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Cultural-ecological synergies: Traditional practices and biophysical systems in India's agro-climatic regions

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Abstract

India's diverse ago-climatic zones have fostered rich traditional knowledge systems intricately tied to local ecological conditions. This study examines the biophysical characteristics and indigenous practices across six major regions—North, North-East, East, South, West, and Central—highlighting how climate, soil, vegetation, and water resources shape region-specific traditions in farming, water management, handicrafts, and agroforestry. The rationale stems from growing concerns over the erosion of these systems due to modernization, urbanization, and climate change, which threaten both biodiversity and cultural heritage. Employing a combination of primary and secondary research, the study explores how traditional ecological knowledge contributes to environmental sustainability, economic resilience, and social cohesion. Region-wise analysis reveals that these practices are not only adaptive but also offer valuable insights for sustainable resource management. Findings indicate a progressive decline in traditional practices, with notable regional disparities in their resilience and revival. The study emphasizes the critical need for integrating traditional knowledge with modern science and policy frameworks. In conclusion, the research advocates for targeted policy interventions, community-based documentation, and participatory conservation efforts to safeguard India's cultural and ecological wealth. Strengthening these traditional systems can significantly enhance sustainable development, climate adaptation, and rural livelihoods.

Keywords: Argo-Climatic Zones; Traditional Ecological Knowledge; Biophysical Resources; Cultural Sustainability; Indigenous Practices

1. Introduction

India's rich ecological diversity, shaped by its varied agro-climatic zones, has fostered the development of unique cultural practices and traditional knowledge systems deeply rooted in local geography and environmental conditions (Ramakrishnan, 2007; Gadgil & Guha, 1992). From the high-altitude deserts of Ladakh to the humid coastal plains of Andhra Pradesh, communities across the country have adapted to their respective environments through age-old methods of agriculture, water management, forest conservation, and craft traditions (Berkes, Colding, & Folke, 2000; Singh et al., 2020). These indigenous systems reflect not only environmental wisdom but also a holistic worldview where nature, livelihood, and culture are inextricably linked (Gadgil, Berkes, & Folke, 1993).

The present study examines the traditional and bio-physical aspects of cultural resources in India's agro-climatic regions—North, North-East, East, South, West, and Central—by identifying the interrelationship between ecological features (like climate, soil, vegetation, and water) and region-specific traditional practices (Planning Commission of India, 2001; Venkateswarlu et al., 2011). It provides a region-wise comparative overview of sustainable agricultural techniques, community-based water harvesting systems, forest-dependent livelihoods, and socio-cultural rituals connected to nature (Sharma et al., 2010; Pandey, 2019). The documentation spans practices such as the Ahar-Pyne irrigation system in Bihar, sacred groves of Maharashtra, large cardamom agroforestry in Sikkim, and traditional

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handicrafts of Andhra Pradesh—each of which has evolved in harmony with the natural landscape (Behera & Mishra, 2006; Tiwari et al., 2010; Singh, 2018; Rao et al., 2020).

These traditional practices, however, are now facing unprecedented challenges due to rapid urbanization, modernization, changing climatic patterns, and socio-economic transformations (UNESCO, 2017; IPCC, 2021). As traditional methods are replaced by commercial agriculture, industrial development, and unsustainable land use practices, there is a growing risk of losing invaluable cultural knowledge and ecological resilience (Pretty et al., 2009; Altieri, 2004). This research adopts a multidisciplinary approach combining ecological mapping, cultural documentation, and climatic analysis (Berkes, 2012; Singh et al., 2020). Its aim is not only to highlight the environmental significance of traditional practices but also to advocate for their preservation and integration into sustainable development strategies (FAO, 2017; Mishra et al., 2022). As climate change and environmental degradation continue to threaten ecological and cultural diversity, reviving and reinforcing traditional systems offers a pathway to resilience, self-reliance, and environmental justice for future generations (Altieri & Nicholls, 2020; Agarwal, 1991).

