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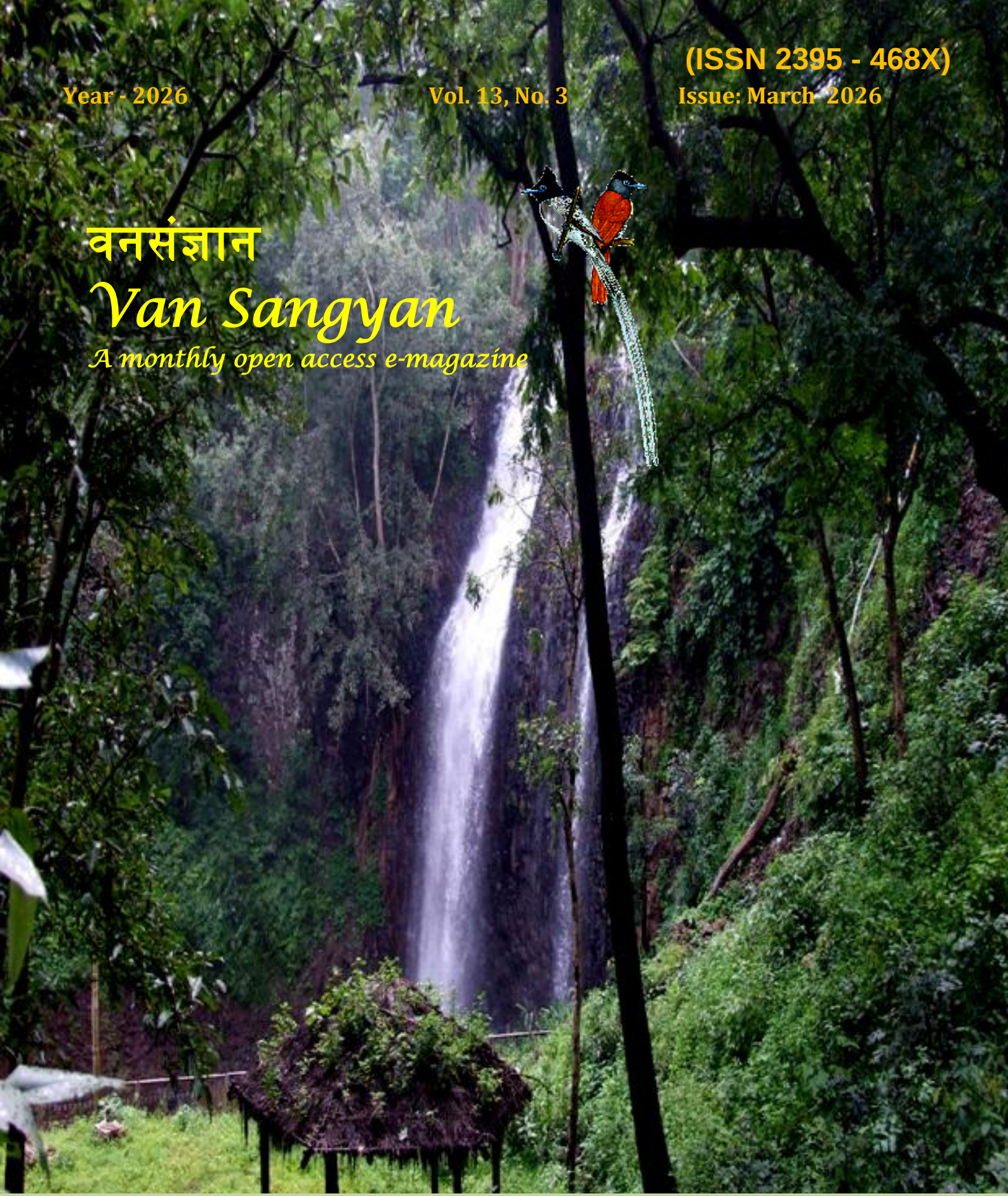

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Van Sangyan

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Van Sangyan

Note to Authors:

We welcome the readers of Van Sangyan to write to us about their views and issues in forestry. Those who wish to share their knowledge and experiences can send them:

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The articles can be in English, Hindi, Marathi, Chhattisgarhi and Oriya, and should contain the writers name, designation and full postal address, including e-mail id and contact number. TFRI, Jabalpur houses experts from all fields of forestry who would be happy to answer reader's queries on various scientific issues. Your queries may be sent to The Editor, and the expert's reply to the same will be published in the next issue of Van Sangyan.

Cover Photo: Panoramic view of Achanakmar-Amarkantak Biosphere Reserve

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From the Editor's desk

India's forests stand at a critical inflection point, transitioning from passive victims of climate variability to active agents of climate resilience. Increasing frequency of heatwaves, erratic monsoon patterns, intensified droughts, and forest fires—particularly across central and Himalayan landscapes—are exposing structural vulnerabilities in forest ecosystems, including biodiversity loss, altered phenology, and declining carbon sequestration capacity. Reports from the Intergovernmental Panel on Climate Change underscore that tropical and subtropical forests, such as those in India, are approaching ecological thresholds beyond which recovery may be nonlinear or irreversible. However, this vulnerability also presents an opportunity to reimagine forest governance through resilience-centric frameworks that integrate ecological restoration, climate-smart silviculture, and community-led conservation. Initiatives like Joint Forest Management and afforestation under the Green India Mission exemplify policy pathways toward adaptive capacity building, though their effectiveness depends on improved monitoring, transparent governance, and integration of indigenous knowledge systems. Advancements in remote sensing, AI-driven forest health diagnostics, and carbon accounting now enable precision forestry, allowing proactive responses to stress signals and disturbance regimes. Ultimately, transforming India's forests from climate-vulnerable systems into resilient socio-ecological assets requires a convergence of science, policy, and local stewardship, positioning forests not merely as carbon sinks but as dynamic buffers against climate uncertainty and pillars of sustainable development.

