets
- Blending farmers' traditional knowledge of soil and water conservation with advanced technologies for sustainable agriculture.

Conclusion

The sustainability of agro-ecotourism in the coastal region of India can be achieved through a multi-faceted approach that combines both traditional knowledge and scientific advancements. To cope with land degradation and poor soil quality, key strategies, such as soil and water conservation measures, rainwater harvesting, mulching, and solar-powered micro-irrigation techniques, help to optimize the inputs and improve the productivity and income of these lands. These practices are considered to be efficient, environmentally sustainable, and farmer-friendly. These strategies help control soil erosion and enhance the soil moisture regime and soil fertility. Blending traditional knowledge with new technologies and restoration measures is also one of the most viable approaches. However, it is important to identify existing traditional technologies and knowledge on this aspect, refine them through advanced scientific methods, and implement interventions in priority areas. Agro ecotourism with the integration of traditional wisdom and scientific advancements can offer additional socioeconomic benefits, allowing the local communities to benefit from tourism while preserving the natural resources like land and water and traditional agricultural practices of the farmers. Therefore, by implementing sustainable land and water management practices, agroecotourism can better withstand weather aberrations and climate change impacts, thus ensuring food security and economic stability for farmers in the coastal region.

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Agro-ecotourism potentiality mapping using remote sensing and GIS

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1. Introduction

Ecotourism has emerged as a crucial approach in today's world, playing a pivotal role in promoting environmental conservation, supporting local communities, and fostering sustainable development. Unlike traditional tourism, which often depletes natural resources and contributes to environmental degradation, ecotourism emphasizes responsible travel practices designed to minimize negative impacts on ecosystems. By visiting natural areas and engaging in eco-friendly activities, travelers actively contribute to preserving biodiversity, protecting endangered species, and ensuring the long-term health of fragile ecosystems (Honey, 2008). This approach helps maintain ecological balance, safeguards unique habitats, and benefits both the environment and the species that rely on it (Das & Chatterjee, 2015).

The concept of ecotourism has evolved over the years as a response to the environmental and cultural challenges posed by conventional tourism. Its roots can be traced back to the late 19th and early 20th centuries, when naturalists and conservationists advocated for the preservation of pristine environments and the responsible enjoyment of nature. Mexican environmentalist Héctor Ceballos-Lascuráin is credited with coining the term in 1983. Ecotourism, as a concept, has been defined and interpreted in diverse ways by researchers and organizations worldwide. Despite variations in wording, these definitions share a common emphasis on environmental conservation, cultural preservation, and responsible tourism practices. Ceballos-Lascuráin (1987) was among the first to define ecotourism as "traveling to relatively undisturbed or uncontaminated natural areas with the specific objective of studying, admiring, and enjoying the scenery and its wild plants and animals, as well as any existing cultural manifestations."

This definition highlights the dual focus of ecotourism: nature appreciation and cultural engagement. The International Union for Conservation of Nature (IUCN) (1996) expanded on this idea by defining ecotourism as "environmentally responsible travel and visitation to relatively undisturbed natural areas in order to enjoy and appreciate nature (and any accompanying cultural features—both past and present) that promotes conservation, has low visitor impact, and provides for beneficially active socio-economic involvement of local populations." This definition underscores the principles of sustainability and community benefit as integral to ecotourism. Blamey (1997) offered a more educational perspective, describing ecotourism as "a form of tourism that fosters learning experiences and appreciation of the natural environment, or some component thereof, within its associated cultural context." This definition emphasizes the role of ecotourism in promoting environmental awareness among travelers. Honey (2008) further refined the concept, defining ecotourism as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education." Honey's definition incorporates the importance of education and the welfare of local communities alongside conservation efforts. Weaver (2008) described ecotourism as "tourism that is based on the natural environment, is ecologically sustainable, promotes environmental education and awareness, and incorporates cultural elements to enhance the experience." This comprehensive definition encapsulates the ecological, educational, and cultural dimensions of ecotourism. Despite slight differences in focus, these definitions collectively reflect ecotourism's commitment to preserving natural and cultural heritage, fostering sustainable practices, and educating travelers. They also underline the importance of balancing economic development with environmental and social responsibility, making ecotourism a vital tool in the global pursuit of sustainable development.

A significant aspect of ecotourism is its ability to empower local communities. It creates economic opportunities for people living in or near natural and cultural heritage sites by providing employment in tourism-related activities such as guided tours, homestays, handicrafts, and traditional food services. These initiatives not only enhance the livelihoods of local populations but also encourage their active participation in conservation efforts (Scheyvens, 1999). By involving communities in tourism planning and decision-making, ecotourism fosters a sense of ownership and pride, ensuring that natural and cultural resources are cherished and preserved (UNWTO, 2020). Moreover, ecotourism raises awareness about critical environmental and social issues. Travelers gain a deeper understanding of the interconnectedness between humans and nature, as well as the importance of conservation. Educational components, such as guided tours, workshops, and cultural exchanges, help visitors learn about sustainable practices and the need to respect cultural diversity. This heightened awareness often inspires eco-friendly habits, encouraging travelers to adopt sustainable lifestyles and spread these principles within their communities (Weaver, 2008). In addition to these advantages, ecotourism contributes to sustainable development by balancing economic growth with environmental protection. It promotes the use of renewable energy, efficient waste management, and eco-friendly infrastructure, ensuring that tourism activities do not exhaust natural resources or harm ecosystems. These practices align with long-term sustainability goals, such as reducing carbon emissions, conserving water, and preserving biodiversity (Das & Chatterjee, 2015).

As global challenges like climate change, habitat loss, and pollution intensify, ecotourism offers a practical and ethical way to enjoy nature responsibly. With growing awareness about the environment, climate change, and solid waste management, researchers have focused on promoting the ecotourism industry (Shasha *et al.*, 2020). It ensures equitable distribution of tourism benefits among stakeholders while preserving the planet's natural and cultural heritage for future generations (UNEP, 2002). By choosing ecotourism, travelers become active participants in protecting the environment, uplifting communities, and contributing to a more sustainable future.

2. Site Suitability Criteria for Ecotourism Development

Site suitability for ecotourism development is influenced by multiple environmental, social, and economic factors. These factors guide the identification and prioritization of areas that can support sustainable ecotourism. Key parameters typically include accessibility, landscape features, topography, wildlife, climate, and geology.

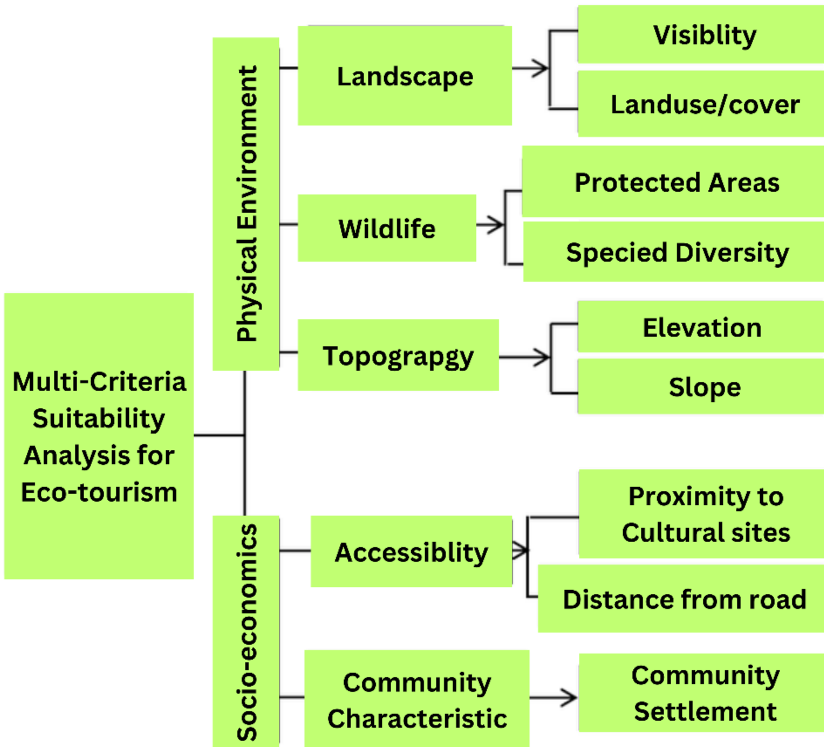

Fig. 1. Decision criteria and factors affecting Eco-tourism

2.1. Accessibility

2.1.1 Proximity to Roads: Roads facilitate visitor access to ecotourism sites, making proximity to roads a critical factor for site suitability. According to Suryabhagavan, 2015 the area within a buffer of 0–2 km was deemed highly suitable, the area within a buffer of 2–4 km was deemed moderately suitable, the area within a buffer of 4–8 km was deemed marginally suitable, and the area beyond an 8 km buffer was deemed not potential for ecotourism development. Sites close to major roads (within 0–7 km) are considered highly suitable due to easier transportation access for tourists (Yasin & Woldemariam, 2023; Islam *et al.*, 2022).

2.1.2 Proximity to Rivers and Water Bodies: Water bodies not only enhance the scenic value of a location but also support various recreational activities such as swimming, boating, and fishing. Areas within 0–3 km of rivers were deemed highly suitable (Bunruamkaew & Murayama, 2012). According to Ambecha *et al.* (2020), water bodies support a wide range of flora and fauna and are important to ecological function. Rivers are a vital resource for the growth of ecotourism (Aiping *et al.*, 2015; Goharipour & Hajiluie, 2016). River proximity was assessed using a Multiple-ring Buffer ArcGIS analysis within varying kilometers of natural attraction locations. Suryabhagavan in 2015 determined that areas close to buffers of 0–5 km were highly suitable, buffers of 5–8 km were moderately suitable, buffers of 8–12 km were marginally suitable, and buffers of >12 km were not suitable for the development of ecotourism.

2.1.3 Proximity to Cultural and Historical Sites: Historical monasteries, palaces, historic structures, bridges, museums, venues for cultural celebrations, and other cultural assets are all considered tourist destinations (Achamyeleh, 2020). Sites near cultural landmarks or historical monuments are attractive to tourists interested in heritage tourism. For ecotourism, proximity to historical and cultural landmarks within a range of 0–15 km was considered highly suitable, 15–30 km as moderately suitable, 30–45 km as marginally suitable, and > 45 km as not suitable (Sahani, 2019; Bunruamkaew & Murayama, 2012).

2.1.4 Proximity to Towns: Accessibility to services, infrastructure, and local communities is an important factor. The proximity of a place to a town plays a significant role in determining whether or not it is suitable for the development of ecotourism. Because of their proximity to towns, investors and entrepreneurs can take advantage of the labor markets, infrastructure, and services already in place, supporting sustainable ecotourism missions (Ullah and Hafiz, 2014) . Being close to towns also helps local economies by encouraging local entrepreneurship, job creation, and an increase in demand for goods and services made locally (Komppula 2014). Sites within 10 km of towns are favored due to the availability of accommodations, health facilities, and other amenities (Abrehe *et al.*, 2021).

2.2 Landscape and Naturalness

2.2.1 Land Use and Land Cover (LULC): Natural landscapes such as forests, water bodies, and grasslands are ideal for ecotourism due to their ecological value and attractiveness. Ambecha *et al.* (2020) classified wooded grassland, built-upland, and water bodies as moderately suitable, while woodland, bush land, and water bodies were classified as highly suitable. Additionally, developed land and bare land were deemed unsuitable for the development of ecotourism, while farmed land was designated as marginally suitable. Areas with minimal urbanization, such as forests or lakes are generally preferred by tourists.

2.2.2 Scenic Value and Visibility (Viewshed Analysis): Aesthetic landscapes, such as mountains or panoramic views, play a crucial role in attracting tourists. According to Chettri *et al.* (2008), areas with panoramic views, such as mountains, ridgelines, and valleys, are especially valuable in ecotourism because of their ability to provide immersive natural experiences. The study also noted that visibility, as measured by viewshed analysis, is an important determinant of site suitability, as higher visibility is frequently associated with increased tourist interest and satisfaction. In a similar vein, Bunruamkaew and Murayama (2012) used viewshed analysis to evaluate the scenic potential of ecotourism destinations in Surat Thani, Thailand. They concluded that areas with high visibility, such as hilltops or open landscapes, were ideal locations for ecotourism development. These areas offer not only breathtaking views, but also opportunities for tourists to participate in environmentally friendly activities such as wildlife watching and landscape photography. Mansour *et al.* (2020) conducted a similar study on Masirah Island, Oman, using viewshed analysis to assess the scenic potential of different landscapes. Their findings showed that locations with unobstructed views of the ocean or dramatic landscapes were deemed highly suitable for ecotourism due to their visual appeal and potential for sustainable tourism activities such as bird watching and nature trails. The study also found that regions with less visible, urbanized landscapes were less appealing for ecotourism, emphasizing the importance of untouched natural areas.

2.3 Topography

2.3.1 Elevation: Elevation plays a pivotal role in determining the suitability of sites for ecotourism, as it directly influences climatic conditions, biodiversity, and scenic appeal. Studies consistently highlight moderate to high elevations as highly suitable for ecotourism development. For instance, Mehiret Geremew & Yohannes Hailemeriam, (2015)found elevations between 1,948 and 3,388 meters in the East Hararghe Zone, Ethiopia, to be ideal due to their cooler climates, rich biodiversity, and scenic vistas. Similarly, Ambecha *et al.* (2020) emphasized the ecological value of high-altitude areas in the Andiracha District, Ethiopia, noting their role in supporting lush vegetation and unique ecosystems. Research by Bunruamkaew and Murayama (2012) in Surat Thani, Thailand, revealed that moderate elevations were preferred for their favorable temperatures and reduced environmental risks, while Mansour *et al*. (2020) identified mid-elevation areas on Masirah Island, Oman, as stable and visually appealing, making them optimal for tourism. Chettri *et al*. (2008) highlighted the biodiversity and unique landscapes of protected areas in the moderate to high elevations of the Hindu Kush-Himalayas as key attractions. Conversely, Yasin and Woldemariam (2023) classified elevations of 2,000 to 3,500 meters as most suitable in East Hararghe Zone, Ethiopia, while noting accessibility challenges at higher altitudes. Overall, elevations between 1,500 and 3,500 meters emerge as the most favorable for ecotourism, balancing accessibility, ecological significance, and visitor comfort. Moderate to high elevations are desirable for ecotourism due to their cooler climates, scenic vistas, and biodiversity.