2. Methodology

This research adopts a qualitative, comparative, and interdisciplinary approach to investigate the traditional and biophysical aspects of cultural resources across India's diverse agro-climatic zones (Berkes, 2012; Kumar, 2021; Yin, 2018). The study begins by categorizing the country into six major regions—North, North-East, East, South, West, and Central—selected based on their distinctive ecological and cultural characteristics (Planning Commission of India, 2001; Venkateswarlu et al., 2011). Within each region, traditional practices related to agriculture, water management, forest use, and handicrafts were identified and analyzed in connection with local geography, climate, and natural resources (Gadgil & Guha, 1992; Pandey, 2019). The data for this analysis was sourced from a range of government reports, peer-reviewed academic literature, historical documents, and studies conducted by NGOs and environmental organizations (Sharma et al., 2010; Tiwari et al., 2010; UNESCO, 2017). These sources facilitated the tracing of both the cultural evolution and environmental significance of traditional systems, while also revealing patterns of decline, adaptation, or transformation in the face of modernization and climate change (Altieri, 2004; Pretty et al., 2009; IPCC, 2021).

A thematic and comparative framework was employed to map key biophysical parameters—such as soil type, vegetation cover, altitude, and water availability—against the corresponding traditional practices in each region (Behera & Mishra, 2006; Singh et al., 2020). This cross-regional mapping enabled a nuanced understanding of the ecological logic underpinning cultural expressions (Ramakrishnan, 2007; Gadgil et al., 1993). The final stage of the methodology involved an evaluation of the sustainability and contemporary relevance of these traditional systems, particularly in the context of environmental degradation, policy marginalization, and climate threats (Agarwal, 1991; Berkes et al., 2000; Altieri & Nicholls, 2020). By integrating traditional ecological knowledge with insights from scientific climate data, the study offers a holistic lens to inform strategies for cultural preservation, environmental resilience, and sustainable development (FAO, 2017; Mishra et al., 2022).

2.1. Agro-climatic Zones

The Figure 1 divides India into different agro-climatic zones, which are labeled with Roman numerals and are color-coded to highlight the regions (Sharma et al., 2022). Each zone represents a distinct ecological or geographical area, influenced by climatic and environmental conditions. Following are the regions denoted with Roman numbers in the map:

- Western Himalayan Region (I): Covering the north-western part, including parts of Jammu & Kashmir, Himachal Pradesh, and Uttarakhand.
- Eastern Himalayan Region (II): Covering the northeastern states like Arunachal Pradesh and Sikkim.
- Lower Gangetic Plain Region (III): The region surrounding the lower parts of the Ganges river in West Bengal.
- Middle Gangetic Plain Region (IV): Centered around the middle stretch of the Ganges, including Uttar Pradesh and parts of Bihar.
- Upper Gangetic Plains Region (V): The upper part of the Ganges, mainly in western Uttar Pradesh.
- Trans-Ganga Plains Region (VI): The plains beyond the Ganges, stretching towards the northwestern part.
- Eastern Plateau and Hills (VII): Includes parts of Chhattisgarh and Odisha.
- Central Plateau and Hills (VIII): Covering Madhya Pradesh and surrounding areas.
- Western Plateau and Hills (IX): Maharashtra and nearby regions.