In line with the above this issue of Van Sangyan contains an article on From vulnerability to resilience: Climate change and forests in India. There are also useful articles viz. Agroforestry practices in south India: Benefits and challenges for adoption, Conservation of endangered freshwater turtles along the Chambal River, Rajasthan, तालमखाना - Hygrophilla Spinosa (White Flower), Conocarpus erectus – between myth and science: The tree that divides opinions, Valeriana jatamansi: Protecting a Precious Himalayan Herbal Legacy, Fundamentals of remote sensing in forest ecosystems, Bergenia ligulata (Pashanbheda): Ethnobotany, phytochemistry, pharmacology and conservation perspectives and Medicinal and aromatic plants of India: Integrating ancient heritage with modern science.

Looking forward to meet you allthrough forthcoming issues

Dr. Naseer Mohammad

Chief Editor

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Contents **Page**

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From vulnerability to resilience: Climate change and forests in India

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Introduction

Climate change is one of the most complex and far-reaching environmental challenges of the twenty-first century, significantly affecting ecological systems, natural resources, and human societies worldwide. The rising concentration of greenhouse gases (GHGs), mainly due to anthropogenic activities such as fossil fuel combustion, deforestation, industrialization, and intensive agriculture, has led to major alterations in the Earth's climate system. These changes are evident in rising global temperatures, altered precipitation patterns, increased frequency and intensity of extreme weather events, sea-level rise, and widespread ecological disruptions (IPCC, 2021).

Forests play a critical role in the climate system due to their dual function as both vulnerable ecosystems and effective climate mitigators. Forest ecosystems are highly sensitive to climatic variations that influence their structure, composition, productivity, and resilience. At the same time, forests act as major carbon sinks by absorbing atmospheric carbon dioxide and storing it in biomass and soil. According to the Food and Agriculture Organization, forests account for nearly 80% of terrestrial aboveground biomass carbon, making them vital regulators of the global carbon cycle (FAO, 2020). Consequently, changes in forest dynamics have profound implications for global climate regulation and ecosystem stability.

India represents a unique case in climate change and forestry due to its diverse geography and climatic conditions. The country hosts a wide range of forest types, including tropical evergreen, deciduous, subtropical, temperate, alpine, and mangrove forests, which provide essential ecosystem services such as carbon sequestration, biodiversity conservation, soil and water regulation, and livelihood support for forest-dependent communities. Forests and tree cover together account for about 24.62% of India's geographical area, underscoring their ecological importance (Forest Survey of India, 2023).

Indian forests are increasingly vulnerable to climate change impacts such as rising temperatures, erratic rainfall, prolonged droughts, cyclones, and frequent forest fires, which affect forest productivity, species distribution, and ecosystem stability. Climate-induced shifts in vegetation and phenology have been documented, and modelling studies indicate that significant changes in forest types may occur under future climate scenarios, potentially leading to biodiversity loss and reduced ecosystem

services (Chaturvedi *et al.*, 2011; Ravindranath*et al.*, 2006).

Beyond ecological impacts, climate change poses serious socioeconomic challenges for forest-dependent populations by threatening livelihoods, food security, and cultural heritage. These impacts are intensified by anthropogenic pressures such as deforestation, land-use change, urbanization, and industrial expansion (MoEFCC, 2018). Globally, forests are recognized as key components of climate mitigation and adaptation strategies under frameworks such as the UNFCCC, the Paris Agreement, and REDD+. India has committed to creating an additional carbon sink of 2.5–3.0 billion tonnes of CO_2 equivalent by 2030 through forest and tree cover as part of its Nationally Determined Contribution (MoEFCC, 2015). Understanding forest–climate interactions is therefore essential for developing effective climate-smart forestry strategies and sustainable environmental planning.

Scientific Basis of Climate Change and Forest Ecosystems

Greenhouse Gas Dynamics

Major greenhouse gases influencing climate change include:

Gas	Chemical Formula	Major Sources	Atmospheric Lifetime (Years)	Global Warming Potential (100 Years)*	Environmental Significance
Carbon dioxide	CO_2	Fossil fuel combustion, deforestation, cement production, industrial processes	100–1000	1	Primary driver of global warming; responsible for ~75% of anthropogenic GHG emissions
Methane	CH_4	Agriculture (rice cultivation, livestock), wetlands, landfills, fossil fuel extraction	~12	28–34	Highly potent GHG; contributes significantly to short-term warming
Nitrous oxide	N_2O	Nitrogen fertilizers, biomass burning, industrial processes	~114	265–298	Strong long-lived GHG; major contributor from agricultural

					activities
Tropospheric ozone	O_3	Secondary pollutant formed from NOx and VOCs	Hours–weeks	Not fixed	Contributes to warming and damages vegetation and crops
Water vapour	H_2O	Evaporation, transpiration	Days	Not applicable	Acts as a feedback mechanism rather than a direct driver
Hydrofluorocarbons	HFCs	Refrigeration, air conditioning, foam blowing	15–270	12–14,800	Synthetic gases with extremely high warming potential
Perfluorocarbons	PFCs	Aluminium production, semiconductor industry	2,600–50,000	6,500–12,200	Very long-lived industrial gases
Sulfur hexafluoride	SF_6	Electrical insulation, magnesium production	~3,200	23,500	One of the most potent GHGs known
Nitrogen trifluoride	NF_3	Electronics and solar panel manufacturing	~740	16,100	Emerging industrial GHG with high warming impact
Black carbon (aerosol)	—	Diesel engines, biomass burning	Days–weeks	Not fixed	Short-lived climate pollutant affecting glaciers and regional climate