2.3.2 Slope: The slope of the terrain affects the ease of access and the potential environmental impact of ecotourism activities. The suitability of slopes for ecotourism development has been extensively analyzed by various researchers, highlighting the importance of topography in site selection. Gentle slopes (0–5°) are widely considered highly suitable due to their ease of access, reduced construction costs, and minimal environmental risks. Studies by Bunruamkaew and Murayama (2012) and Geremew and Hailemeriam (2018) emphasize that such slopes are ideal for activities like hiking and nature walks, contributing to visitor safety and ecological sustainability. Similarly, Islam *et al*. (2022) found that gentle slopes enhance the aesthetic appeal of landscapes while facilitating the development of eco-friendly infrastructure. Moderate slopes (6–15°) are classified as moderately suitable. While they present challenges such as increased erosion risk and construction difficulties, these slopes can still support ecotourism if appropriate measures, like erosion control and strategic planning, are implemented. Geremew and Hailemeriam (2018) noted that slopes in this range are often preferred in forested areas with natural attractions. Moreover, Mansour *et al*. (2020) highlighted the potential of moderate slopes for adventure-based ecotourism activities, such as zip-lining or canopy walks, where minimal alterations are required.

2.4 Wildlife and Protected Areas

2.4.1 Presence of Wildlife: Protected areas like national parks and wildlife sanctuaries are often highly rated due to their biodiversity. The presence of wildlife is a pivotal factor in ecotourism, as it significantly enhances the appeal of natural sites and supports biodiversity conservation. Numerous researchers have emphasized the role of diverse fauna in attracting ecotourists, particularly in areas with unique or endangered species. Yasin & Woldemariam, (2023) highlighted that regions rich in wildlife are highly suitable for ecotourism due to their ability to offer immersive experiences such as safaris, bird watching, and photography, contributing to conservation funding through tourism revenue. Additionally, Goharipour & Hajiluie, (2016) observed that riverine ecosystems with rich wildlife diversity, such as fish and bird species, offer excellent opportunities for sustainable ecotourism when managed effectively. Sahani, (2019)noted that excessive human activity in wildlife habitats could lead to disturbances, emphasizing the need for low-impact tourism practices. Mansour *et al*., (2020) recommended zoning strategies and visitor management plans to ensure that tourism activities do not compromise the ecological integrity of these areas.

2.4.2 Proximity to Protected Areas: Protected areas like national parks, wildlife sanctuaries, and nature reserves frequently have unique biodiversity and pristine ecosystems, making them ideal for nature-based tourism. Numerous researchers have emphasized the significance of proximity to these areas, as it increases the possibility of wildlife observation, biodiversity conservation, and environmentally friendly recreational activities. Bunruamkaew and Murayama (2012) stated that areas within a 0-5 km radius of protected areas are ideal for ecotourism due to their abundance of natural attractions and ease of access for tourists. Similarly, Ambecha *et al*. (2020) found that regions near protected zones have diverse flora and fauna, which is consistent with ecotourism principles. Yasin and Woldemariam (2023) discovered that ecotourism potential decreases significantly as distance from protected areas increases, with areas greater than 15 km deemed unsuitable for effective tourism development due to reduced access to natural habitats.

2.5. Geology

2.5.1 Proximity to Fault Lines: Geologically stable areas are safer for ecotourism development. The proximity to fault lines is an important factor in determining a site's suitability for ecotourism development because geological stability has a direct impact on safety and sustainability. Areas near active fault lines are generally regarded as unsuitable due to the risk of earthquakes and other seismic activity, which could endanger tourists and infrastructure. Mansour *et al*. (2020) investigated Masirah Island, Oman, and concluded that locations within a 6-kilometer radius of fault lines were unsuitable for ecotourism. Geological stability is also necessary for the construction of environmentally friendly infrastructure. Islam *et al*. (2022) found that choosing sites away from fault lines not only reduces the risks associated with seismic activities, but also ensures the long-term viability of tourism activities.

2.6 Climate

2.6.1 Rainfall: Rainfall is an important factor in determining a site's suitability for ecotourism development because it has a direct impact on the local climate, vegetation, biodiversity, and overall aesthetic appeal of the destination. Adequate rainfall promotes lush vegetation, diverse ecosystems, and visually appealing landscapes, all of which are popular among ecotourists. Several studies have looked into the effect of rainfall on ecotourism site suitability, with different outcomes depending on the region and specific ecological characteristics. Ambecha *et al*. (2020) discovered that regions with annual rainfall between 1,071 mm and 1,273 mm are ideal for ecotourism because this range promotes the growth of diverse vegetation and wildlife. Mehiret Geremew and Yohannes Hailemeriam (2015) identified areas with rainfall ranging from 1,000 to 1,500 mm as ideal for supporting diverse ecosystems, which are necessary for ecotourism activities such as bird watching, hiking, and nature tours. Furthermore, Suryabhagavan (2015) observed that areas with irregular rainfall patterns or extreme climatic conditions, such as arid regions or areas with high seasonal variation, may be unsuitable for ecotourism.

2.6.2 Temperature: Temperature is an important factor in determining ecotourism site suitability. Moderate temperatures are generally beneficial to both the environment and visitor comfort, promoting biodiversity and improving ecotourism opportunities. Extreme temperatures, whether too high or too low, can limit the scope of ecotourism activities and present new challenges for sustainable tourism management. Temperature should thus be a key consideration in ecotourism site planning and development, with a focus on developing resilient, adaptable strategies for sites in both tropical and temperate climates. Moderate temperatures, typically ranging from 10°C to 14°C, are considered ideal for most ecotourism activities because they provide a comfortable climate for visitors while also protecting the health of local flora and fauna. High temperatures (over 23°C) are generally less suitable for ecotourism, especially in tropical climates (Bunruamkaew & Murayama, 2012). Studies by Ambecha *et al*. (2020) and Islam *et al*. (2022) support this view, indicating that areas with temperatures between 15°C and 20°C tend to attract more ecotourism activities because they foster biodiversity, promote sustainable visitation, and offer pleasant conditions for a range of eco-friendly activities.

2.7 Socioeconomic Factors

2.7.1 Community Involvement: Community involvement is critical to the success and sustainability of ecotourism initiatives, as it promotes local empowerment, economic benefits, and long-term environmental stewardship. According to Scheyvens (1999), community-based ecotourism not only provides economic opportunities for local communities, but it also encourages them to play an active role in the preservation of their natural and cultural heritage. This involvement promotes a sense of ownership, which is critical for ensuring long-term resource management. Similarly, Syraji *et al*. (2017) discovered that ecotourism projects that actively involve local communities in decision-making processes have higher success rates, as community members are more likely to maintain and protect resources when they have a stake in the benefits.

2.7.2 Economic Viability: Assessing the economic potential of ecotourism sites is critical for ensuring long-term financial sustainability. According to Abrehe *et al*. (2021), economic viability is frequently measured by the potential for revenue generation from tourism-related activities such as lodging, guided tours, handicrafts, and local services. They argue that ecotourism should not only generate financial returns but also ensure an equitable distribution of benefits to local communities, thereby reducing poverty and fostering sustainable development. Komppula (2014) adds to this perspective, stating that the economic benefits of ecotourism must be carefully balanced with environmental conservation. She discovered that regions with well-developed infrastructure, such as transportation, medical facilities, and hospitality services, attract more visitors, resulting in better economic outcomes. Similarly, Mthembu and Mutambara (2018) discovered that ecotourism initiatives benefitted rural communities in Kwa-Zulu Natal, South Africa, with job creation and increased local entrepreneurship playing critical roles in the region's success. They stress the importance of integrating local businesses into the tourism value chain in order to maximize economic viability.

3. Models for Assessing Ecotourism Site Suitability

Several models are used to analyze site suitability parameters of ecosystems, especially in the context of ecotourism, land-use planning, and conservation efforts. These models integrate various environmental, socioeconomic, and spatial data to assess the appropriateness of specific areas for development or conservation. Below are some common models and techniques used in site suitability analysis for ecosystems:

3.1 Geographical Information Systems (GIS)

3.1.1 GIS-based Analysis: GIS is one of the most widely used tools for site suitability analysis. It allows for the integration, analysis, and visualization of spatial data related to various site suitability parameters such as elevation, land use, proximity to roads, water bodies, and protected areas. GIS helps in overlaying multiple thematic maps to identify suitable areas for ecotourism, conservation, or other land uses.

3.1.2 Suitability Index Mapping: GIS-based suitability index mapping involves combining various criteria (e.g., climate, topography, wildlife, accessibility) into a single index to visualize suitability levels. It is commonly used in landscape and conservation planning (Yasin & Woldemariam, 2023; Bunruamkaew & Murayama, 2012).

3.2 Multi-Criteria Decision-Making (MCDM)

3.2.1 Analytic Hierarchy Process (AHP): AHP is a popular MCDM method that helps prioritize factors based on expert judgment and pairwise comparisons. It is used to assess the relative importance of various site suitability parameters (e.g., climate, slope, biodiversity) and combine them into a weighted score for site selection. AHP is often combined with GIS for spatial decision-making (Saaty, 1980).

3.2.2 Weighted Linear Combination (WLC): WLC is a mathematical method used in conjunction with AHP to combine multiple suitability criteria into a final suitability map. Each criterion is assigned a weight based on its importance, and spatial layers are overlaid and weighted accordingly to produce a composite suitability index.

3.3.3 Fuzzy Logic: Fuzzy logic models handle uncertainty and imprecision in the evaluation of site suitability. These models can be used to assess criteria that cannot be precisely defined, such as the "naturalness" or "aesthetic value" of a landscape, and convert them into numerical values for further analysis (García *et al.*, 2014).

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Ecosystem-based fisheries management for estuarine ecosystems

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Until the early 1980s, limited attention was paid to ecosystem studies related to fisheries. Recently, however, there has been a shift towards understanding the entire ecosystem, rather than focusing solely on isolated components or single-species models. In 1955, at the Nations Technical Conference of the UN on the Conservation of the Living Resources of the Sea, an ecosystem-specific strategy for managing commercial fisheries, known as the "Ecosystem Approach to Fisheries (EAF)", was emphasized. The need for "ecosystem-based fisheries management (EBFM)" was emphasized as a key component of fisheries management in the Code of Conduct for Responsible Fisheries (CCRF) established by the Food and Agriculture Organization (FAO) of the UN (FAO, 2003).

The pedigree of EBFM can be traced back to the middle phase of the 20th century, when ecological research translated into the recognition of ecosystems as interconnected or mixed systems. Pioneering works by scientists such as ***Eugene Odum*** have emphasized the interdependence of species, habitats, and abiotic factors, laying the groundwork for a holistic approach to ecosystem thinking. During the 1970s and the 1980s, overfishing and environmental degradation highlighted the limitations of single-species management approaches, which often overlooked trophic relationships and habitat dependence. This phase witnessed the development of multi-species and ecosystem modeling tools, which underscored the need for more comprehensive management frameworks. A key milestone occurred in Rio de Janeiro in 1992, during the Earth Summit, when the Convention on Biological Diversity (CBD) formally endorsed the ecosystem approach, paving the way for its integration into fisheries management. Subsequently, organizations such as the FAO and ICES began incorporating ecosystem considerations into fisheries management guidelines.In 2001, under the Reykjavik Declaration, 57 countries committed to adopting and integrating an ecosystem-based approach into fisheries management. Today, EBFM stands as a cornerstone of sustainable fisheries management, further bolstered by advancements in technology, including remote sensing, genetic tools, and sophisticated ecosystem modeling (FAO, 2003).

Introduction

Estuaries, buffer zones where rivers meet the marine environment, are among the most biologically productive environments on Earth (Sreekanth et al. 2020). These ecosystems provide essential habitats for diverse fauna and flora species that are both commercially and ecologically significant. However, the dynamic nature of estuaries, coupled with anthropogenic pressures, presents significant challenges for their effective management (Kiranya et al. 2022). It can be seen that EBFM is ideal for the estuaries which are haphazardly impacted by extensive anthropogenic stresses from the very beginning. Ecosystem modeling serves as a substitute for investigational tools that forecast ecosystem dynamics and uncover complex ecosystem characteristics. This approach supports fishery managers and researchers in evaluating the impacts of anthropogenic pressures on ecosystems (Heymans et al. 2016). The EBFM offers a comprehensive framework to address these challenges by considering the ecological, social, and economic dimensions of fishery governance.

Recent advancements in the development of ecosystem models for aquatic environments have made it possible to create them more efficiently and accurately while also enhancing their predictive capabilities (Christensen and Pauly 1993). Ecopath with Ecosim (EwE) is a mass-balance modelling tool for creating ecosystem models and unraveling trophic organization (Polovian 1984; Christensen et al. 2008). This modelling approach enables the examination of exploited aquatic systems by incorporating the trophic spectrum, from primary producer groups, small benthic groups, and primary consumers to top predators. It offers valuable insights into ecosystem dynamics and how they react to anthropogenic pressures over time (Christensen and Walters 2004). The development of ecosystem models is primarily based on the biomass of groups, diet matrix, consumption rates, and mortality rates in an ecosystem (Tajzadeh-Namin et al. 2020).

This brief chapter documents the concepts, characteristics, and challenges of applying ecosystem modeling tools used in estuaries.

Characteristics of EBFM

1. **Holistic approach:** EBFM takes a holistic approach by addressing the entire ecosystem rather than focusing solely on a single species.
2. **Integration of socio-ecological systems**: This combines ecological sustainability and human benefits, balancing habitat conservation goals with socio-economic interests.
3. **Adaptive approach**: It utilizes a flexible approach, updating strategies based on ongoing monitoring and scientific research to respond effectively to environmental dynamics.
4. **Ecosystem services**: EBFM decisions explicitly account for a wide range of ecosystem services, such as food, water filtration, carbon storage, and cultural values.
5. **Participatory approach**: It prioritizes the participation of fishers, indigenous groups, policymakers, and other local stakeholders, fostering shared governance and benefits.