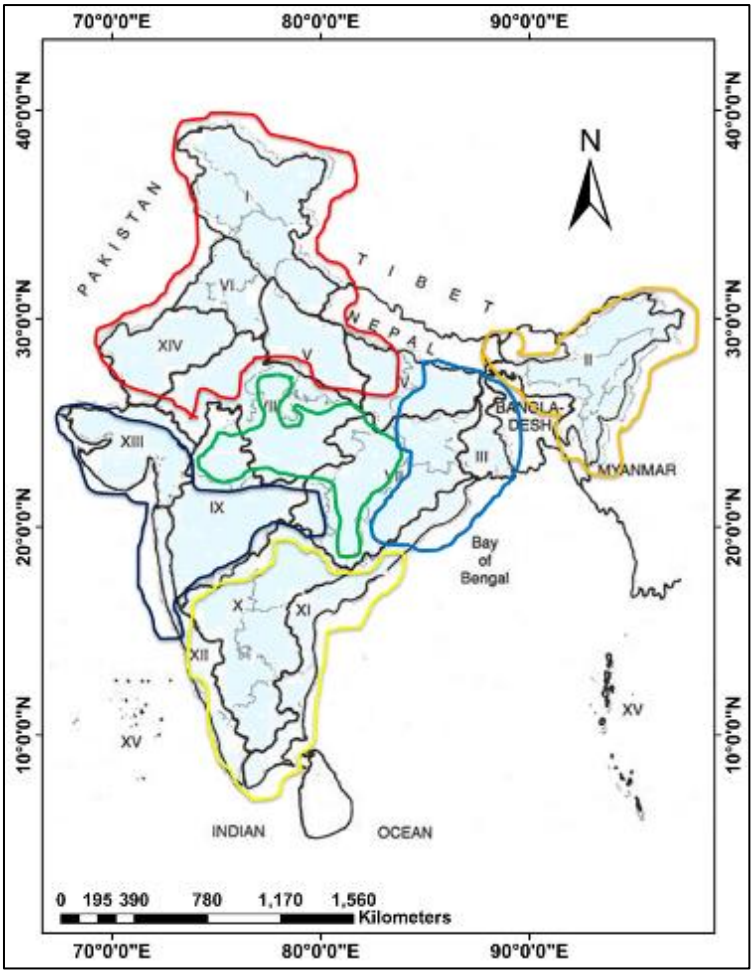

Figure 1 Agro-Climatic Zones of India Categorized into Six Major Regions.

- Southern Plateau and Hills (X): Deccan plateau regions in southern India.
- Eastern Coastal Plains and Ghats (XI): Coastal areas along the eastern seaboard, including Andhra Pradesh, Tamil Nadu, and Odisha.
- Western Coastal Plains and Ghats (XII): The western coastal region, including Kerala, Goa, and Karnataka.
- Gujarat Plains and Hills (XIII): The Gujarat region with its unique topographical features.
- Western Dry Region (XIV): The desert and arid regions in Rajasthan.
- Island Region (XV): Refers to the Andaman & Nicobar Islands.

For this study, India has been categorized into six major regions—North, North-East, East, South, West, and Central—each comprising specific agro-climatic zones (Figure 1). These regions are defined by distinct biophysical characteristics, including geography, climate, soil types, and water availability (Planning Commission of India, 2001). For example, the Western Himalayan Region features a cold and arid climate, while the Lower Gangetic Plains are typified by hot and humid conditions. This classification enables a comprehensive region-wise analysis of bio-physical conditions, traditional knowledge systems, and the challenges each zone faces due to climate change, modernization, and socio-economic shifts. Each region demonstrates unique environmental and cultural traits that have historically shaped localized traditional practices in agriculture, water management, forestry, and crafts (Gadgil & Guha, 1992; Pandey, 2019).

2.2. Selection of Study Areas

Figure 2 displays a state boundary of India with red dots marking the specific study sites. These locations represent sites of interest selected for their ecological, climatic, or cultural relevance. The mapped distribution allows for a visual understanding of how the study areas are spread across different agro-climatic regions and ensures spatial context by aligning them with state and national boundaries. This helps underscore the regional diversity of environmental systems and facilitates comparative analysis of traditional practices across zones.