Source: IPCC, 2021

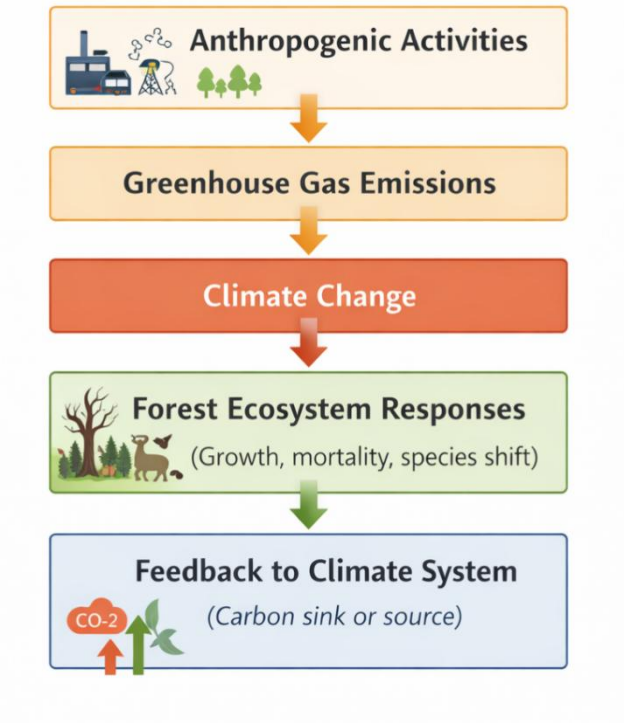

Fig 1: Forest–Climate Interaction Model

Role of Forests in the Global Carbon Cycle

Forests act as major carbon reservoirs in:

- Aboveground biomass
- Belowground biomass
- Deadwood and litter
- Soil organic carbon

Table 2: Carbon Pools in Forest Ecosystems

Carbon Pool	Approximate Share (%)
Aboveground biomass	30–40
Belowground biomass	15–25
Soil organic carbon	30–50
Deadwood & litter	5–10

Source: FAO, 2018

Impacts of Climate Change on Indian Forests

Changes in Forest Structure and Productivity

Climate change affects forest productivity through:

- Altered precipitation patterns
- Increased temperature stress
- Changes in phenology
- Increased pest and disease outbreaks

Studies indicate that nearly 45% of India's forested grids may experience shifts in forest types by 2085 under climate change scenarios (Chaturvedi *et al.*, 2011).

Biodiversity Loss and Species Migration

Rising temperatures force species to migrate to higher altitudes or latitudes.

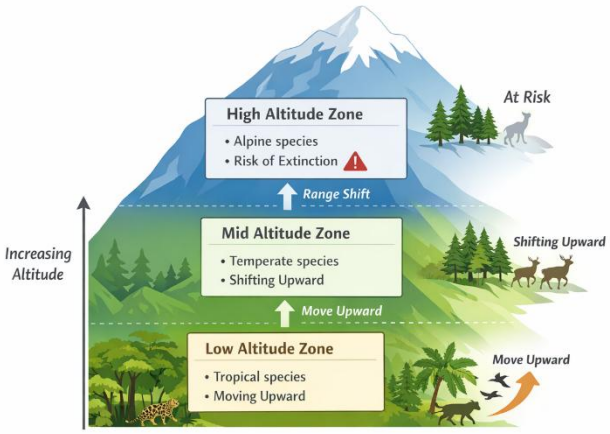

Fig 2: Altitudinal Shift of Forest Species

Forest Disturbances

Disturbance Type	Climate Link
Forest fires	Increased temperature and drought
Invasive species	Altered climate suitability
Drought	Reduced rainfall
Cyclones	Sea-level rise and ocean warming

India has witnessed a significant increase in forest fire incidents, especially in central and northeastern regions (FSI, 2021).

Carbon Sequestration Potential of Indian Forests

Forest-Based Mitigation

India's forests currently sequester about 7,124 million tonnes of carbon in biomass and soil (FSI, 2023).

Table 3: Carbon Sequestration by Forest Types in India

Forest Type	Carbon Stock (tC/ha)
Tropical evergreen	180–250
Tropical moist deciduous	120–180
Tropical dry deciduous	60–120
Mangroves	200–400
Himalayan forests	100–200

Source: FSI, 2023; FAO, 2020

REDD+ and Climate Finance

REDD+ (Reducing Emissions from Deforestation and Forest Degradation) is a global mechanism to incentivize forest conservation.

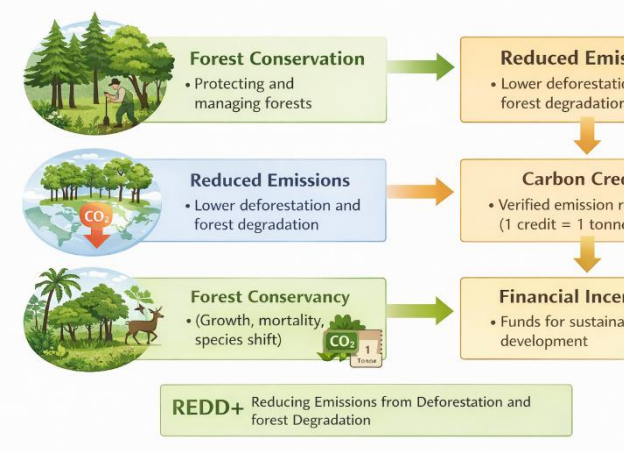

Fig 3: REDD+ Framework

Forestry-Based Adaptation and Mitigation Strategies

Climate-Resilient Forest Management

Key strategies include:

- Assisted natural regeneration
- Mixed-species plantations
- Drought-tolerant species selection
- Fire management systems
- Landscape-level planning

Table 4: Traditional vs Climate-Smart Forestry

Aspect	Traditional Forestry	Climate-Smart Forestry
Species selection	Monoculture	Mixed species
Management goal	Timber production	Multiple ecosystem services
Risk management	Limited	Integrated
Carbon focus	Low	High

Afforestation and Agroforestry

India's National Agroforestry Policy (2014) promotes tree-based farming systems.