Ecosystem modelling tools

The transition in resource management in fisheries from a single-species research to an ecosystem-based context necessitates tools that explicitly consider trophic interactions, specifically pre-predator relationships (Heymans et al. 2016). Modelling is a scientific method in translating the ecosystem approaches for fishery management where '*Models*' are mathematical abstractions of non-mathematical processes with the basic characteristics.A model can analyze the factors influencing primary productivity and how changes impact the interactions among all ecosystem components. It can also aid in evaluating trade-offs between harvesting fish species from various trophic levels (Christensen and Pauly 1993).

Ecopath with Ecosim (EwE)

The EwE model utilizes a defined set of linear equations to quantify energy transfer within an ecosystem, providing a "snapshot of its trophic functioning" (Christensen and Walters, 2004). The Ecopath model sits on top of the two master equations: production and consumption.

Production = catches + predation mortality + biomass accumulation + net migration + other mortality....................................(Eqn. 1)

Consumption = production + respiration + unassimilated food....................(Eqn. 2)

The basic task of the modelling approach is to find solutions for keeping the stock biomass for all ecological groups above the threshold biomass level, which would sustain the ecology of the ecosystem (Fig. 1).

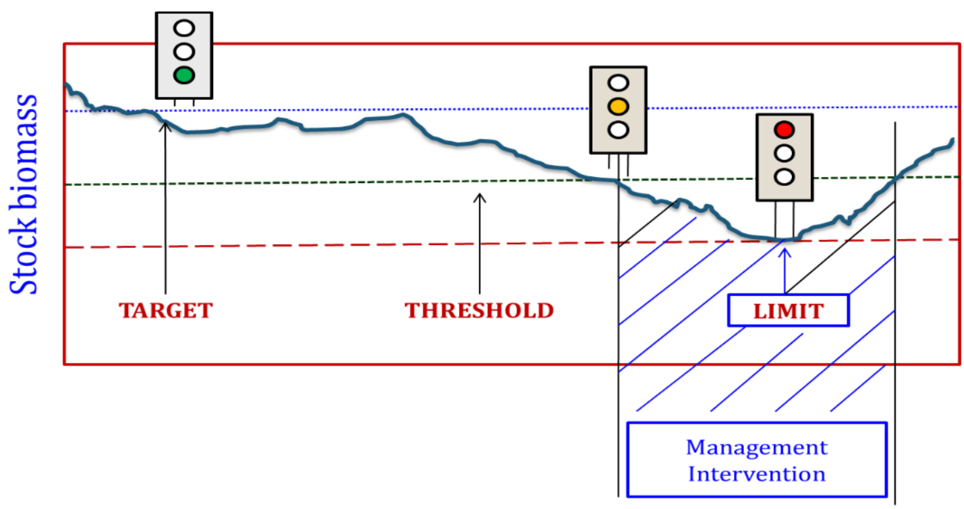

Fig. 1 The classical diagram representing the target, threshold and limit reference points for the stock biomass for ecological groups in an ecosystem

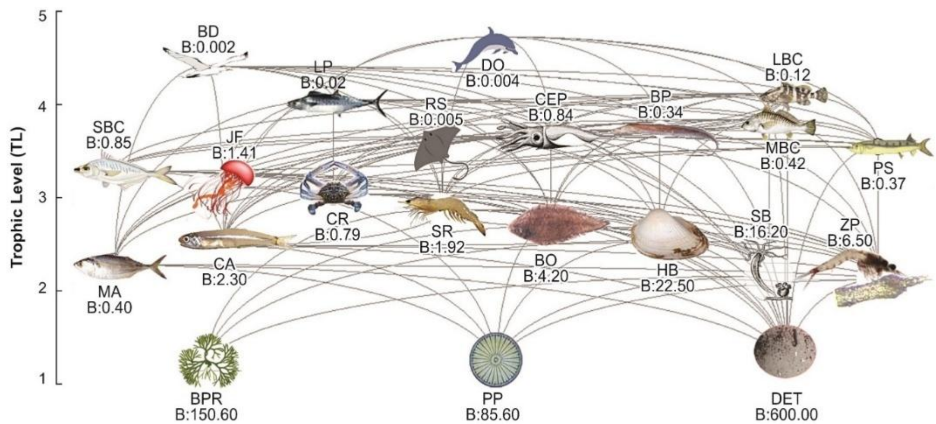

Fig. 2. A model trophic network diagram of an estuarine food web ('B' - biomass (t km^{-2} $year^{-1}$) (adapted from Zuari estuary, west coast of India, Sreekanth et al. 2020).

Attempts on ecosystem modelling in estuaries around the globe

Numerous studies have been carried out in estuaries worldwide using the Ecopath approach to provide a comprehensive picture of ecosystem properties and food web characteristics (Fig. 2). The increasing number of research efforts to develop Ecopath models is expected to strengthen our understanding of ecosystem properties and implement management and conservation priorities (Lira et al. 2018). Ecosystem models based on the Ecopath approach are widely used worldwide as efficient methods for systematically addressing ecosystems and their properties (Table 1).

Table. 1 Attempts on ecosystem modelling in various estuaries around the world

Study area	**Region**	**References**
Caete estuary	Brazil	Wolff et al. (2000)
Danshuei estuary	Taiwan	Lin et al. (2007)
Seine estuary	France	Rybarczyk and Elkaïm (2003)
Weeks Bay	North America	Althauser, L.L (2003)
Mondego estuary	Portugal	Patrı´cio et al. (2006)
Gironde estuary	France	Lobry et al. (2008)
Pearl River estuary	China	Duan et al. (2009)

Canche estuary	France	Selleslagh et al. (2012)
Yangtze estuary	China	Yu-Fang et al. (2014)
Cameroon estuary	Africa	Simon and Raffaelli (2015)
Senegal estuary	Africa	Colleter et al. (2015)
Río de la Plata estuary	South America	Lercari et al. (2015)
Ogun estuary	Nigeria	Abdul and Adekoya (2016)
Sirinhaém estuary	Brazil	Lira et al. (2018)
Yangtze estuary	China	Xu et al. (2018)
Eden estuary	Brazil	Watson et al. (2020)

Attempts on Ecosystem modelling in India

Aravindan (1993) pioneered the application of the Ecopath model in India with his study of Veli Lake in Kerala. In India, ecosystem models have been applied to aquatic systems such as estuaries, lagoons, lakes, and reservoirs to study ecosystem functioning, food web dynamics, and fishery productivity using spatial simulations to detect variations (see Table. 2).

Table 2. Summary of published studies on ecosystem modelling in various aquatic ecosystems of India

Type of ecosystem	Study area	References
Lake	Veli lake, Kerala	Aravindan (1993)
Open sea	Karnataka	Mohamed et al. (2008)
Reservoir	Wyra, Karnataka	Panikkar and Khan (2008)
Reservoir	Kelavarapalli, Karnataka	Feroz Khan and Panikkar (2009)
Open sea	Bay of Bengal	Ullahet al. (2012)
Estuary	Vellar, Tamilnadu	Murugan (2014)
Reservoir	Hemavathy Reservoir, Karnataka	Khan et al. (2015)
Lake	Vellayani, Kerala	Bijukumar et al. (2015)
Estuary	Sundarban, West Bengal	Dutta et al. (2017)
Estuary	Hooghly-Matla, West Bengal	Mukherjee et al. (2019)
Estuary	Hooghly-Matla, West Bengal	Rakshit et al. (2017)
Lake	Shasthamkotta Lake, Kerala	Regi et al. (2020)

Lake	Chilka lake, Odisha	Behera et al. (202)
Estuary	Zuari estuary, Goa	Sreekanth et al. (2020)
Estuary	Terekhol, Goa	Bhavan et al. (2021)
Estuary	Mandovi, Goa	Sreekanth et al. (2021)
Estuary	Ulhas, Maharashtra	Lal et al. (2021)
Estuary	Poonthura, Kerala	Kiranya et al. 2023

ECOSIM- the simulation module

ECOSIM is a widely used ecological modelling tool, an extension of Ecopath, designed to simulate and assess the dynamics of ecosystems, particularly in relation to fisheries management. It is part of the broader ecosystem modeling approach, which seeks to unravel the complex dynamics between species, their habitats, and the ecosystem. These models are specifically used to explore how ecological and economic factors influence the trophic functioning of ecosystems over time. It is a dynamic simulation model for each functional group of an ecosystem, and depends on the input derived from ECOPATH (Walters et. al. 1997). Time dynamic simulations are influenced by temporal trends related to fishing or environmental factors, helping to identify the strength of prey-predator relationships and the impact of other environmental factors.

The ECOSIM serves as a critical tool for understanding and managing complex ecosystems, offering valuable support for sustainable fisheries management, conservation, and ecosystem restoration. The main characteristics of EcoSim are as follows:

Multi-species modeling: This tool is created to model the interactions among various species, such as predator-prey dynamics, resource competition, and the impact of fishing on different species. Unlike traditional single-species models, which concentrate on individual species and often ignore wider ecological contexts, EcoSim takes a more comprehensive approach.

Environmental and anthropogenic factors: The model considers not only biological factors but also environmental variables, including temperature, nutrient availability, and habitat conditions, as well as human-driven impacts, such as fishing pressure, pollution, and habitat degradation. These elements allow the prediction of how ecosystems may react to different management strategies or environmental changes.

Sustainability and management Scenarios: By modelling various scenarios (e.g., fishing regulations, habitat restoration, and climate change), the tool can help decision-makers understand potential outcomes and make informed choices about how to manage both fisheries and ecosystems in a sustainable manner.

ECOSPACE: Ecospace is a spatially dynamic, mesoscale version of Ecopath, which is also the simulation tool ECOSIM (Walters et al., 2000). This spatial-scale module provides temporal trends in functional group biomass and fishing patterns. It predicts the spatiotemporal distribution of groups, including biomass, catch, fishing mortality, habitat preference scales, and predation. This module examines how fish-protected areas (FPAs) and marine-protected areas (MPAs) can serve as tools to mitigate and potentially minimize the ecological impacts of fishing (Fig. 3).

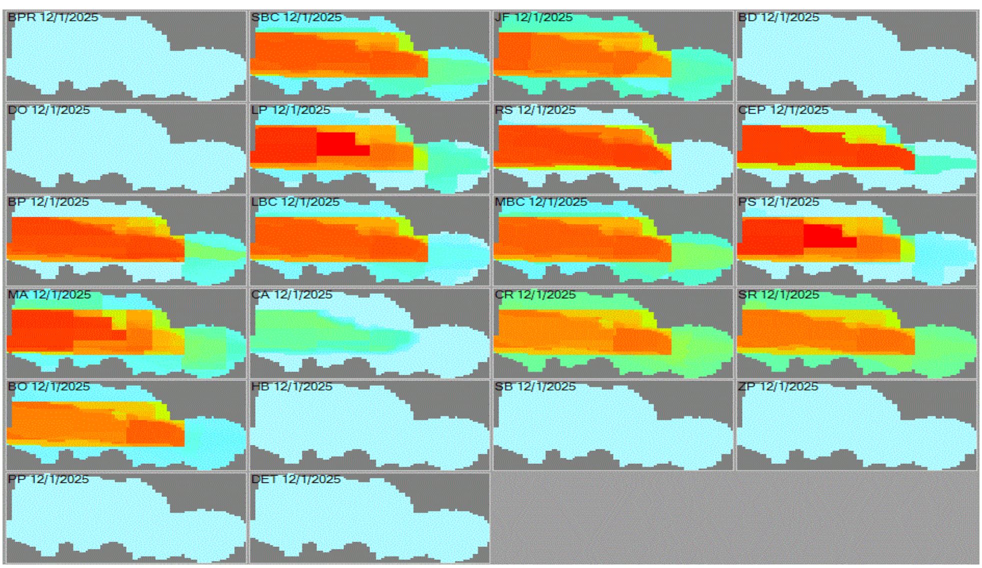

Fig. 3. Ecosystem model simulation in Ecospace showing the spatial fish harvest patterns (relative) for various fished ecological groups in an estuarine ecosystem.

ECORANGER

ECORANGER is a sophisticated ecological modeling tool designed to simulate and analyze interactions within ecosystems. This study aims to understand how various environmental and biological factors influence ecosystem health and stability. The tool integrates components such as species populations, habitat types, and the effects of human activities, including pollution and land-use changes. This module allows users to visualize and predict ecosystem responses to different scenarios such as climate change, conservation strategies, and resource management practices. modelling these interactions over time aids in identifying the most effective measures for preserving biodiversity, reducing environmental degradation, and ensuring the long-term sustainability of fishery resources. The flexibility of the module allows it to be applied across different ecosystems, whether terrestrial, marine, or freshwater, thus making it a versatile tool for global environmental studies. Combining cutting-edge simulation technology with ecological principles contributes significantly to the field of environmental management and conservation.

ECOTRACER

ECOTRACER is a powerful tool for tracking and analyzing intricate interactions within ecosystems. By utilizing Ecopath mass balance models, researchers and policymakers can gain a deeper understanding of ecosystem functionality, predict potential changes under various scenarios, and support sustainable environmental management. The insights provided by the module are essential for maintaining ecological balance and addressing global challenges, such as climate change, overfishing, and habitat degradation (Walters and Christensen, 2018).

Advantages of EBFM

The EBFM offers numerous advantages that enhance the sustainability and resilience of estuarine ecosystems. First, it prioritizes ecosystem health, ensuring that fisheries do not degrade the broader ecological functions that support biodiversity and productivity (Marshall et al. 2018). By maintaining habitat integrity and promoting species diversity, the EBFM contributes to the long-term sustainability of fish populations and the resulting resilience of food webs. The EBFM fosters adaptive management, which is particularly valuable in dynamic and unpredictable estuarine environments. By integrating continuous monitoring and feedback mechanisms, managers can respond effectively to emerging challenges such as climate-induced shifts in species distributions or sudden changes in water quality (Brodziak and Link, 2002).

The EBFM promotes stakeholder participation and enhances the legitimacy and effectiveness of management measures. Involving fishers, local communities, and other stakeholders in decision-making not only builds trust but also leverages diverse knowledge systems. This inclusivity often results in higher compliance with regulations and innovative solutions to complex problems (Marshall et al. 2018). It aligns ecological goals with socioeconomic benefits, recognizing that healthy ecosystems underpin sustainable livelihoods (Brodziak and Link, 2002). Restoring habitats such as oyster reefs or mangroves can enhance fisheries production while providing additional benefits such as coastal protection and carbon sequestration. The EBFM encourages integrated approaches that address the cumulative impacts and cross-sectoral conflicts. By considering upstream activities, land-use changes, and climate dynamics, the EBFM offers a holistic framework for managing estuarine ecosystems in the face of complex interrelated pressures.