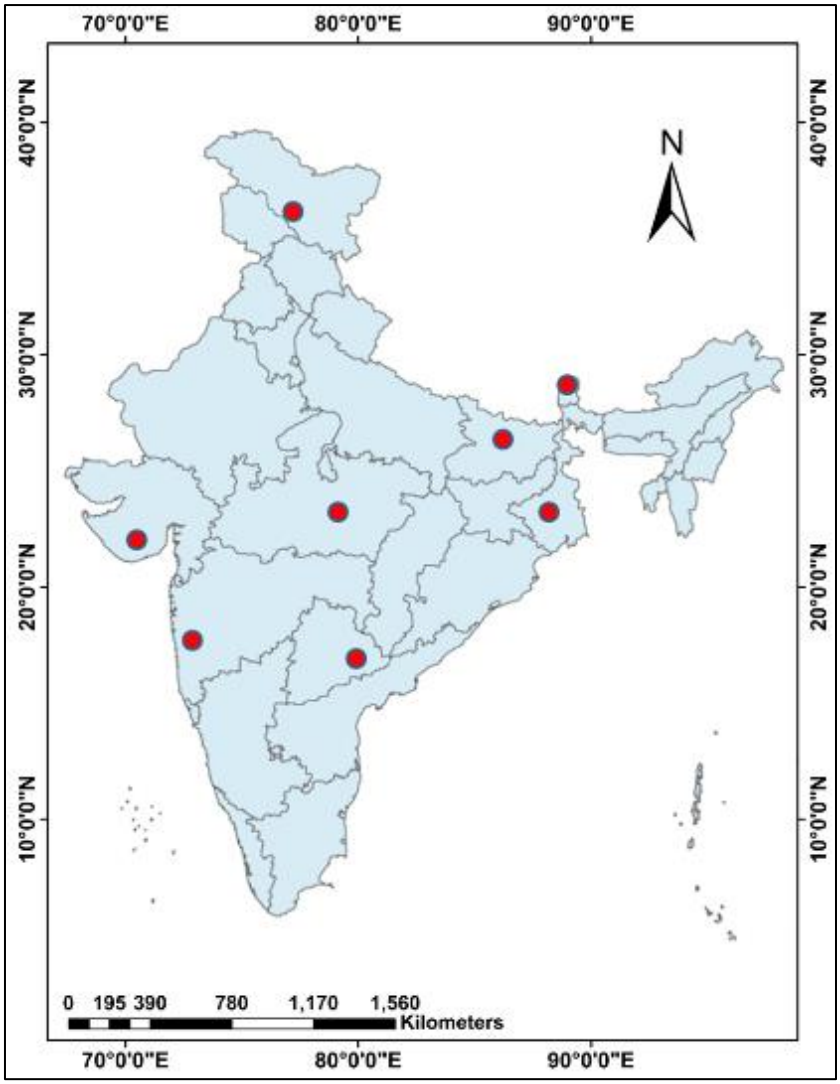

Figure 2 Distribution of areas under study, possibly focusing on different climates, ecological systems, or regional development projects in India

The red dots on the map represent the study areas, which are distributed across various states and regions of India. These locations span diverse geographical and political zones, encompassing a wide range of environmental conditions i.e.,

- Northern India (including the regions near the Himalayas)
- Central India (Madhya Pradesh)
- Western India (Gujarat, Maharashtra)
- Southern India (Telangana, Tamil Nadu, Karnataka)
- Eastern India (Odisha, West Bengal)

3. Result and discussions

(A) In the **North region**, particularly the Western Himalayan zone in Ladakh, the study highlights the harsh, cold-arid conditions where traditional farming systems have evolved to be self-sustaining, focusing on crops like barley and wheat. These practices are under pressure due to modern agricultural policies and the rise of tourism, which is rapidly replacing agriculture as the dominant economic activity. The region's water resources, primarily dependent on glacial melt, are managed through ancient irrigation systems, but they are also at risk due to climate change and modernization. A table 1 provides details about the bio-physical features and traditional practices in North region of India. It highlights regional elements and discusses traditional knowledge/ cultural practices. The table underscores the importance of the particular resource while also noting the challenges which are leading to a decline in traditional knowledge.

Table 1 Details about the bio-physical features and traditional practices in Northen region of India

Agro-climatic Zone	**Western Himalayan Region**
Ecological Region	Trans-Himalayan region
Climate	Cold Arid, Polar Tundra, Arid Dessert/ Steppe Cold
Altitude	3,000 to 4,300 m
Ecosystem	Dry and Moist Tundra (Alvar and Alpine)
Location	Ladakh
Biophysical Aspect	Soil, Water, Animal
Traditional Practice/ Knowledge	Traditional Farming System
Methodology	both primary and secondary sources, purposive sampling method,
Impact On	Environment, Economy, Society
Benefits	ecologically sustainable, deep sense of psychological security, great role in the economy of the region
Environmental Significance	Ladakh traditional agriculture has always been focused on the production of food to support the population, and the continuous re-production of the conditions for long-term conservation of the whole system: in brief, it has been focused on sustainability.
Issues	Decrease in local cultivation of wheat and barley Subsidised rice supplied through the PDS is increasingly replacing locally grown barley as the main staple diet. Traditional crops replaced by cash crops leading to loss of agro-biodiversity, Change in socio-economic transformation, Modernization and government development programs, farmers often adopt new technological adjustments Impacts of Tourism - Agriculture has now taken a back seat Government Initiative to Enhance Agriculture Productivity: high input agriculture has many negative impacts on environmental and social scale. Environmental and Uneconomic Modernization is undermining the very foundations of the traditional culture
Economic Change	There was dominance of primary sector in Ladakh. In 1971, primary sector employed 84.69 per cent of total workers as against 3.55 per cent and 11.76 per cent in secondary and tertiary sector respectively. 1971-2011, with a marginal change in secondary sector. Primary sector constituted 27.21 per cent workers in 2011, while their share in tertiary sector rose to 71.02 per cent. Increase in the tertiary sector was at the expense of primary sector. Reason is Tourism industry and stationing of defence forces.