Agroforestry enhances:

- Carbon sequestration
- Soil fertility
- Farmer income
- Climate resilience

Policy and Institutional Framework in India

Major policies:

1. National Forest Policy (1988)
2. National Action Plan on Climate Change (NAPCC)
3. Green India Mission

4. CAMPA and Compensatory Afforestation

India aims to create an additional carbon sink of 2.5–3 billion tonnes of CO_2 equivalent by 2030 (MoEFCC, 2015).

Challenges in Implementing Forest-Based Climate Solutions

Key Constraints

Land-Use Conflicts

Land-use conflicts arise due to competing demands for land from agriculture, urbanization, infrastructure development, and industrial expansion, which often lead to deforestation and forest fragmentation. Such conflicts reduce the effectiveness of conservation and climate mitigation initiatives. According to the FAO, "land-use change remains one of the principal drivers of deforestation and forest degradation worldwide" (FAO, 2020).

Lack of Long-Term Monitoring

Effective climate-smart forestry requires continuous monitoring of forest cover, carbon stocks, biodiversity, and ecosystem health. However, many developing countries lack systematic, long-term monitoring frameworks and technical capacity. The IPCC highlights that "robust and sustained monitoring systems are essential for assessing climate impacts and mitigation outcomes in forest ecosystems" (IPCC, 2021).

Socioeconomic Pressures

Forest-dependent communities often rely on forests for livelihoods, fuelwood, and non-timber forest products, leading to overexploitation under economic stress. Poverty, population growth, and unemployment further intensify pressure on forest resources. As noted by the World Bank, "socioeconomic drivers are among the most significant underlying causes of forest degradation in developing regions" (World Bank, 2019).

Institutional Limitations

Weak governance, fragmented institutional responsibilities, and inadequate policy implementation hinder effective forest management and climate action. Institutional constraints often result in poor coordination among agencies and limited enforcement of forest laws. The UNFCCC emphasizes that "institutional capacity and governance structures are critical for the success of climate mitigation and adaptation strategies" (UNFCCC, 2015).

Inadequate Funding

Insufficient financial resources restrict the implementation of afforestation, conservation, and climate adaptation projects. Limited access to climate finance and carbon markets further constrains forest-based initiatives. According to the OECD, "the scale of climate finance remains inadequate compared to the growing needs for mitigation and adaptation in developing countries" (OECD, 2020).

Future Prospects and Research Needs

Priority research areas:

- Climate modeling for forest ecosystems
- Long-term carbon monitoring
- Genetic improvement of tree species
- Remote sensing and GIS applications
- Socioeconomic valuation of ecosystem services