Challenges and Future Directions

Despite its potential, implementing EBFM in estuarine ecosystems faces several challenges:

Complexity and uncertainty: Estuarine systems are highly dynamic, which makes it difficult to predict responses to management actions.

Conflicts and social barriers: Balancing interests requires effective communication and conflict resolution mechanisms.

Limited resources: Monitoring and enforcement require significant financial and human resources that may be limited to some regions.

Ecosystem-Based Fisheries Management represents a transformative approach for managing estuarine ecosystems, addressing the interconnected challenges of conservation, fisheries sustainability, and climate resilience. By integrating ecological principles, stakeholder engagement, and adaptive strategies, the EBFM offers a pathway to ensure the long-term health and productivity of these vital ecosystems. However, realizing its full potential requires overcoming significant challenges through collaboration, innovation, and sustained commitments.

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Ornamental Fisheries in Agro-Ecotourism: Unlocking Opportunities for Sustainable Livelihoods and Ecological Harmony

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Introduction

Agroecotourism is an innovative approach that integrates agricultural practices with tourism, offering a unique opportunity for visitors to engage with rural culture and the agrarian landscape. This form of tourism allows tourists to experience farmers' daily lives and promotes educational experiences related to agricultural production, local goods, and traditional food. By fostering a connection between urban dwellers and rural environments, agro-ecotourism is a vital livelihood strategy that enhances the economic viability of small farms and rural communities. It encompasses a range of activities, from direct sales of farm products to interactive experiences, such as farm tours and participation in agricultural operations, thereby creating additional revenue streams for farmers while promoting environmental sustainability and community development (Kumar et al., 2021). This approach to rural economic diversification is prevalent in various countries, including South Africa, Uganda, and Botswana, and has seen significant growth across Asia, Europe, and North America (Djuwendah et al., 2023). Additionally, agro-ecotourism is a promising platform for promoting ornamental fisheries.

Ornamental fishkeeping is popular worldwide and offers aesthetic pleasure and financial benefits. It involves rearing colorful and attractive fish in confined aquatic systems, such as aquariums or garden pools, primarily for enjoyment and decoration (Jayasankar, 1998). More than 30,000 fish species have been reported worldwide, of which approximately 800 are ornamental fish (Panchani, 2020). The ornamental fish trade has become a billion-dollar industry, with an estimated 1.5 billion ornamental fish traded each year (Biondo and Burki,

2019) globally. The global ornamental fish market has seen significant growth in recent years, with the market size reaching USD 5.42 billion in 2019 and USD 5.95 billion in 2022. Projections indicate further expansion, with an estimated market value of USD 11.68 billion by 2031, representing a compound annual growth rate (CAGR) of 8.5% during the forecast period of 2024-2031. The market spans North America, Europe, the Asia-Pacific region, South America, the Middle East, Africa, and other regions (Tandel et al., 2024). The top exporting country is Singapore, followed by Hong Kong, Malaysia, Thailand, Philippines, Sri Lanka, Taiwan, Indonesia, and India. The USA is the largest importer of ornamental fish, followed by Europe and Japan. The emerging markets are China, South Africa, and the Gulf countries. Integrating ornamental fisheries within agro-ecotourism initiatives can unlock multiple benefits from economic empowerment to ecological sustainability (Swain et al., 2020). In the agro–ecotourism industry, the major ornamental fishery components are fishing, aquatourism, fish pedicure, display aquariums, and scuba diving. A conceptual framework of the fisheries and aquatic components is presented in **Fig. 1.**

Fig. 1. Fisheries and Ecotourism

The Ornamental Fish Industry in India

India has an exceptional biological diversity, encompassing a variety of natural and cultural habitats. The economy and livelihoods of millions rely heavily on the conservation and sustainable utilization of these biological resources

(MoEF&CC and UNDP, 2022). This nation possesses an impressive array of freshwater and marine ornamental fish species, many of which are endemic. India is rich in freshwater ornamental fish species, particularly in the northeastern hills and the Western Ghats. The Western Ghats alone are home to 155 ornamental species, of which 117 are endemic. However, only a small fraction of the endemic fish diversity is utilized in the ornamental fish trade, with most of the market being dominated by exotic species. India possesses rich marine ornamental fishes in lagoons and coral reefs, with approximately 300 species in the Lakshadweep Islands, 150 in the Andaman and Nicobar Islands, and 113 in the Gulf of Mannar and Palk Bay. India's ornamental fishery resources and territories are greater than those of Sri Lanka, Africa, Singapore, Malaysia, and the Maldive. India has a vast coastline of 7,516 km, with approximately 400 species of ornamental fishes belonging to 175 genera from under 50 reef families occurring in the Indian seas (Ramachandran, 2001).

Ornamental fish are becoming an increasingly valuable component of India's aquaculture industry. Kolkata is leading in distribution and exports, and its adjoining districts have become major ornamental fish-producing zones in India. Approximately 90% of Indian exports go from Kolkata, 8% from Mumbai, and 2% from Chennai (Panchani, 2020). Tamil Nadu is the second-largest producer, with significant hubs in Kolathur village, near Chennai and Madurai. Kerala is an emerging player in ornamental fish culture, with production units at Thiruvananthapuram, Ernakulam, Thrissur, Alappuzha, and Kottayam. The structure of the ornamental fish trade in India is summarized in **Fig. 2.**

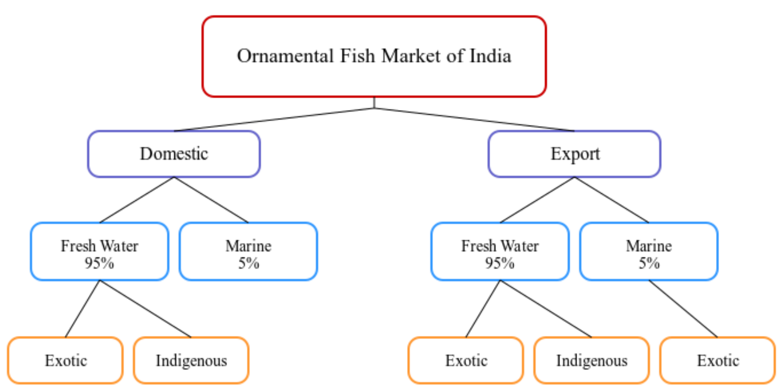


Fig. 2. Ornamental Fish Market of India

Despite its potential, this industry remains underutilized in India. India's contribution to the international ornamental fish trade is negligible standing at 1.6 million US$ ranking 31st in the world (Raja et al., 2019). Challenges such as inadequate infrastructure, lack of skilled human resources, limited market access, lack of latest techniques in packaging technology, lack of techniques in intensive farming, lack of quality brooders, lack of species-specific feeds, and restrictions and lack of incentives in the marketing of marine fish and invertebrates hinder their growth (Satam et al., 2018; Raja et al., 2019). However, integrating this industry into agro-ecotourism frameworks can address these barriers while creating new opportunities for rural and peri-urban communities. Ornamental fish culture can be undertaken on both large and small scales, thus offering opportunities for small entrepreneurs. Local communities can adopt eco-friendly breeding, rearing, and collection techniques, with proper education and technical guidance. This sector can boost foreign exchange, generate employment, and promote self-reliance in rural areas.

Ornamental Fish Biodiversity of India

India, known for its rich biodiversity, boasts of approximately 374 indigenous freshwater ornamental sh species. Among these, 261 were egg-laying species and 27 were live-bearing freshwater exotic fishes. Approximately 90% of India's freshwater ornamental fish exports consists of wild-caught indigenous species (Shraborni et al., 2024). They belonged to eight closely related families: Anabantidae, Callichthyidae, Characidae, Cichlidae, Cobitidae, Cyprinodontidae, Cyprinidae, and Poeciliidae. Examples of commercially important freshwater ornamental fish species include **Goldfish, Gouramis, Siamese fighting fish, Zebra danio, Rosy barb, and Indian garfish,** and some marine ornamental fishes include **Clownfish, Sea angelfish, Scorpionfish,** and **Butterflyfish**. Some of the world's most expensive ornamental fish, such as Bladefin Basslet and Australian Flathead Perch, priced as high as 10,000 USD and 5,000 USD, respectively, are found in India (Raja et al., 2019).

Status of ornamental fisheries agro-ecotourism at the international level:

Globally, ornamental fish-themed attractions offer diverse experiences combining education, recreation, and conservation. These include public ornamental aquariums, ornamental fish-theme parks, fish pedicure spas, and aquarium restaurants. Examples of public ornamental aquariums include the

Dubai Aquarium & Underwater Zoo, UAE, an aquarium located within one of the world's largest shopping malls, the Dubai Mall, and the **Monterey Bay Aquarium,** which offers world-class exhibits and unique oceanfront experiences that attract visitors globally, showcasing over 200 exhibits and 80,000 plants and animals, thereby inspiring love for ocean conservation (Buchanan, 2020). **SEA LIFE Bangkok Ocean World**, Thailand, offers visitors the opportunity to explore an amazing underwater world and come close to various marine creatures such as sharks, turtles, and penguins. It also offers various attractions and activities, including the Seahorse Kingdom, Jellyfish Lab, different feeding shows, and an underwater tunnel (Bangkok, n.d.). The "Endless Ocean Aquarium" at **SeaWorld Abu Dhabi**, a marine life-themed park, features a diverse array of colorful ornamental fish, while the "Tropical Ocean realm" enhances the park's aesthetic and biodiversity with its vibrant species (SeaWorld Yas Island Abu Dhabi, n.d.). The **Sekupang Deer Park**, Indonesia, utilizes koi fish in addition to goldfish, tilapia, catfish, deer, chickens, and pigeons to enhance visitor experiences by offering fish-farming ponds, fishing ponds, jogging track facilities, fountains, and children's playgrounds (Fairuzzabadi et al., 2024). Speaking of koi fish, **Ojiya City**, the birthplace of Japan's legendary koi fish, has developed a vibrant tourism industry centered around its numerous koi farms and specialized tours that offer unique cultural experiences. This thriving market, attracting wealthy buyers, significantly boosts the local economy (hidden Japan, n.d.). Many renowned Japanese shrines and temples in **Kyoto,** such as **Byodo-In Temple**, **Ryoanji Temple**, **Heian Shrine**, **Kinkaku-ji (The Golden Pavilion),** and **Tenryu-ji Temple,** feature serene koi ponds that add aesthetic and meditative qualities to the gardens. Many of these sites also allow visitors to feed on the koi, providing an interactive experience that invites them to pause, reflect, and connect with nature and history (Kodama Koi Farm, n.d.). Ornamental fish spas featuring the unique *Garra rufa* fish offer a delightful and therapeutic experience, in which these tiny fish nibble away dead skin, contributing to the wellness tourism sector by attracting visitors seeking relaxation and novelty. Kangal, a small town in central Turkey, was where the fish spa phenomenon began. **Kangal Hot Springs** are home to thousands of doctor fish, and visitors flock here for a unique experience (FasterCapital 2024).

Fish pedicure

Underwater restaurant

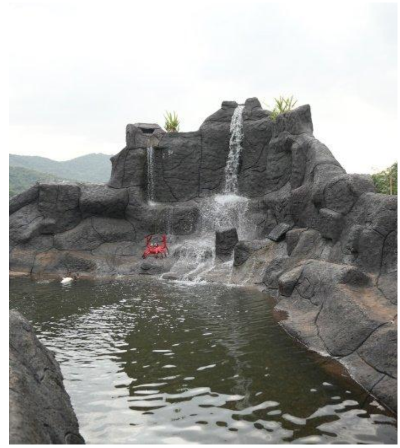
Hidetomo Kimura's Art Aquarium Museum in Tokyo showcases over 30,000 live fish displayed in creatively designed water tanks, transforming them into mesmerizing interactive artworks enhanced by colorful LED lights. This unique approach blends art, design, and nature, highlighting the aesthetic value of fish and celebrating their cultural significance in Japan (Jamal, 2020). **Nishikigoi no Sato (Nishikigoi Village)** is a unique attraction that blends the elements of a museum, aquarium, and Japanese garden, providing a comprehensive experience of Ojiya's koi culture. Visitors can explore informative displays, observe koi in beautifully designed tanks, and enjoy the serene surroundings of the garden, making it a perfect destination for education and art (Michael, 2019). Dining beneath the waves offers a unique experience, especially at restaurants where ornamental fish create a stunning backdrop. **The Ithaa Undersea Restaurant** in the Maldives is renowned for its all-glass design, which allows diners to enjoy panoramic views of vibrant marine life while savoring gourmet dishes. Similarly, **Al Mahara** in Dubai boasts a spectacular floor-to-ceiling aquarium filled with exotic fish, enhancing its luxurious ambiance, as guests indulge in fresh seafood delicacies. The **Aquarium Restaurant in Nashville** uses this concept further with a massive 200,000-gallon aquarium, showcasing over 100 fish species, making it a family friendly destination for dining and entertainment (Kilberg, 2014).