(B) In the **North-East region**, such as the Eastern Himalayan zone in Sikkim, traditional agro-forestry systems like large cardamom farming play a vital role in the local economy and environmental sustainability. The study emphasizes on how these systems, which improve soil fertility and conserve water, are being threatened by diseases, pests, and climate change. The shift to modern farming practices and the degradation of plantations are resulting in the loss of traditional methods, though they continue to be important for many indigenous communities. A table 2 provides details about the bio-physical features and traditional practices in North-East region of India.

Table 2 Details about the bio-physical features and traditional practices in North-East region of India

Agro-climatic Zone	**Eastern Himalayan Region**
Ecological Region	Eastern Himalayas
Climate	Cold, Polar, Tundra, Temperate Dry/ Humid Winter, Hot/Warm Summer,
Altitude	> 3500 m to 100-500 m
Ecosystem	Dry/Moist Tundra, Moist Alpine Scrub, Tropical Moist Forest,
Location	Sikkim and the Darjeeling district of West Bengal
Biophysical Aspect	Vegetation, Soil
Traditional Practice/ Knowledge	Agroforesty - large cardamom based Jhum cultivation, terrace paddy cultivation, Alder-based jhum and wet terrace paddy cultivation by Angami tribe, Zabo system of Chakhesang tribe, tree-based cultivation of Konyak tribe in Nagaland, paddy-cum-fish farming and jhum cultivation by Apatani tribe in Arunachal Pradesh, jhum and bun (terrace) farming by ethnic Khasi tribe of Meghalaya, rice-based farming in Tripura, organic farming, as well as terrace rice cultivation in the river valleys of Sikkim.
Impact On	Environment, Economics, Society
Benefits	The large cardamom based agroforestry system is observed to accelerate the nutrient cycling, increases the soil fertility and productivity, reduces soil erosion, conserves biodiversity, conserves water and soil, serves as carbon sink, improves the living standards of the communities by increasing the farm incomes and also provides aesthetic values for the mountain societies. Spiritual and cultural services
Environmental Significance	Accelerate the nutrient cycling, increases the soil fertility and productivity, reduces soil erosion, conserves biodiversity, conserves water and soil, serves as carbon sink
Issues	Large scale land use transition for maximizing the benefits to meet the rising demands for food and other ecosystem services for the well-being of the societies has been the main problem confronting sustainable development in the mountain areas. Diseases such as chirkey and phurke in case of cardamom Diseases and pests, old plantations, poor management, unavailability of good quality planting material and lack of irrigation facilities. Climate change

(C) The **East region**, encompassing the Lower and Middle Gangetic Plains (West Bengal and Bihar), showcases the rich biodiversity of tropical forests and fertile soils. West Bengal, once a reservoir of rice biodiversity, has seen a decline in traditional rice varieties due to the introduction of high-yielding varieties and poor infrastructure. In Bihar, the traditional Ahar-Pyne system—an ancient water management practice—is also facing challenges from siltation, encroachment, and modern irrigation schemes. Both regions are witnessing a decline in traditional practices, but efforts to revive these systems are gaining momentum, albeit slowly. A table 3 provides details about the bio-physical features and traditional practices in East region of India focusing on Lower Gangetic Plains.

Table 3 Details about the bio-physical features and traditional practices in East region of India focusing on Lower Gangetic Plains

Agro-climatic Zone	**Lower Gangetic Plain Region**
Ecological Region	Indo Gangetic Plain
Climate	Hot & Humid, heavy rainfall, Tropical Savanah type, Monsoon type with dry winters
Altitude	< 100 m
Ecosystem	Tropical Dry & Moist Forest
Location	West Bengal
Biophysical Aspect	Vegetation
Traditional Practice/ Knowledge	Agriculture Practice: Traditional varieties of Rice/paddy Indigenous Technical Knowledge (ITK): indigenous farming systems
Impact On	Environment, Economics, Society, Culture
Benefits	Aesthetic and Medicinal values culture value and existence value potentiality to resist against the various biotic and abiotic stress Economic: varieties are the backbone of sustainable agriculture, By-products / Extended Use of Rice specific to the State:
Environmental Significance	Maintain sustainable genetic diversity Maintain ecosystem Rice biodiversity
Issues	75% of folk varieties become vanished from the rice fields Slowing down of the agricultural growth in the state are the limited investments of both public and private sector, poor infrastructure with weak marketing linkages and low agricultural productivity. pests and diseases

(D) A table 4 provides details about the bio-physical features and traditional practices in East region of India focusing on Middle Gangetic Plains.