Conclusion

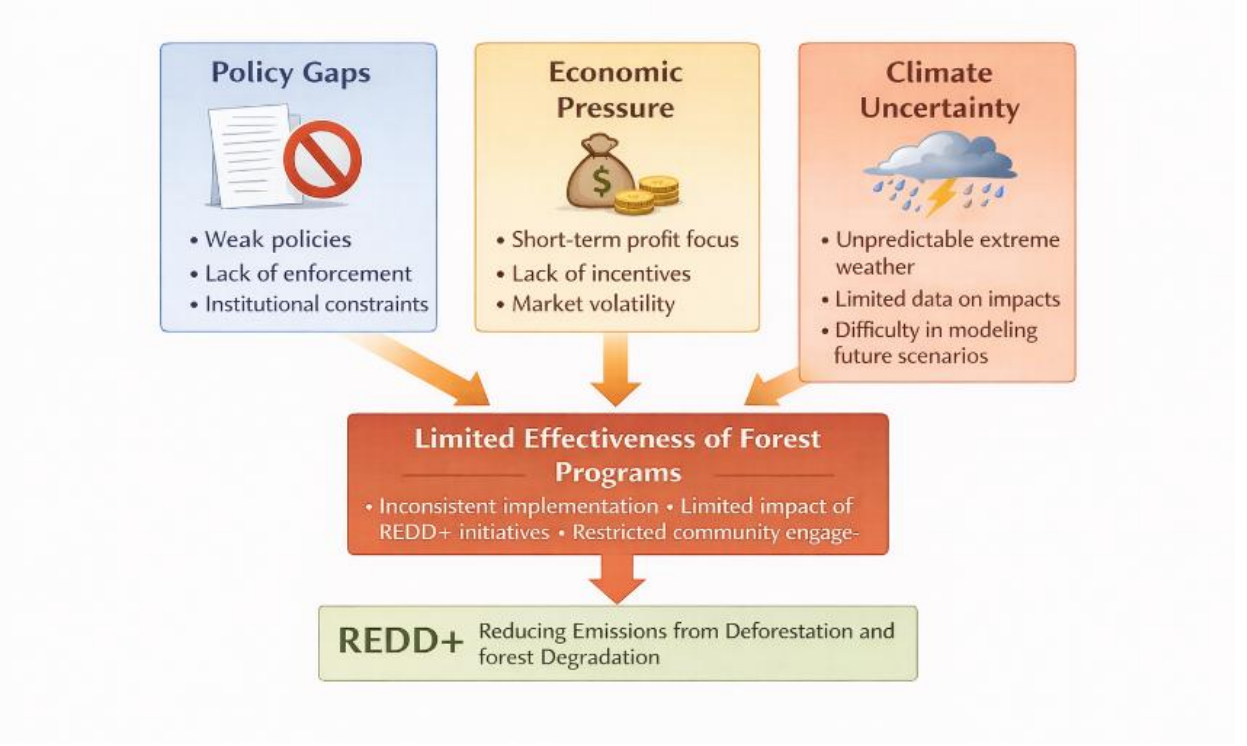

Fig 4: Barriers to Climate-Smart Forestry

Forests are central to India's climate strategy. While climate change poses serious threats to forest ecosystems, it also offers opportunities to integrate sustainable forest management with climate mitigation and adaptation goals. Strengthening scientific research, policy integration, and community participation is essential to ensure resilient forest landscapes.Forestry-based climate solutions represent one of the most cost-effective and sustainable approaches to achieving India's climate commitments and global environmental sustainability.

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Agroforestry practices in south India: Benefits and challenges for adoption

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Introduction

Agroforestry is a land-use system in which trees, crops, and sometimes livestock are deliberately integrated on the same piece of land to create ecological and economic synergies. Unlike conventional monocropping or segregated forestry, agroforestry emphasizes diversity, resilience, and multifunctionality, enabling farmers to derive multiple benefits from a single landscape. This integration improves soil health, enhances biodiversity, stabilizes farm income, and contributes to climate change mitigation by sequestering carbon both above and below ground (Nair, 2012; Chavan *et al*., 2015; Dev *et al*., 2019).In South India, agroforestry is attracting renewed attention due to increasing climatic variability, declining soil fertility, fragmented landholdings, and the rising vulnerability of smallholder farmers. Frequent droughts, erratic monsoons, and market instability have exposed the limitations of input-intensive monoculture systems. Agroforestry offers a practical alternative by spreading risk across multiple products—food, fodder, fuelwood, fruits, and timber—while restoring ecological balance. Policymakers and researchers increasingly recognize agroforestry as a climate-smart and livelihood-secure farming strategy for the region (Pathak *et al*., 2005; Chavan *et al*., 2015).South India has a long tradition of integrating trees into farming landscapes, particularly through home gardens, boundary planting, and scattered trees on croplands. Historical land-use systems combined subsistence crops with fruit trees, spices, medicinal plants, and livestock, especially in humid and semi-humid zones. However, colonial forestry policies and later Green Revolution strategies promoted a separation of agriculture and forestry, leading to declining tree cover on farms in many areas. Recent decades have seen a policy shift recognizing "trees outside forests" as vital for sustainable land management and rural livelihoods (Alavalapati *et al*., 1995; Place *et al*., 2012). South India spans diverse agroecological zones, including arid and semi-arid drylands of Tamil Nadu and Karnataka, humid tropical zones of Kerala, and transitional rainfed regions of interior peninsular India. This diversity allows for a wide range of agroforestry systems adapted to local soil, rainfall, and socio-economic conditions. Species selection and system design vary significantly across these zones, highlighting the need for location-specific agroforestry strategies rather than uniform models (Pathak *et al*., 2005; Chavan *et al*., 2015).

Classification of Agroforestry Systems

Agroforestry systems in South India can be broadly (Table. 1 & Fig. 1) classified into alley cropping, silvopasture, home gardens, and boundary planting. Alley cropping involves growing annual crops between rows of trees, commonly practiced in semi-arid regions for soil moisture conservation. Silvopasture integrates trees with grazing systems, providing fodder, shade, and improved animal productivity. Home gardens represent complex, multi-layered systems combining trees, shrubs, crops, and livestock, while boundary planting uses trees along field borders to provide timber and wind protection (Nair, 2012; Sollen-Norrlin*et al*., 2020). In Tamil Nadu's dry zones, farmers commonly integrate drought-tolerant species such as neem, tamarind, and pongamia with millets and pulses to stabilize yields under water stress. Kerala's traditional home gardens are among the most biodiverse agroforestry systems globally, combining coconut, arecanut, spices, fruits, vegetables, and medicinal plants in vertical layers. In Karnataka's rainfed regions, fruit-based agroforestry systems promoted by NGOs have shown strong long-term adoption and livelihood benefits, particularly when supported by soil and water conservation measures (Alavalapati *et al*., 1995; Pathak *et al*., 2005).