Status of ornamental fisheries agro-ecotourism at the national level:

Ornamental fisheries have immense potential to contribute to agro-ecotourism in India by offering unique models that blend ecological education, sustainable livelihoods, and cultural experiences. For instance, **Galiff Street**

Market, held every Sunday in Kolkata, is a popular destination for pet lovers, offering colorful birds, poultry, white rats, guinea pigs, puppies, rabbits, and ornamental fish. It is the largest wholesale ornamental fish market in eastern and northeastern India (Gupta and Banerjee, 2012). **Kolathur, Tamil Nadu's ornamental fish market**, the second biggest in the country, sells over 1,000 fish types, including Oscars, Gourami, Goldfish, and guppies, with a monthly business of 300 crores in the ornamental fish trade, attracting enthusiasts and traders alike with its new trade center dedicated to enhancing the local ornamental fish market (Omjasvin, 2024). In addition, Kolathur Village is renowned for its traditional breeding techniques, attracting tourists interested in indigenous practices. Fish farms such as **Aqua Pets Ornamental Fish Farm**, Kozhikode, and Kerala allow visitors to experience fish farm activities, rural life, engage in fishing activities, and purchase fish (Kerala tourism, n.d.). **The Fish World Aqua Tourism Village** in Vaikom, Kerala, offers a unique blend of aquatic experiences, including canoeing, butterfly parks, and aquariums featuring ornamental fishes. The village also boasts restaurants with seafood delicacies, pet shops, and various leisure activities. Public ornamental aquariums serve as key attractions, offering education and entertainment by showcasing a diverse aquatic life. **Taraporewala Aquarium**, India's oldest public ornamental aquarium and a major attraction in Mumbai, houses over 2,000 fish, spanning 400 species, and is maintained by the Department of Fisheries. India's Largest Public Aquarium, **Marine World**, Thrissur, Kerala, is home to over 300 species of marine aquatic life, showcasing a stunning variety of marine ecosystems, including artificial rainforests and underwater tunnels. The aquarium offers a fun day out and aims to educate visitors about the importance of ocean conservation and the delicate balance of marine ecosystems (Marine World, n.d.). **Namma Bengaluru Aquarium**, also known as the Government Aquarium or Bangalore Aquarium, is the second-largest aquarium in India. However, fish housed in the aquarium are only freshwater fish, both native and foreign. **The Ganga Aquarium**, located in the lush-green surroundings of the National Bureau of Fish Genetic Resources, Lucknow, U.P, features 42 air-conditioned aquaria with capacities ranging from 800 to 1600 liters, showcasing over 100 fish species from around the world. The **Abyss Marine Aquarium** in Goa is a unique aquarium showcasing over 60 varieties of marine life, including lobsters, starfish, and lionfish, all displayed in impressive aquariums. Located conveniently along the national highway, it offers visitors an interactive experience with safe, open aquariums, where they can engage with the vibrant world of marine creatures. Ornamental fish play a crucial role in supporting scuba diving, snorkeling businesses, and marine tourism by enhancing the allure of underwater ecosystems. **Netrani Island**, off the coast of Karnataka, stands out for its vibrant coral reefs and diverse marine life, including reef sharks and colorful fish. **The Andaman and Nicobar Islands**, particularly **Havelock Island** and **Neil Island**, offer excellent visibility and rich underwater ecosystems, making them prime spots for diving enthusiasts. Additionally, the **Lakshadweep Archipelago** features remote islands adorned with colorful reefs and opportunities to encounter larger marine species. Scuba and snorkeling are prominent tourism industries on the beaches of **Malvan**, Sindhudurg. Ideal for Scuba Diving among corals covering a total area of 29.12 sq.km. and was established in 1987, the **Malvan Marine Sanctuary** is known for its rich marine biodiversity, including corals, mollusks, and pearl oysters (Sindhudurg, Directorate of Tourism Maharashtra, n.d.). The Garra rufa, also known as the 'Nibble fish,' has been identified as a potential candidate species for ecotourism in North-East India (Shil et al., 2021). Its therapeutic use in ornamental fish spas at Tarkarli and Devbag beaches on the Malvan coast offers tourists a unique wellness experience, further enhancing the region's appeal for relaxation and ecotourism. India's first fish theme park, **KSR Global Aquarium**, Sindhudurg, offers a unique and immersive experience where visitors can explore a diverse array of diverse ranges of aquatic life, including various species of fish, colorful birds, reptiles, and other animals. The facility also features engaging activities, such as artificial waterfalls, river crossings, and go-karting, contributing significantly to the district's tourism appeal (KSR Global Aquarium, n.d.). An aquarium accessory store can enhance tourism by providing visitors with the necessary supplies to maintain their aquatic environments, encouraging them to engage more deeply with marine life and conservation. **Utekar Fisheries**, Mumbai, specializes in high-quality aquarium products, offering a wide range of accessories that cater to both novice and experienced aquarium enthusiasts (Utekar Fisheries Pvt Ltd, n.d.).

Fish watching through scuba diving



KSR Global aquarium

Government and Institutional Support

Pradhan Mantri Matsya Sampada Yojana (PMMSY) significantly promotes and develops ornamental fisheries by targeting a substantial investment of ₹576 crores to upgrade the sector and generate 7 lakh employment opportunities. This initiative focused on enhancing ornamental aquaculture through financial support and infrastructure development. By addressing the financial needs of farmers and fostering innovation, the PMMSY aims to expand ornamental fish farming, improve production efficiency, and boost trade value in the sector, ultimately contributing to the economic upliftment of rural communities. **ICAR- Central Institute of Freshwater Aquaculture (CIFA),** Bhubaneswar, plays a key role in promoting and developing ornamental fisheries by advancing captive breeding and culture techniques for indigenous ornamental fish, including barb species from the Western Ghats. The institute provides regular training to stakeholders, develops model ornamental fish-rearing units for demonstration, and offers expert advice for national projects. It introduced India's first improved ornamental fish variety, the 'Shining Barb,' through mass selection technology, which marked a significant milestone in ornamental fish development. **The Central Marine Fisheries Research Institute (CMFRI)** has played a pivotal role in the development of ornamental fisheries by standardizing breeding and seed production techniques for various marine ornamental fish species and supplying fingerlings to farmers. Additionally, the CMFRI has been instrumental in producing the "Varsha" series of ornamental fish feed using commercial extruders, further enhancing the ornamental fish farming industry. Moreover, the institute has successfully bred two clownfish species, Amphiprion perideraion (Pink Skunk clown) and A. clarkii (Clark's anemonefish), in captivity at the Vizhinjam Research Centre, demonstrating their high fecundity and strong demand in the international market (CMFRI, 2012). **National Fisheries Development Board (NFDB)** provided financial assistance for developing ornamental fisheries to establish backyard rearing units, medium-scale rearing units, integrated (breeding cum-rearing) units, aquarium fabrication units, and ornamental fish markets. **Marine Products Export Development Authority (MPEDA)** has played a significant role in developing ornamental fisheries by organizing domestic fairs across the country to highlight the potential of fisheries, aquaculture, and ornamental fish sectors. They have also conducted skill development programs in ornamental fish farming, empowering individuals with necessary expertise. Furthermore, the MPEDA introduced a scheme offering incentives for the export of ornamental fish, promoting sustainable growth in the sector. **ICAR- Central Coastal Agricultural Research Institute (CCARI)** actively works on promoting indigenous ornamental fish species in Goa through research, conservation, and sustainable aquaculture initiatives.

Agro-Ecotourism and Its Synergies with Ornamental Fisheries

The convergence of agro-ecotourism with ornamental fisheries represents an innovative paradigm for sustainable rural development, offering multifaceted benefits for environmental conservation and economic diversification. This integrated approach leverages the inherent complementarity between agricultural landscapes, aquatic ecosystems, and tourism activities, while capitalizing on the growing market for ornamental fish species.

Visitor engagement in such integrated systems extends beyond passive observations. Tourists participate in activities ranging from fish breeding demonstrations to sustainable farming practices to create immersive educational experiences. This experiential learning component has been shown to enhance visitor satisfaction and increase the average length of stay compared with conventional agro-ecotourism destinations.

Benefits of Integration:

- **Economic Diversification and Revenue Enhancement**

  Integrated facilities typically achieve higher profit margins than stand-alone operations. The combination of admission fees, specialized experience, and retail sales creates robust revenue streams while optimizing resource utilization. Premium pricing opportunities emerge through unique experiences such as interactive feeding sessions, breeding demonstrations, and specialized photography tours.

- **Market Innovation and Product Development:**

  The synthesis of tourism using ornamental fisheries drives continuous innovation in experience design and service offerings. Facilities have successfully developed unique products ranging from therapeutic spa treatments to underwater dining experiences, creating additional revenue streams and market differentiation opportunities.

- **Employment Generation and Skill Development**

  Integrated operations create diverse employment opportunities, from technical aquaculture specialists to hospitality service personnel. These facilities generate more employment opportunities than traditional aquaculture operations, providing valuable training in specialized skills.

- **Conservation and Education**

  These integrated systems are powerful platforms for environmental education and species conservation. Visitors are directly exposed to aquatic biodiversity and conservation practices, while facilities often contribute to breeding programs for rare species. This educational component enhances value proposition and contributes to broader conservation objectives.

Case Studies and Success Stories:

Southern India's Ornamental Fish Industry Hub in Kolathur (Parappurathu et al., 2021):

The Kolathur region near Chennai, Tamil Nadu, exemplifies a well-established ornamental fish production and trade ecosystem that demonstrates the economic viability of the integrated ornamental fish enterprises. The area hosts approximately 1,850 production units across three distinct operational scales: hatcheries, small-scale grow-out facilities, and large-scale farms in nearby Athur and Devanpumedu villages. This hierarchical production system generates an estimated 94.95 million ornamental fish annually, valued between ₹47-95 crores in the wholesale market. The industry's structure is particularly noteworthy, with specialized hatcheries in New Lakshmipuram and Vinayagapuram focusing on popular species such as goldfish, guppy, and angel fish, while small-scale units conduct grow-out operations in 20-30 cent plots with sophisticated filtration and aeration systems. Large-scale farms converted from paddy fields and shrimp farms demonstrated successful land-use transformation for ornamental fish production. The region has also fostered the development of ancillary industries, including feed manufacturing, with companies such as Taiyo Feed Mill Pvt. Ltd. achieving significant domestic and international market presence. This integrated approach of combining production, feed manufacturing, and trade networks has established Kolathur as a prominent hub in India's ornamental fish industry, offering valuable insights into similar developments in other regions.

Northeast India's Ornamental Fish Agro-ecotourism Potential (Sharma et al., 2023)

Given its exceptional biodiversity and established ornamental fish industry, the Northeast region of India presents a compelling case study for developing ornamental fish-based tourism initiatives. The region's unique geographical and hydrobiological characteristics have fostered the development of diverse aquatic ecosystems, hosting approximately 422 fish species, of which 250 possess ornamental value. The wetlands, lakes, and hill streams of the region create distinct microhabitats that support a remarkable variety of aesthetically appealing species, including globally renowned snakeheads, of which 17 species have been discovered. The ornamental fish sector has demonstrated significant commercial success, with Kolkata serving as the primary export hub for specimens sourced from the Northeast. The hill streams of Arunachal Pradesh, Meghalaya, and Nagaland are particularly noteworthy as they harbor species with exceptional ornamental characteristics, including unique morphological features, striking coloration patterns, and distinctive behaviors. Species such as Devario, Garra, and Barilius, and various loaches, eels, barbs, and catfish offer diverse visual appeals that could form the foundation for specialized tourism experiences. The established infrastructure for ornamental fish collection and rearing, combined with the region's natural beauty and cultural heritage, positions Northeast India as an ideal candidate for developing integrated ornamental fish tourism attractions that could showcase native species and conservation efforts, while creating sustainable economic opportunities for local communities.

Challenges and Solutions

Although promising, the integration of ornamental fisheries with tourism activities presents several significant challenges that require careful consideration and strategic solutions. Understanding and addressing these challenges are crucial for establishing successful and sustainable integrated operations.

1. **Water Quality Management and Environmental Control**

   Maintaining optimal water quality parameters while accommodating high visitor traffic is the primary challenge. Tourism activities can compromise the water quality through increased organic loads and environmental disturbances. To be successful, facilities must implement advanced filtration systems and establish visitor capacity limits based on scientific analyses. Additionally, installing sophisticated monitoring systems may enable real-time water quality management, allowing operators to maintain optimal conditions for ornamental fish species, while ensuring visitor safety.

2. **Seasonal Variability and Revenue Stability**

   Tourism flows often exhibit seasonal patterns, and ornamental fish production requires consistent care and yearly maintenance. Leading facilities address this challenge through strategic programming, offering specialized events during off-peak seasons, and developing indoor attractions that remain viable, regardless of weather conditions. Some operations have successfully implemented dynamic pricing strategies that help balance visitor numbers throughout the year, while maintaining revenue stability.

3. Technical Expertise and Staffing

The combination of ornamental fisheries and tourism requires personnel with diverse skill sets, ranging from aquaculture specialists to hospitality professionals. This challenge is particularly acute in rural areas, where skilled labor may be scarce. Progressive organizations have addressed this issue through comprehensive training programs and partnerships with educational institutions. Some facilities have implemented mentorship programs in which experienced staff train local community members and build a sustainable talent pipeline.

4. Disease Management and Biosecurity

High visitor traffic increases the risk of disease introduction and spread within ornamental fish populations. Successful operations have implemented stringent biosecurity protocols, including designated viewing areas that minimize direct contact between visitors and fish populations. Advanced facilities utilize quarantine systems for new specimens and maintain separate breeding areas away from public viewing spaces, thereby ensuring both safety and operational continuity.

5. Infrastructure Development and Maintenance

Establishing and maintaining facilities that support ornamental fish production and tourism activities requires significant capital investment. Successful operations have addressed this challenge through phased development approaches, beginning with core facilities and expanding based on the demonstrated demand. Some facilities have secured government support or entered public-private partnerships to finance infrastructure development.

6. Environmental Impact Management

It is challenging to balance sustainable tourism with environmental conservation because these two factors are always contradictory (Rahmani et al., 2023). Progressive facilities have implemented environmental management systems to monitor and minimize ecological impacts. Some operations have established conservation programs that contribute to local biodiversity while enhancing market position through ecological stewardship.

7. Visitor Experience and Education

Maintaining engaging visitor experiences while ensuring the welfare of ornamental fish populations requires a careful balance. Leading facilities have developed innovative interpretation programs that educate visitors about aquatic ecosystems while managing visitor behavior. Some operations utilize technology, such as underwater cameras and interactive displays, to enhance visitor experiences while minimizing direct disturbances to fish populations.

Future Prospects:

- **Economic Growth and Export Potential**

The global ornamental fish market is projected to reach USD 11.68 billion by 2031, presenting India with a lucrative opportunity to capture a significant share. India can enhance its production capacity by promoting indigenous ornamental fish species as state-specific icons and improving breeding capabilities. Diversifying export markets and adopting robust strategies could position India as a global hub for ornamental fisheries.

- **Community Empowerment**

The integration of ornamental fisheries with agro-ecotourism has immense potential for rural development. By creating employment opportunities, especially for women and youth, this sector can contribute to inclusive economic growth. Engaging local communities in fish breeding, aquarium maintenance, and tourism management will foster sustainable livelihood and empower rural populations.

- **Establishment of Koi Fish Ponds**

Creating koi fishponds in public spaces can beautify urban landscapes, attract tourists, and encourage community participation in ornamental fish culture.