Table 4 Details about the bio-physical features and traditional practices in East region of India focusing on Middle Gangetic Plains

Agro-climatic Zone	**Middle Gangetic Plain Region**
Ecological Region	Eastern Highlands
Climate	Composite, Sub-humid, Temperate Dry Winter Hot Summer, Monsoon type with dry winters
Altitude	< 100 m
Ecosystem	Tropical Dry Forest (Plains), moist deciduous forests, Agriculture
Location	Bihar
Biophysical Aspect	Water, Vegetation
Traditional Practice/ Knowledge	Ahar-Pyne System: Indigenous Irrigation Technology/ Traditional Water Management Systems Ahar-Pyne system is composed of two components- Ahar which is reservoir with embankments on three sides, and

	Pynes which are diversion channels constructed originating from rivers that impound water in Ahar.
Impact On	Environment, Economics, Society, Culture
Benefits	Socio-economical, Environmental
Environmental Significance	Maintain physical and natural habitat, ecological condition of the area
Issues	The system went into disuse because of siltation as well as encroachment Small landholdings, land reform system and Conversion of Aahars into agricultural field Development of new irrigation sources Heading towards commercial farming Collective action marred by Social problems Lack of convergence between old systems and new schemes of irrigation Abolition of the Zamindari System and Absence of centralized authority Repair, maintenance and management at present and dependence on governance schemes

(E) In the **South region**, particularly in Andhra Pradesh's Eastern Coastal Plains, traditional knowledge thrives in areas like handicrafts, water harvesting, and pulses storage. The use of plant materials for making ropes, furniture, and other handicrafts highlights the deep connection between culture and the environment. However, urbanization and the loss of indigenous knowledge threaten these practices. Many artisans are abandoning traditional crafts due to low incomes, and industrial-scale resource extraction is putting local biodiversity at risk. A table 5 provides details about the bio-physical features and traditional practices in Southern region of India.

Table 5 Details about the bio-physical features and traditional practices in Southern region of India

Agro-climatic Zone	**Eastern Coastal Plains and Hills**
Ecological Region	Eastern Coastal Plain
Climate	Hot & Humid, Tropical Savannah, Monsoon type with dry season in high sun period
Altitude	< 100 m
Ecosystem	Tropical Dry Forest
Location	Andhra Pradesh
Biophysical Aspect	Plants and Water
Traditional Practice/ Knowledge	Traditional Handicraft – Use of Plants Traditional Water Harvesting System Traditional Pulses Storage and Processing System
Impact On	Environment, Economics, Society, Culture
Benefits	Socio-economical, Environmental
Environmental Significance	Maintain physical and natural habitat, ecological condition of the area
Issues	Lack of traditional knowledge and its usage in present generation Lots of migration for tertiary and secondary sector Endangered or Vulnerability of plant species Use of forest products in high scale industries Less focus on small scale industries

(F) The **West region** features agro-climatic zones such as the Western Plateau and Hills (Maharashtra) and Gujarat Plains. Sacred groves—protected forest areas with religious and cultural significance—are a key traditional resource in Maharashtra. These groves, along with water harvesting systems, help conserve biodiversity and water resources, but they are increasingly under threat from development and agriculture encroachment. Similarly, in Gujarat, traditional farming systems are crucial for local livelihoods, though they face pressures from modern agricultural commercialization and biodiversity loss. A table 6 and 7 provides details about the bio-physical features and traditional practices in Western region (Maharashtra and Gujarat) of India.

Table 6 Details about the bio-physical features and traditional practices in Western region (Maharashtra) of India.

Agro-climatic Zone	**Western Coastal Plains and Ghats**
Ecological Region	Western Coastal Plains
Climate	Hot & Humid, Tropical Monsoon, Monsoon type with short dry winter season
Altitude	< 100 m
Ecosystem	Tropical Wet and Moist Forest, Mangrove Forest
Location	Maharashtra
Biophysical Aspect	Forest, Water
Traditional Practice/ Knowledge	Tradition of Scared Groves Traditional Water Harvesting Systems
Impact On	Environment, Culture, Economics, Society,
Benefits	Traditional, Medicinal, Soli Erosions, Conserving Water & Biodiversity, etc.
Environmental Significance	Maintain physical and natural habitat, ecological condition of the area
Issues	Economic development and the increased pressure to use natural resources and social changes Agriculture encroachment; resource extraction Livestock grazing; spread of invasive species Development encroachment Cattle passage and related trampling

Table 7 provides details about the bio-physical features and traditional practices in Western region (Gujarat) of India.