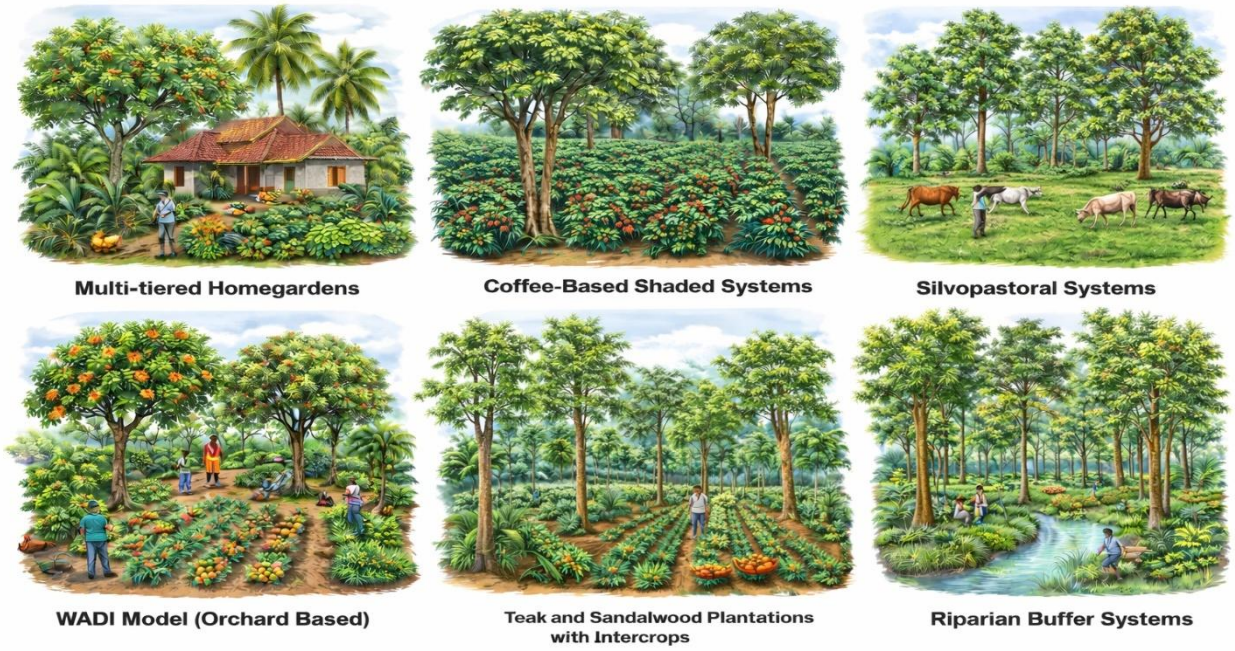

Fig. 1 Agroforestry systems in South India

Table 1: Common Agroforestry Systems in South India

Sr. No.	Name of Agroforestry Practice	State / Region	Components of Agroforestry Practices	Area / Coverage	References
1	Multi-tiered Homegardens	Kerala	Coconut (*Cocos nucifera*), Jackfruit (*Artocarpus heterophyllus*), Mango (*Mangifera indica*), Arecanut (*Areca catechu*)	~5.2 million homesteads	Jaslam*et al*., 2017
2	Coffee-Based Shaded Systems	Kodagu, Karnataka	Coffee (*Coffea* spp.), Jackfruit (*Artocarpus heterophyllus*), Silver oak (*Grevillea robusta*)	~100,000 ha	Maheswarappa*et al*., 2021
3	Silvopastoral Systems	Andhra Pradesh	*Prosopis juliflora*, *Acacia nilotica* integrated with goats and pasture	~300,000 ha	Ramana (2022); Rao *et al*., 2017
4	Alley Cropping & Farm Forestry	Telangana	*Gliricidia sepium*, *Pongamia pinnata* with pulse intercrops	~15,000 farms	Pratik *et al*., 2015; Srinivasarao *et al*., 2014
5	WADI Model (Orchard-based)	Tamil Nadu (Tribal areas)	Mango (*Mangifera indica*), Tamarind (*Tamarindus indica*) with intercrops	~15,000 farms	Pratik *et al*., 2015
6	Coconut-Based Intercropping Systems	Coastal Karnataka	Coconut (*Cocos nucifera*) with spices, vegetables, and tuber crops	Widely practiced (area not quantified)	Alavalapati*et al*., 1995
7	Teak and Sandalwood Plantations with Intercrops	Malnad region, Karnataka	Teak (*Tectona grandis*), Sandalwood (*Santalum album*) with agricultural intercrops	Region-specific plantations	Place *et al*., 2012
8	Riparian Buffer Systems	Tamil Nadu (along water bodies)	Native trees, grasses, shrubs along streams and canals	Site-specific	Chavan *et al*., 2015

Benefits of Agroforestry

Environmental Benefits

Agroforestry significantly improves soil fertility by enhancing organic matter, nutrient cycling, and microbial activity, while tree roots reduce erosion and improve water infiltration. The presence of diverse plant species supports birds, insects, and pollinators, contributing to on-farm biodiversity. Agroforestry systems also actas carbon sinks, storing substantial amounts of carbon in biomass and soil, making them valuable tools for climate change mitigation in South India's vulnerable landscapes (Chavan *et al*., 2015; Sollen-Norrlin*et al*., 2020).

Economic Benefits

From an economic perspective, agroforestry provides farmers with multiple income streams, (Fig. 2**)** reducing dependence on a single crop or market. Timber, fruits, fodder, fuelwood and non-timber forest products can be harvested at different times, offering both short- and long-term returns. Studies from South India show that agroforestry adopters often earn higher and more stable incomes than non-adopters, particularly when fruit-based or home-garden systems are well managed (Alavalapati *et al*., 1995; Pathak *et al*., 2005).

Social and Livelihood Benefits

Agroforestry strengthens food and nutritional security by increasing the availability of fruits, vegetables, and animal products at the household level. It generates on-farm employment and reduces seasonal migration by diversifying livelihood options. Community-based agroforestry initiatives have also enhanced social cohesion and knowledge sharing, contributing to broader rural development goals in South India (Dev *et al*., 2019; Pathak *et al*., 2005).

Fig. 2 Different Benefits of Agroforestry

Challenges to Adoption

Institutional and Policy Challenges

Despite its benefits, agroforestry adoption in South India faces institutional barriers,

including (Table 2) complex regulations governing tree felling and transport. Unclear land and tree tenure rights discourage farmers from planting long-rotation species. Although national policies recognize agroforestry, implementation at the state and local levels remains inconsistent (Place *et al*., 2012; Chavan *et al*., 2015).

Financial Constraints

Agroforestry often requires high initial investment and involves delayed returns, particularly for timber and fruit trees. Limited access to credit, insurance, and subsidies makes it difficult for smallholders to adopt and sustain agroforestry systems, especially in resource-poor regions (Alavalapati *et al*., 1995; Dev *et al*., 2019).