- **Coral Reef Conservation and Scuba Diving**

  Protecting coral reef areas rich in marine ornamental fish species will not only support biodiversity but also boost eco-tourism activities, such as scuba diving. In turn, this can generate livelihood opportunities for local communities that are dependent on coastal ecosystems.

- **Collaboration with the Tourism Industry**

  Partnering the tourism sector to showcase ornamental fish as souvenirs or home decor items can boost market visibility. Displaying aquariums featuring locally bred species in hotels, resorts, and tourist destinations will create demand and promote ornamental fish as a unique, eco-friendly product.

- **Branding and Online Market Development**

  Developing a strong branding and labeling strategy for locally bred ornamental fish will help distinguish between Indian varieties in domestic and international markets. Leveraging online platforms, local fairs, and fish markets can expand reach, boost sales, and enhance India's position as a leader in the ornamental fish industry.

The way forward:

The successful integration of ornamental fisheries with tourism requires a comprehensive strategic approach that encompasses multiple dimensions. At the policy level, a robust institutional framework is essential, with national policies explicitly recognizing and supporting ornamental fisheries as a component of agro-ecotourism and rural development. The implementation of targeted subsidies and financial incentives, coupled with strengthened execution of schemes like the Pradhan Mantri Matsya Sampada Yojana (PMMSY), can provide crucial support for sector development. Education and conservation initiatives play a vital role in sector advancement. By introducing educational programs on ornamental fish farming and aquatic biodiversity while establishing public aquariums and fish-themed parks, communities can develop greater awareness of environmental conservation. These facilities serve dual purposes, as tourist attractions and platforms for ecological education. Regular training workshops for Self-Help Groups, fish farmers, and local youth enhance expertise in breeding, cultural techniques, and tank management, thereby empowering communities and supporting sustainable livelihoods. The establishment of demonstration units and farmer cooperatives is another crucial component of the sector's development. The strategic placement of ornamental fish culture demonstration units serves as a knowledge hub, showcasing advanced techniques and inspiring innovation. Simultaneously, the formation of Farmer Producer Organizations and cooperatives can streamline production and marketing processes, enhancing economies of scale and market access.

Financial support through low-interest loans, grants, and subsidies is essential for infrastructure development and entrepreneurial investment in this sector. This support should be complemented by comprehensive capacity-building programs that equip stakeholders with the necessary skills for fish breeding, disease management, and aquascaping. Partnerships with educational institutions can further strengthen these initiatives by developing specialized curricula that combine fishery expertise with tourism management. Research and development efforts should prioritize the domestication of high-value indigenous species and development of eco-friendly technologies. This includes establishing sustainable harvesting protocols and implementing effective water-quality management systems. Community engagement remains crucial, with local communities empowered to develop tourism programs that showcase their cultural heritage along with aquatic biodiversity. Infrastructure development should focus on creating integrated facilities combining aquariums, breeding units, and recreational facilities. Improving connectivity to established centers such as Kolathur in Tamil Nadu and various fish farms in Kerala is essential for attracting visitors and facilitating trade. These developments must be implemented while ensuring environmental sustainability and equitable benefit distribution through partnerships among local governments, NGOs, and private enterprises.

Conclusion

When integrated into agro-ecotourism, ornamental fisheries offer a win-win solution for sustainable livelihood and ecological conservation in India. By strategically leveraging its rich aquatic biodiversity and cultural heritage, India can transform its ornamental fisheries into a cornerstone of agro-ecotourism. This integration promises economic resilience, ecological balance, and community empowerment. This sector can achieve sustainable growth through collaborative efforts among stakeholders, placing India at the forefront of global ornamental fisheries and agro-ecotourism initiatives. Through strategic investments, capacity building, and community involvement, India can position itself as a worldwide leader in ornamental fish-based agroecotourism.

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Life Cycle Assessment for AET: Advancing Sustainability through Carbon Footprint Analysis

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Food consumption about environmental impact has received political and social attention in recent years. Research into the environmental effects of food consumption usually focuses on energy use and the production of waste and rarely has been evaluated for greenhouse gases (GHGs) emission. From the view of food consumption, carbon dioxide (CO2) is the most important GHG followed by methane (CH4) and nitrous oxide (N2O) (Krammer et al. 1999). Fuel combustion activities are the main sources of CO 2 emission, whereas animal husbandry and rice cultivation are the main sources of CH 4 emission, and the emission of N2O is mainly from turnover of nitrogen in soil, application of N fertilizer and industry.

Food production systems as a group are very heterogeneous. The range of products is huge and production systems vary within product groups as well. However, there are some common traits. For the production of food crops (e.g. cereals, pulses and oilseeds), emissions of CO2 from fossil fuel use in various operations is less important than for most other industrial products, instead emissions of biogenic GHGs are more important for crop production. Products of animal origin, such as meat and dairy, have on average higher emissions per kilogram than vegetable products, but there are many exceptions (Pathak et al. 2010). Meat and dairy production contributes to approximately 18% of global GHGs emissions. Transport of food products plays an important role in GHGs emission. Food waste ending up in landfills are also an important contribution to GHGs emissions, methane is formed when food is degraded under anaerobic conditions in the landfills. Packaging can be of significance, but it is a trade-off between role of the packaging for protecting the food and emissions of the packaging material.

Society has become more concerned about the issues of natural resource depletion and environmental degradation due to increased awareness. It is thus essential to evaluate the environmental impact and the utilization of resources in food production and distribution systems for sustainable consumption. In recent years Life cycle assessment (LCA) has become an increasingly common approach across different industries, including agriculture, for environmental impact assessment. LCA was developed for the manufacturing sector and has since been applied to the agricultural sector (Brock et al. 2012). There is a need for analysis of the impacts of different agricultural production systems on GHGs emissions and how management practices affect these emissions. The LCA is a tool for evaluating and generating environmental information about a product, accounting for all resources consumed, all wastes generated, and the emissions to the environment of a product, process, or activity throughout its life cycle, which is also known as a 'cradle to grave' analysis (Arvanitoyannis 2008). "Cradle-to-grave" begins with the collection of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent and one operation leads to the next (Roy et al. 2009).). Product and process evaluations may be based on Life Cycle Assessment in order to account for all environmental impacts of the product assessed. The LCA assessments are supposed to give valuable information of pollution loads like leaching of pollutants resulting in acidification of water bodies and eutrophication in agriculture and their possible ways of reduction through development of cleaner technologies (Breiling et al. 1999).

According to the International Organization of Standardization (ISO), LCA is divided into four phases: goal and scope definition, inventory analysis, life cycle impact assessment and interpretation (ISO14040 2006).

Concept of life cycle assessment

Life cycle assessment (LCA) is an upcoming international standardized method (ISO 2006) aimed at learning knowledge and skills to analyze the various processes involved in the agricultural production chain and find out their impact on the environment and climate change. The LCA also known as life cycle analysis, is a structured, comprehensive and internationally standardized method used to evaluate the global impact of the various products, production systems and the different processes involved in it on the environment. Life cycle thinking (LCT) and LCA are the scientific approaches behind modern environmental policies and business decision support related to Sustainable Consumption and Production (SCP). The LCA study quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services ("products"). It takes into account a product's full life cycle to perform a function from the extraction of resources, through production, use, and recycling up to the disposal of remaining waste (cradle to grave). It is a vital and powerful decision support tool, complementing other methods, which are equally necessary to help effectively and efficiently make consumption and production more sustainable. The LCA is performed in iterative loops of goal and scope definition, inventory data collection and modeling (LCI), impact assessment (LCIA), and with completeness, sensitivity and consistency checks (evaluation) as a steering instrument.

Some people find the LCA useful as a conceptual framework, while others see it as a set of practical tools. However, both views are correct, depending on the context. Generally, this method relies on gathering information on all phases of the 'Life cycle' of product including raw material use, energy of productions, manufacturing and transport. It envisages analyzing contribution of a product (production processes) towards global warming potential (GWP), eutrophication, acidification, ozone layer depletion, ecotoxicity (freshwater and marine), etc. on a global as well as regional basis. Such methodology can be effectively utilized in identifying the potential hot spots in a production process so that modified or alternative methods or processes can be evolved which can replace those hot spots so as to mitigate the potential impact.

Goal definition and scoping

This is the first and a very important step of LCA because it defines the purpose, expected product, system boundaries, functional unit (FU) and assumptions of the study. For LCA studies in the agricultural sector this could be for instance to investigate the environmental impacts of emissions in crop production or to analyze the advantages and disadvantages of different farming systems. System boundaries are generally presented in the form of an input and output flow diagram. All operations that contribute to the life cycle of the product, process, or activity fall within the system boundaries (Roy et al. 2009). The FU determines equivalence between systems. It is defined as the reference unit to which the inventory data is normalized. It is generally based on the mass of the product under study. Choosing a functional unit is not always straightforward and can have a profound impact on the results of the study.

System boundary

In LCA, each and every flow should be followed until its economic input and output have been translated into environmental intervention, i.e flows of the natural resources into the product system without prior humane transformation or the flow of the materials leaving the product system which are discarded to the environment without subsequent humane transformation. Every product system is a collection of materially and energetically connected unit processes which performs one or more defined functions. For example: in the fish meal production process fishing, transport and treatment of the fish at factory are the few unit processes.

While performing a life cycle assessment data are collected for each smallest portion of a product system, i.e. unit process. Since it is not possible to include all the unit processes into the study of a product system, there is a necessity to define the system boundary. The 'System boundary' defines the unit processes to be included in the system to be modeled.

Three boundary issues in LCA

a) Boundary between the product system and the environment affected

b) Boundary between the processes that are relevant and irrelevant to the product system

c) Boundary between the product system under consideration and other product system [allocation] (to produce rice bran, paddy crop has to be raised. Since rice is the main produce in rice processing process and rice bran is the co-product, allocation is made, mostly on the basis on economic value).

ii) Designing the flow diagram with unit processes

The flow diagram provides an outline of the major unit processes within a production system including their inter-relation. It starts with preparation of the initial flow diagram for each alternative product system studied at the level of aggregated processes for each life cycle stage. It starts from the reference flow, the process producing the reference flow and the adjacent processes including the processes producing the main materials and those managing the main waste flows. This is followed by detailed diagrams, at the level of unit processes in iteration with the data collection step.

Data collection is the most demanding task in an LCA and is determined by goal and scope. The data collection phase primarily involves collection of the relevant data on the unit processes and quantifying all flows connected to the unit processes. In most of the existing LCA Data base, the process data are always almost quantified in relation to some physical (reference) flow (1 kg of material or I MJ of energy). During data collection one may find a need to review the goal and scope again and again (iteration) due to some technical problems such as i) sometimes initial decisions are not practical (data not available), ii) Important choices forgotten, iii) Too ambitious for the time and budget. The data should be relevant (represents what it is supposed to represent), reliable (based on precision and uncertainty) and reproducible (documented transparently). It is to be checked whether the data is the average of few data or generated from a single producer.

The collected data are classified as the foreground and background data. The foreground data (primary data collected on site) refers to processes that are of specific interest for the current LCA, like production processes while the background data (secondary data collected from generic sources) refers to processes that support the foreground data, like electricity, transport processes, waste treatment, auxiliary materials etc. The decision is made on the system boundary for the production system depending on the relevance of contribution of a unit process for the production of functional unit and only those material and energy inputs and waste and emission outputs of all economic processes that are within the system boundaries are considered. Inventory table for each unit processes within the system boundary are prepared followed by preparation of aggregate inventory table for reference flow.

iii) Data validation

Validity of the process data is done in this step, for which various tools are available including the mass balance, energy balance and comparison with data from other sources. Inadequate data and missing data are taken care of and decision is taken how to fill the gap.

iv) Allocation

The problem of how to divide emissions and material consumption between several product or processes is called allocation. Generally multi-output and multi-input processes require allocation. Due to the multifunctional nature of the product processes having more than one product and use of raw material input often including intermediate and discarded products, it becomes critical to make decision about which of the economic flow and environmental intervention are to be allocated to the functional unit produced by the system. Co-production, waste treatment, recycling and reuse are 3 types of processes where allocation is necessary. The wheat bran is a co-product and to get it, wheat has to be produced. Then the problem comes in determining what portion of the impact of wheat production should be allocated to the production of the wheat flour.

Inventory analysis

This phase is the most work intensive and time consuming compared to other phases in an LCA. The step involves collection of data and quantification of the use of resources and energy as well as the environmental releases associated with the system being evaluated. The data collection is a strategic point in order to go through a valid and robust analysis and then to result in high-quality decisions (Gilani 2010). Every data entering the system (like raw materials, water, fuels and other inputs) or coming out to the environment (products, emissions, effluents, by-products and wastes) is quantified. This database is the input to the Impact Assessment stage. The impact assessment is done by calculations done according to specific methodology and the assumptions defined in the Goal and Scope stage. The inputs for all the subsystems are used for calculating the mass balance of all the overall system. The elementary flows associated with the life cycle of the product system that generates the reference flow are to be quantified. These are the material and energy inputs and waste and emission outputs of all economic processes that are within the system boundaries.

Impact assessment

The impact assessment phase of an LCA is defined as “a quantitative and/or qualitative process to identify, characterize and assess the potential impacts of the environmental burdens identified in the inventory analysis” to understand their environmental importance and to estimate the possible environmental impacts on different categories (atmosphere, resource depletion, human, etc.) in relation to various inputs and outputs. The categories are selected on the basis of the existing inventory data, expert judgment about cause-effect relationships and the assigning inventory data into the different impact categories. This step of the impact assessment is called Classification. The second step is the characterization step, in which analysis/quantification, of the impacts within the selected impact categories is done and is transformed to results called "environmental profile. The final step is the valuation (assigning weight) of different impact categories so as to compare them amongst themselves.

Interpretation

The purpose of an LCA is to draw conclusions that can support a decision or can provide a readily understandable result of an LCA (Roy et al. 2009). During this step, results of the other steps are interpreted according to the goal of the study. ISO and other sources define an interpretation component, as being the final component of the impact assessment (Huppes et al. 2010).

Methodology of LCA is explained by using an example of rice and wheat crops which are the two most important crops in India.