Agro-climatic Zone	**Gujarat Plains and Hills**
Ecological Region	Western Coastal Plains
Climate	Semi-arid Steppe type, Arid Steppe Hot
Altitude	<100 m
Ecosystem	Tropical Dry Forest
Location	Gujarat
Biophysical Aspect	Vegetation
Traditional Practice/ Knowledge	Traditional Systems in Agriculture
Impact On	Environment, Economics, Society, Culture
Benefits	Socio-economical, Environmental
Environmental Significance	Maintain physical and natural habitat, ecological condition of the area

Issues	Declining crop productivities, damage to environment, chemical contaminations etc. Unsustainable modern system of farming, Maintaining crop yield Demand of food and raw materials for industry Absence of linkages between the farmers and markets and absence of financial support from the governments, Food security and environmental quality

(G) In the **Central region**, Madhya Pradesh's Central Plateau and Hills face challenges in maintaining their traditional water harvesting and farming systems. The region is rich in forests and water resources, but rapid deforestation, industrialization, and the depletion of water sources are threatening traditional livelihoods. Despite efforts to revive traditional practices, modern economic and social changes are making it difficult to preserve these systems. A table 8 provides details about the bio-physical features and traditional practices in Central region of India.

Table 8 Details about the bio-physical features and traditional practices in Central region of India.

Agro-climatic Zone	**Central Plateau and Hills**
Ecological Region	Central Highlands
Climate	Composite, Temperate Dry Winter Hot Summer, Monsoon type with dry winters, moderate rainfall
Altitude	400-500m
Ecosystem	Tropical Moist Forest, Tropical Dry Deciduous Forest
Location	Madhya Pradesh
Biophysical Aspect	Water, Agriculture
Traditional Practice/ Knowledge	Traditional Water Harvesting System
Impact On	Environment, Economics, Society, Culture
Benefits	Socio-economical, Environmental
Environmental Significance	Maintain physical and natural habitat, ecological condition of the area
Issues	Less scientific investigation Quality of food, contamination due to chemicals, serious health hazards and environmental issue Declining crop productivities, damage to environment, chemical contaminations etc. Absence of linkages between the farmers and markets and absence of financial support from the governments Food security and environmental quality

4. Conclusion

Each region in India is home to unique bio-physical aspects and traditional practices that have developed over centuries in response to the natural environment. Across all regions, the study finds that modernization and climate change eroding traditional practices that have long supported environmental and social stability. These agro-climatic zones, while rich in traditional knowledge, are under increasing pressure from urbanization, industrialization, and the commercialization of agriculture. The study calls for a blending of modern technology and traditional knowledge to create sustainable agricultural systems that can adapt to the challenges of the future. It emphasizes the need for better documentation, government support, and local community involvement to ensure that these practices continue to contribute to both environmental conservation and rural livelihoods. The study highlights the common challenges faced by all regions:

- **Urbanization**, modernization, and climate change are leading to the decline of traditional knowledge and practices.

- **Government initiatives** and efforts to revive these practices are critical, but need to be better integrated with modern agricultural and environmental strategies to ensure their sustainability and continued relevance in contemporary times.

The comparative analysis of bio-physical characteristics and traditional practices across various agro-climatic zones of India highlights the ecological diversity and cultural richness of regions from the Western Himalayas to the Central Plateau. Each region possesses unique natural resources—such as plants, soil types, and water systems—alongside time-tested indigenous knowledge systems in agriculture, water management, and other sustainable practices. These traditional methods offer substantial ecological, economic, and cultural value, supporting sustainable development and community well-being. However, challenges such as urbanization, climate change, commercialization, and the erosion of traditional knowledge due to lack of documentation and awareness threaten their continuity. This study emphasizes the need to preserve, promote, and integrate traditional practices into modern development planning. The findings can benefit society by fostering environmental sustainability and guiding policies that blend traditional wisdom with innovative approaches for a resilient future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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