Knowledge and Technical Barriers

Lack of technical knowledge, inadequate extension services, and limited access to quality planting material remain major constraints. Farmers frequently lack guidance on species selection, spacing, and management, leading to suboptimal outcomes and discouraging further adoption (Pathak *et al*., 2005; Place *et al*., 2012).

Market and Value Chain Limitations

Weak market linkages, price volatility, and inadequate processing infrastructure reduce the profitability of agroforestry products. Without assured markets for timber, fruits, or non-timber products, farmers are reluctant to invest in tree-based systems (Dev *et al*., 2019; Sollen-Norrlin*et al*., 2020).

Table 2: Major Challenges to Agroforestry Adoption in South India

Challenge Category	Key Issues	Implications for Adoption	References
Institutional & Policy Challenges	Complex tree felling and transit regulations; unclear land and tree tenure; inconsistent policy implementation	Discourages long-rotation tree planting and reduces farmer confidence in long-term investments	Place *et al*., 2012; Chavan *et al*., 2015
Financial Constraints	High initial costs; delayed returns; limited access to credit, insurance, and subsidies	Restricts adoption by smallholders and increases financial risk	Alavalapati*et al*., 1995; Dev *et al*., 2019
Knowledge & Technical Barriers	Weak extension support; limited technical know-how; poor access to quality planting material	Results in suboptimal system design and lower productivity	Pathak *et al*., 2005; Place *et al*., 2012
Market & Value Chain Limitations	Poor market linkages; price volatility; inadequate processing and storage facilities	Reduces profitability and increases market uncertainty	Dev *et al*., 2019; Sollen-Norrlin*et al*., 2020

Policy and Practice

Government and NGO Initiatives

India's National Agroforestry Policy provides a framework for integrating trees

into agriculture, while state-level programs (Fig. 3)in Tamil Nadu, Karnataka, and Kerala offer subsidies and technical support. NGOs have played a crucial role in promoting context-specific agroforestry models, particularly among smallholders and rainfed farmers (Pathak *et al*., 2005; Chavan *et al*., 2015).

Best Practices for Farmers

Successful agroforestry adoption depends on participatory planning, farmer involvement in decision-making, and careful species selection suited to local agroecological conditions. Combining traditional knowledge with scientific inputs has proven particularly effective in South India (Alavalapati*et al*., 1995; Pathak *et al*., 2005).

Research and Innovation

Participatory research, long-term field trials, and digital advisory tools are increasingly supporting agroforestry expansion. Mobile-based advisories and decision-support systems help farmers access timely information, improving system performance and adoption rates (Chavan *et al*., 2015; Dev *et al*., 2019).

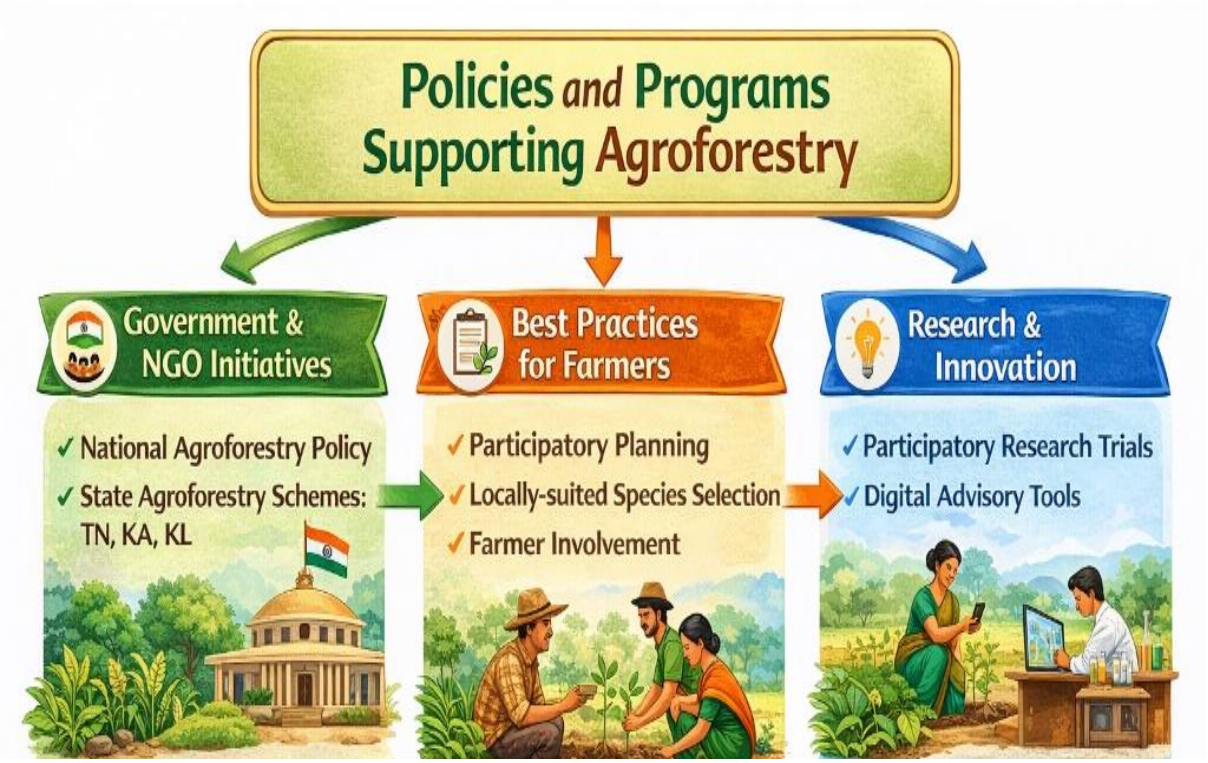

Fig. 3 Policy and supporting agroforestry programs

Conclusion

Agroforestry in South India constitutes a scientifically robust, culturally embedded, and socio-economically viable approach to sustainable land management and resilient rural livelihoods. The integration of trees with crops and livestock enhances ecological stability while addressing key challenges such as climate variability, soil degradation, income insecurity, and fragmented landholdings. Traditional systems, including Kerala's biodiverse home gardens and