Use of LCA software for data analysis

The SIMAPRO software is specifically designed for the LCA study and simultaneously learnt to handle the database. The SIMAPRO Software has important contributions to the LCA methodology since 1990 and is the world's most widely used LCA software. Approximately 10,000 processes are available in the software with multiple impact assessment methods such as Eco-indicator 95/99, CML2 Baseline 2000. It has unique features of databases, libraries, processes and product stages. It also has provisions for programming, managing of data, storing of data, making calculations and to check the reliability. This gave the idea about the type of data required to be collected to conduct the LCA study.

The collected data has to be analysed with the 'SIMAPRO' software to identify the hot spots and to understand their contribution towards global warming and climate change processes. Comparisons can be drawn on the impacts between the different production systems and with different production levels within the same production system. Many times during the analysis, based on the outcome of the analysed data further modifications have to be made in the questionnaire meant for the LCA study.

The impact categories quantification output based on the characterisation and normalisation values is in terms of graphical representation as per cent contribution from each process to the impact category and the normalised values to the total. The contribution from each phase of the production process to the total is also quantified. The analysis also displays the network which shows the contribution from each input (materials) and also the processes contributing to global warming potential.

Limitations in the LCA

The LCA cannot or at least should not be used to claim that a particular product is environmentally friendly. At best it is only possible to say, using a specified set of criteria, that one product is better than another in certain aspects of its performance. Comparison studies based on selected indicators or impact categories (e.g. Carbon footprint based comparisons) shall highlight that the comparison is not suitable to identify environmental preferable alternatives, as it only covers the considered impact(s) (e.g. Climate change). A life cycle study with a strong focus on sustainability would find the lack of integration between life cycle costing and social life cycle assessment problematic.

Conclusion

The LCA as a decision support tool used in the right way, can help to ensure environmental soundness, whether in the design, manufacture or use of a product or system. On the financial side, companies using the LCA can discover important product improvements, new approaches to process optimization and even, in some cases, radically new ways of meeting the same need, but with a new product, or with a service. Eco-labelling of products has proceeded less fast in many countries, but where it has been used, there has been an almost automatic requirement for LCA inputs. Finally, alternate scenarios can be made for the processes contributing more towards global warming potential.

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Harnessing Floriculture and Landscaping in Agro-Eco-Tourism: Creating Visually Splendid Visitor Experiences

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Agroecotourism, an amalgamation of agriculture, ecology, and tourism, has gained significant importance in recent years. Agro-eco-tourism associated with floriculture and landscaping has immense potential to boost economic growth, especially in rural areas. The concept of agro-ecotourism entails visiting a farm for leisure, refreshment, recreation, education, and active involvement in agriculture and horticulture. Goas have tremendous potential for agro-ecotourism because of their unique heritage, culture, and natural attractions. Agro-ecotourism can create new jobs in rural areas, attract youth for employment, and slow down the migration of rural people to urban areas. This tourism enterprise keeps tourists relaxed and helps them revitalize in the pure natural environment, surrounded by a magnificent horticultural setting. Considering the scope of floriculture and landscaping, it is essential to promote the agro-eco-tourism concept combined with this sector to create visually splendid visitor experiences. It is possible for farmers to agri-preuner through floriculture-integrated AET units. Flower crops suitable for each agroclimatic zone can be promoted in the AET units of the respective regions. Conservation, cultivation, diversification, value addition, and the overall promotion of floriculture can be achieved in agroecotourism. This paper highlights some areas in floriculture and landscaping that can be utilized to promote a sustainable and eco-friendly agro-eco-tourism model.

Plant Genetic resources of flower crops

Floriculture deals with the cultivation of flowering and ornamental plants for sale or use as raw materials in the cosmetic, perfume, and pharmaceutical industries. Flower crops have unique opportunities for tourism and can be included as a potential component of agro-ecotourism. The National Agricultural Research and Education System (NARES) has made significant contributions to the collection, maintenance, evaluation, and commercial exploitation of valuable genetic resources for traditional or loose flower crops, cut flower crops, cut foliage, and filler crops. Many valuable plant genetic resources from exotic and domestic sources are being used in crop improvement programs nationwide. Since novelty is given more importance in the floriculture industry, priority is always given to new and novel germplasms of ornamental crops. Indigenous and new varieties of flower crops can be maintained in agroecotourism units to provide information to visitors and to create awareness about biodiversity in the area. Biodiversity parks comprising different species (annuals, herbs, shrubs, trees, climbers, creepers, cactus, succulents, ferns, and palms) can be demonstrated in these units. Popular traditional loose flower crops, cut flower crops, specialty flowers, underutilized and exotic flowers, cut foliages and filler crops and indigenous or native ornamental crops which are suited as potential components for Agro Eco Tourism are mentioned below.

Traditional or Loose flower crops

The traditional or loose flower sector is one of the major stays of Indian floriculture, which comprises the growth of traditional or loose flower crops under open field conditions. Major loose flower crops include marigold, rose, jasmine, crosssandra, China Aster, chrysanthemum (including annual chrysanthemum), and tuberose. Some more loose flower crops, which have been cultivated for a long time but are gaining popularity on a commercial scale at present, include *Gaillardia*, Nerium, Spider lily, Barleria, *Michelia champaca*, Hibiscus, *Gomphrena*, Calendula, Gazania, Helichrysum, Acroclinum, Lotus, Water Lilies, *Tabernamontana coronaria*. Loose flowers are used on all festive occasions, marriages, religious ceremonies, and social functions for decorating marriage halls, worship, and temple activities. Fragrant loose flowers such as jasmine, tuberose, and champaca are used for the extraction of essential oils, perfumes, and cosmetics. There is seasonal variation in the amount of trade that takes place in major markets. However, the market value of traditional flowers has not been well documented. The domestic market for traditional flowers is substantially higher than that for cut flowers in terms of value, although exact numbers are unavailable.

Cut flower Crops

Cut Flower crops are grown primarily in naturally ventilated polyhouses to meet the demand of domestic and export markets. The overall objective of protected cultivation is to modify the natural environment using structures to achieve optimal crop productivity by enhancing yield, improving quality, and extending the effective harvest period. Polyhouses comprising different cut flowers, such as Rose, Gladiolus, Gerbera, Carnation, Lilium, Tuberose, Chrysanthemum, Anthurium, Orchid, Tulip, can be demonstrated in the units. Protected cultivation is undoubtedly intensive cultivation with high investment, which in return also gives high returns per unit area as compared with open cultivation of any other flower crops. Owing to locational advantages as well as good marketing networks, protected cultivation has huge potential in many untapped regions.

Specialty flowers / underutilized and exotic flower crops

Underutilized and exotic flower production has the potential to increase the income of both small and large farmers. Intensification of cultivation with specialty crops, such as birds of paradise, heliconia, alpinia, hydrangea, ornamental ginger, ornamental pineapple, ornamental banana, lisianthus, limonium, rose hip stems, alstroemeria, and annual flowers, such as antirrhinum, calendula, stock, rice flower, and corn flower, can diversify the basket of cut flowers. Underutilized or underexploited crops have the potential to contribute to food security, health (nutritional or medicinal), income generation, and environmental services, making it easier for farmers to compete with imported products. These crops represent an important component of rural communities in different parts of the world; however, their poor marketing and production conditions make them largely underutilized. By producing unusual, high-quality flowers using proper postharvest handling techniques, growers can continue to expand the market for underutilized flower crops.

Cut Foliages and Filler crops

Foliage and flowering filler crops form the backbone of cut-flower arrangements. A wide variety of cut greens can be grown in shade in multi-tier cropping systems. The demand for cut foliage and filler crops is constant and high, as they are fresh and come in attractive forms, shapes, and colors. They improve the aesthetic value of various flower arrangements, bouquets, wreaths, indoor decorations, wedding decorations, and so on. Nursery hubs in different parts of the country, such as Kadiyam, Pune, and Bengaluru, have a rich collection of cut foliage plants that can be used to produce cut greens for domestic and export markets to reap maximum benefits. Some of the well-known varieties in cut foliage production in India are Areca fronds, Asparagus, Cupressus, Baby Eucalyptus, Ferns, Palm fronds, *Pleomele reflexa*, *Aglaonema*, *Thuja orientalis*, *Calathea*, Asparagus *densiflorus* 'Sprengeri', *Draecena deremensis*, *Asparagus plumosus, Monstera, Anthurium* etc. Flowering fillers include *Solidago canadensis* (golden rod), *Gypsophila* (baby's breath), Limonium (statice), *Aster amellus* (daisy).

Indigenous or native ornamental crops

There is a need to introduce and commercialize the production of native or indigenous ornamental crops to provide a diversified product range. Therefore, there is a need to evaluate the native ornamentals identified in different AET units for commercial exploitation. The introduction of indigenous ornamental crops helps create niche products that can fetch premium production. A teaching and learning center for indigenous or native ornamental crops can be developed within an AET unit for awareness and commercial exploitation.

Orchidarium

It is an area in a park or botanical garden that is dedicated to orchids. Orchidariums can be maintained in agroecotourism units to provide information to visitors. The Orchidarium is a protected area that optimizes environmental conditions for different varieties of orchids to grow strongly and in abundance for commercial cultivation and conservation. Orchidaria are specially designed to control humidity, ventilation, and light exposure. An orchidarium can provide several significant benefits for visitors. This provides an opportunity for visitors to learn about various orchid species, their growth requirements, and the importance of conserving these unique and diverse plants.

Fernery

A fernery is a specialized garden for cultivation and display of ferns. Fernery provides artificial conditions that are similar to those of ferns. It helps in ex situ conservation and their multiplication, besides providing materials for study and ecotourism purposes. Ferneries are indoors, sheltered, or kept in a shaded house to provide a moist environment, filtered light, and protection from frost and other extremes. In mild climates, ferneries are often outdoors and have an array of different species that grow under similar conditions.

Allied enterprises in floriculture for agroecotourism

As a supplementary enterprise, agri-tourism integrated with floriculture enterprises could be a minor activity that would support other products on your farm. Few potential components in floriculture for Agro Eco Tourism diversification are mentioned below.

Plant Nursery Business

The lack of quality planting material for ornamental plants is the major hindrance to realizing the full potential of floriculture in India. Agrotourism centers can be a source of quality plating material. A great scope exists to reduce the reliance on imports of exotic shrubs, trees, and live plants by strengthening their propagation base in AET units and popularizing indigenous ornamental plants. Planting materials of various kinds (seeds, seedlings, budded plants, grafted plants, rooted cuttings, bulbs, tubers, corms, annual seeds, etc.) are required for commercial flower production, pot plant production (and their rentals), home gardens, and landscaping (corporate landscaping, bio aesthetic planting, etc.).

Vertical Gardening / Green walls

With the advent of smart cities across the country, the requirement for green walls and vertical gardens has recently increased. There is a huge scope for the intensive cultivation of crops specific to vertical green walls. Vertical garden-integrated ecotourism offers numerous benefits, ranging from environmental to economic benefits. These contribute to the conservation of green spaces, purification of air, and mitigation of the urban heat island effect. In addition, they promote health and well-being by providing a serene and therapeutic environment.

Vertical farming

Vertical farming refers to the practice of growing plants in vertically stacked layers, often in urban settings, with limited space. Owing to urbanization, vertical farming is increasingly seen as a viable solution to urban crop production, coupled with quality production and ensured supply. Vertical farming can be very well designed in AET units, wherein the floors and vertical space can be utilized for growing crops. It is possible for farmers to agri-preuner by integrating commercial vertical farms into AET units.

Landscaping

Agrotourism centers can be a source of quality plating material that can be used in landscaping. The demand for landscaping our premises is rapidly expanding due to increasing industrialization, environmental regulation, and the quest to refresh and beautify our surroundings. Interior and exterior scaping using ornamental plants is expanding rapidly. The demand for various landscape plants for beautification has synergized the growth of the conventional nursery and foliage plant industries in India.

Dry Flowers

Dry flowers are in very good demand in both domestic and international markets. Dried flowers are exported from India to countries such as the USA, Japan, and Europe. India has a significant share of the global dry-flower industry. India stands first in the export of dry flowers owing to the availability of a variety of plants. Dry flowers include not only the flower parts, but also dried shoots, seeds, bark, and other ornamental crops. Export of dried flowers and plants from India is to the tune of about Rs 322 crores per year. Dry flowers contribute approximately 70 cent revenue of the total floriculture export revenue. The dry flower industry exports 500 varieties of flowers to 20 countries, and dry flowers are in high demand in the USA and UK markets. Customized cultivation of specific dry flowers is limited to a few crops, such as helichrysum, gomphrena, gypsophila, limonium, lotus pods, rose petals, and marigold petals. There is a need to intensify the search for new crops that suit the dry-flower sector. Dried flowers can be widely used to make bookmarks, boxes, candle holders, greeting cards, handmade paper, jute bags, lampshades, photo frames, resin-encapsulated value-added products, topiary, wall quilts, and other gifts. The use of dry flowers to produce these products enhances their value, appearance, and beauty.

Potpourri

Potpourries are a significant and major component of dry flower export. Potpourri is a mixture of dried and sweet-scented plant parts, including flowers, leaves, seeds, stems, and roots. A properly and finely blended potpourri will last for several months and are used to perfume the air with their continual fragrances, scent drawers, and closets, make sweet smelling stationery, add a final touch to room decorations with attractive baskets, or create personal gifts to share with friends. They are also used to repel moths and to protect woolen garments during storage.

Essential Oils, Flower perfumes, Attar and Concrete

Essential oils and perfumery from natural sources are in high demand worldwide. In India, the major flower crops that are grown for essential oil production are limited and include Rose, Jasmine, Tuberose, *Michelia champaca*, Vanilla, Lavender, Magnolia, *Pelargonium graveolens* (Scented Geraniums), *Cestrum nocturnum*, *Nyctanthes arbortristis* (Parijat), *Pandanus odoratissimis* (Kewda). *Rosa damascena* is a rose species that is exclusively cultivated for the extraction of essential oils, rose water, attar, gulkhand, etc., in certain pockets of Rajasthan, Kannauj, and Uttar Pradesh. The promotion of the essential oil sector encourages subsidiary industries, such as steam distillation, solvent extraction, and the use of indigenous technical knowledge (ITK) for producing different value-added products. The basic systems for the extraction of essential oils from flower crops include distillation, cold fat extraction (enfleurage), hot fat extraction (macerage), solvent extraction, and supercritical fluid extraction.

Natural dyes or Pigments from flowers

Many native flower crops possess valuable pigments that can be isolated and used for various applications, including medicinal and pharmaceutical purposes. Flowers with colorful petals can be used for the extraction of nutraceutical pigments. Pigments extracted from marigold petals are widely used in the poultry industry to enhance the color of the meat and yolk of eggs and are also used in the food and textile industry. The isolation protocol for xanthophyll pigment from marigold has been successfully standardized. Large-scale commercial cultivation of marigold has been attempted in several parts of India in collaboration with the extraction industries. More flower crops can be identified and procedures can be standardized for the full exploitation of natural dyes.

Floral Decorations and Floral Crafts

There is an increasing demand for various floral decorations and products due to lavish arrangements during various weddings, social gatherings, conferences, and other official functions, political functions, entertainment, and various sports events. Floral crafts, such as garlands and venis, wedding garlands, bridal crowns, and strings, are also in high demand**.** The testimony of this is the mushrooming growth of florist centers and shops in urban and peri-urban areas. The volume of business in floral decorations and floral craft is quite high and significant, although this sector is more or less unorganized.

Ornamental Pot Plant Production

In the global floriculture business, ornamental pot plant production is considered the second most important segment of floriculture. The sale of potted ornamental plants contributes to a major share of cut flowers in global floriculture. Ornamental potted plants in the floriculture business in India have a high commercial value and can instantly provide landscaping for both indoor and outdoor decorations. Potted ornamental plants can be flowering plants, foliage plants, or cacti and succulents. The market in this sector has grown enormously. Pot plant production has also opened up a novel way out or avenue for plant rentals for interior and outdoor decoration in various corporate houses and for various social and official events. Popular potted plants include *Aglaonema, Aralia, Anthurium, Azalea, Begonia, Bougainvillea, Calathea, Dieffenbachia, Dracaena*, Ferns, *Ficus, Kalanchoe., Maranta*, *Epipremnum*, multi-colored crotons, *Poinsettia* etc. Popularity for indoor ornamental plants such as English Ivy, golden pothos, Boston Fern, bamboo palm, spathiphyllum, agave, sansevieria, and chlorophytum as green walls in smart cities owing to their proven ability to mitigate indoor pollution creates greater potential.

F_1 Hybrid Seed Production

Seasonal flowers or flowering annuals, biennials, and herbaceous perennials are in high demand for beautifying our surroundings. Commercial flower seed production from F_1 hybrids and open-pollinated seeds is considered a highly profitable venture. The commercial cultivation of flowering annuals for producing seeds is rapidly expanding, owing to promising economic returns. Seed production of annuals such as Marigold, Zinnia, Cosmos, Portulaca, Balsam, Pansy, Coreopsis, Gaillardia, Sunflower, Salvia, Celosia, Tithonia, Gomphrena, Verbena, Petunia, Viola, Dahlia, Torenia, Vinca, Dimorphotheca, Alyssum, Poppy, Phlox, Snap Dragon, Sweet William, Sweet Sultan, Sweet Pea, China aster, Annual chrysanthemum, Nasturtium, Stock, and Fuschia holds promise.

Beekeeping Enterprise

The beekeeping industry is an alternative source of livelihood for the rural poor. The vast diversity of ornamental crops provides more opportunities for the development of beekeeping in AET units. Bee keeping leads to the proper utilization of natural resources from attractive seasonal/annual flower crops, such as nectar and pollen, which otherwise go wasted. Beekeeping encourages biodiversity and ecological awareness and helps to increase national income.

Lawn and Turf grass Industry

Lawns, known as the heart of gardens, are the most attractive features of any landscape. Good landscaping with a lush lawn can have economic, environmental, and lifestyle benefits. In addition to being visually appealing, a good turf controls soil erosion, prevents nutrients from leaching into the water supply, and enhances the quality of the air that we breathe by filtering pollutants. The demand for turfgrass is increasing at a rapid pace as new specialized parks, golf courses, stadiums, etc., are emerging in various locations of the country, creating an enormous market for this sector.

Gulal or Herbal coloured powders

The toxic chemical-based colors commonly sold in the market today contain hazardous materials such as heavy metals, sand, asbestos, chalk, silica, and copper sulfate . The use of these harsh chemical-based colors can lead to adverse health effects, including hair and skin problems such as abrasions, irritation, itching, rashes, allergies, eye infections, and hair roughness. Risks increase when these colors are mixed with oils and fluids and applied to the skin. These can be replaced with gulal or herbal-colored powders that are used for typical Hindu rituals, in particular for Holi. Flowers with colorful petals can be dried to prepare natural dyes or natural-colored powders for gulal and holi colors. Organic colors consist of natural components such as flowers, fruits, leaves, and stems, which are skin-friendly. Gulal is also eco-friendly and does not harm the environment. Organic gulals can be prepared from Rose, Marigold, *Clitoria*, *Hibiscus*, *Butea monosperma, Chrysanthemums, Amaltas, Lavender, Jacarnda* etc.

Edible flowers

Some flowers can be eaten as vegetables or may be used as herbs. Edible flowers are used in garnish foods with the intention of providing color, flavor, and aroma. They are rich sources of nutraceuticals. They can be eaten as part of the main dish or incorporated into salads. Only flower petals are eaten, and it is advisable to remove the stamens, pistils, and basal receptacles. Edible ornamentals can be planted in beds, borders, mass effects, pots, or in combination with vegetables in AET units. Some commonly used edible flowers are peppery nasturtiums (*Tropaeloum majus*): Pansy (*Viola spp.*), Rose (*Rosa damascena*), Calendula, Rosemary (*Rosmarinus officinalis*), Safflower (*Carthamus tinctorius*), Scented geraniums (*Pelargonium spp.*), Tuberous begonia (*Begonia spp.*), Tulip (*Tulipa spp.*), Hollyhock (*Althea rosea*), Impatiens (*Impatiens walleriana*), English Daisy (*Bellis perennis*), Dianthus (*Dianthus caryophyllus*), Day Lily (*Hemerocallis species*), Cornflower (*Centaurea cyanus*), Chrysanthemum, cucumber-flavored borage, onion-flavored chive

Utilization of floral waste

Floral waste from temples and various social and cultural events are a major concern, and its disposal is a major problem. Periodical gluts in the market often lead to large-scale waste production. Even the retailers dump the unsold flowers on the pavements after the festivals, as they have to incur additional transport charges while taking them back. The disposal of flowers in rivers, oceans, etc. leads to water pollution and affects living organisms present in the water. Such practices can be minimized, and the income of farmers can be enhanced if integrated flower waste collection centers are planned and implemented. Through solid-state fermentation, floral wastes can be converted into different value-added products, such as compost, biofuels, biogas, bioethanol, organic acids, pigments, dyes, incense sticks, floral bricks, and handmade papers.

Conclusion

The proper introduction of flower crops into ecotourism adds immensely to the decorative value of the site. They improve the aesthetic value by adding a beautiful color display. Flower crops can either be grown on the ground or kept as potted plants to create visually splendid visitor experiences. In new ecotourism spots, until permanent features, such as shrubbery or fruit plants, are established, annual flowering plants can be used to fill gaps. Flower crops have the opportunity to decorate agroecotourism spots most brilliantly, in an artistic manner. They improve the aesthetic appeal and add to the appeal of visitors. In agroecotourism, flower crops provide emotional security to both tourists and visitors. With advancements in communication and information technology, mankind has been isolated from the ecosystem. Agroecotourism with floriculture and landscaping as a potential component is a remedy to bring back the rhythm and harmony of human life and ensure a better living standard. The diversity of colors and shade of flower crops in agroecotourism can act as a therapeutic tool for visitors.

Revolutionizing Sustainability: IARI's Wheat Straw Technology as a Plastic Alternative and Pollution mitigation strategy

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Introduction

Hollow pipes, also known as straws, are used to consume liquid beverages, including fruit juices, cold drinks, and coconut water, worldwide. Drinking straw has been around for over 5000 years, but the first modern drinking straw was invented by Marvin C. Stone in 1888. Friedman invented the first bendy in 1937. This furthers the plastic straws that were created in the 1960s because plastic was very cheap(Chitaka et al., 2020). Surprisingly, a green revolution occurred during this period in India, but the priority was only to produce grain for the human population and fodder for livestock. The first straw used was made from ryegrass stems, and later on, plastic and other materials came into existence. These straws are mainly made up of plastic, and some alternatives are available in the market, such as bamboo, paper, and metal. Reusable straw from bamboo, metal, or glass is generally used by consumers with a very high commitment to the environment, as carrying them always limits their use. Plastic straws are most commonly used, followed by paper straws; the former is cheaper than the latter because the plastic load to the environment makes them the costliest among all degradable and single- or multiple-use straws(Chitaka et al., 2020). There have been several protests and concerns over the disastrous impact of plastic straw on sea life. There is a widespread global interest in eliminating and/or reducing the use of single-use plastics. An increasingly popular target is single-use plastic drinking straw.

Plastic straw is the most commonly found item in coastal litter clean-ups worldwide. Estimates reveal that 8.3 billion plastic straws are dispersed globally along coastlines, accounting for approximately 0.03% of 8.8 MMT of plastic waste entering oceans by weight. Of the plastics that enter the marine environment, almost 60% of the mismanaged plastic waste arises from East Asia and the Pacific, while Europe and Central Asia account for only 3.6%(Manuja & Bhatia, 2020). Delhi, Mumbai, and Bengaluru generate around 287.6 million, 172.8 million, and 252.7 million straws per year, respectively. Furthermore, as plastic straw is 100% recyclable by material, its recyclability rates in India remain unknown(Manuja & Bhatia, 2020).

Fig. 1. Menace of plastic straws in coastal, forest, and tourist places.

Credit: Internet sources

With the existing ban on single-use plastics in India, alternatives to single-use plastic straw matching cost and effectiveness remain largely unanswered.

In India, the southern states are not only producers of tender coconuts but also consumers due to local traditional and tourism preferences as an instant refreshing and revitalizing source. The awareness of the health benefits of tender coconuts has established a surprisingly huge demand in Northern states as well, especially in post-COVID scenarios and social media networks. Today, besides roadside and regular markets, many door-to-door delivery network giants, such as Country Delight, Zomato, and Swiggy, play crucial roles in marketing food and beverages in most cities of India. Unfortunately, plastic straw has been paired with tender coconuts in most states. Paper straws also have a major concern in diverting a large part of fresh pulp in the paper industry, demanding falling more trees and thus increasing environmental concerns rather than a solution.

Wheat is the principal food crop in India, with over 100 million metric tons from a 30m ha area. Wheat is grown primarily owing to its diverse end uses. However, the use of straw is limited to dry fodder in dairy livestock(Bainsla et al., 2020). In India, semi-dwarf spring wheat varieties dominate the total wheat grown. Taller varieties are not preferred because of their weaker stems and their vulnerability to lodging. The varieties under cultivation are chosen mainly for their high grain yield potential and lesser losses due to lodging; hence, the height of the prevailing varieties ranges from 85 to 105 cm. With the increasing demand for wheat worldwide, high-yield potential genotypes are being developed with increased fertilizer responsiveness and early seeding. The alternative use of wheat straw from popular varieties is not possible, including its suitability for straw pipes owing to their diameter, internode length, and stem strength. However, Pusa Srijan, an advanced genotype developed by the Wheat Improvement Program, Division of Genetics, ICAR-ICAR IARI, is a viable option for use as the primary source for straw pipes generating 3-4 straws from a single tiller.

Problem Statement and Gaps

- **Environmental Impact:** Plastic straws contribute significantly to marine pollution and harm marine life and ecosystems. Studies need to be conducted on real-time single-use plastic straws and their fate in all states, particularly in coastal areas.

- **Public Health Concerns:** Microplastics from degrading straw can enter the food chain, posing potential health risks. There are insufficient data; hence, there is an opportunity for researchers to quantify microplastics through single-use plastics in food.

- **Limited Recycling:** Despite being theoretically recyclable, the actual recycling rate of plastic straw in India remains unknown, indicating that a significant portion ends up in landfills or the environment.

- **Missed Opportunity:** Pusa Srijan offers a viable, eco-friendly, developed, and locally sourced made-in-Indian alternative to plastic straw.

Proposed Solution

- **Transition to Pusa Srijan Straws:** Promote the widespread adoption of straw made from Pusa Srijan wheat.

- **Pilot Projects:** Implement pilot projects in major cities and coastal states such as Delhi, Mumbai, Bengaluru, Goa, Chennai, Puducherry, Andaman, and Nicobar Islands, and Lakshadweep to demonstrate the feasibility and effectiveness of the transition.
- **Public Awareness Campaigns:** Conduct extensive public awareness campaigns to educate consumers about the benefits of Pusa Srijan's straws and encourage their use.
- **Incentivize Production:** Provide incentives to farmers to cultivate Pusa Srijan wheat and support the establishment of straw-processing units.
- **Collaborate with Stakeholders:** Partner with government agencies, NGOs, businesses, and educational institutions to ensure the successful implementation of this initiative.

4. Estimated Costs and Benefits

- **Estimated Cost:** Based on preliminary data from Delhi, Mumbai, and Bengaluru, replacing 20% of plastic straw with Pusa Srijan straw could cost approximately **₹ 71.30crores** (assuming a conservative cost of ₹0.50 per straw). However, this cost can be significantly reduced by introducing mechanized processing and packaging units.
- **Benefits:**
    - **Environmental Protection:** Reduced plastic pollution in landfills and marine environments.
    - **Improved Public Health:** Minimized exposure to microplastics.
    - **Economic Opportunities:** Creation of jobs for Pusa Srijan cultivation, straw processing, and distribution.
    - **Enhanced Brand Image:** Businesses adopting Pusa Srijan straws can enhance their environmental and social responsibility images.

5. Call to Action

This proposal calls for a collaborative effort from all stakeholders to make the transition to Pusa Srijan a reality. We urge the government, businesses, and the public to embrace this sustainable solution and contribute to cleaner and healthier India.

Note: This proposal provides the framework for this study. Further research and detailed feasibility studies are necessary to refine cost estimates, develop a comprehensive implementation plan, and ensure the long-term success of this initiative.

By embracing the Pusa Srijan straw, India can demonstrate global leadership in combating plastic pollution and promoting sustainable development.

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Note

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