orchard- and boundary-based models in Tamil Nadu, Karnataka, Telangana, and Andhra Pradesh, reflect an adaptive evolution of indigenous practices. Empirical evidence highlights improvements in soil fertility, biodiversity conservation, erosion control, and carbon sequestration, underscoring agroforestry's role in climate-smart agriculture. Economically, diversified outputs stabilize farm incomes, while socially, agroforestry strengthens food security, employment, and community resilience. Targeted policy support and institutional interventions are essential to realize its full potential for sustainable and inclusive rural development in South India.

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Conservation of endangered freshwater turtles along the Chambal River, Rajasthan

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Freshwater turtles play a crucial role in maintaining riverine ecosystem health by contributing to nutrient cycling and food-web balance. However, the anthropogenic pressures such as sand mining, illegal fishing, poaching, and habitat degradation have led to a sharp decline in turtle populations across India. The Chambal

River, flowing through Rajasthan, Madhya Pradesh, and Uttar Pradesh, is recognized as a critical breeding and nesting habitat for multiple endangered faunal species. The river harbours a variety of aquatic life like the elusive Ganges River Dolphin (*Platanista gangetica*), Gharial (*Gavialis gangeticus*), Crocodile (*Crocodylus palustris*), seven species of fresh water turtles (*Aspideretes gangeticus*, *Lissemys punctata*, *Chitra indica*, *Batagurkachuga*, *Kachugadhongoka*, *Pangshura tentoria* and *Hardellathurjii*), the otter (*Lutraperspicillata*) and a variety of fishes.

Despite its ecological importance, the Chambal's banks in Dholpur and Morena have been under pressure from intensive sand mining. Unregulated extraction had flattened nesting beaches and altered river flow, directly affecting egg survival.Nests are also frequently damaged by cattle that come to the riverbanks for drinking water.In addition, persistent threats such as illegal fishing, poaching, and the collection of turtle eggs have been widely documented across river systems in northern India.

Recognizing the urgency for the conservationof particularly two Critically Endangered turtle species*ie*., the Red-crowned Roofed Turtle (*Batagurkachuga*) and the Three-striped Roofed Turtle (*Batagurdhongoka*), both listed as *Critically Endangered* on the IUCN Red List due to drastic population declines caused by habitat loss and exploitation (IUCN, 2024), the Forest Department initiated intensified surveys and patrols in support with the Wildlife Conservation Trust (WCT) and local communities. Mining activities along key river stretches were strictly regulated, restoring the integrity of nesting habitats. Equally important was the involvement of local villagers, whose knowledge of the river proved invaluable in identifying major nesting and hatching sites.

The survey was conducted along selected stretches of the Chambal River in the Dholpur region, an area recognized as an important breeding and nesting ground for several wildlife species.Field surveys and patrolling related to freshwater turtles began

in January 2025. These activities continued through the peak nesting season from mid-March to mid-April, followed by the incubation period of approximately 60–80 days, and finally the hatching phase, which typically starts in late May.Observations were carried out during the morning hours (6:00 AM to 8:00 AM) and in the evening (4:00 PM to 6:00 PM or until dusk). The surveys focused on locating nesting sites, monitoring adult turtles, documenting threats, and safeguarding eggs and hatchlings. Data collection was supported by earlier research findings and systematic field observations.

Almost, 35 km of river was surveyed to record nesting locations, nesting density, nest depredation rates, and anthropogenic pressures on the turtles.During the peak nesting period, protection camps were established and staffed round-the-clock. These camps became the frontline defence against predators such as hyenas and jackals, as well as against human interference. From these data, it was prioritized to protect the nesting habitat through the establishment of hatcheries for in-situ conservation.Thus, with the help of hatcheries, this year the forest department were able to protect number of eggs, that would have otherwise most likely been destroyed by jackals (Canis aureus).

Vulnerable nesting areas were fenced to prevent eggs from being washed away by fluctuating water levels, a common cause of nest failure in riverine turtles.

Monitoring and patrolling were significantly increased. Once the eggs hatched, the hatchlings were carefully guided toward the river, reducing mortality during the critical first moments of life, a practice shown to improve survivalrate in endangered chelonian populations.

Through sustained efforts of forest

department and community participation, the conservation initiative achieved remarkable

success. More than 3,000 hatchlings of Red-crowned and Three-striped roofed turtles were safely protected and successfully released into the Chambal River. These

efforts significantly improved hatchling survival rates and contributed positively to population recovery in the region.

The Chambal conservation effort in Dholpur demonstrates that effective wildlife protection is rarely the result of a single

action. It emerges instead from coordinated governance, scientific understanding, and community participation. In a landscape shaped by both natural processes and human demands, the survival of endangered turtles now rests on sustaining these collective efforts.

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तालमखाना - Hygrophilla Spinosa (White Flower)

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Honrary Wild Life Warden
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Talimkhana (Kokilakshi) – Hygrophila schulli
Family: Acanthaceae
Genus: Hygrophila
Species: schulli

This is an annual shrub, growing up to two feet tall. The plant is branchless, with a quadrangular stem. The stem and leaves are sessile and grow at equal intervals around the stem. The plant forms tufts, and the outer parts develop into thorns. On the upper flowering stem, flowers arise at each node, usually in clusters of 8 to 24, with a blue to violet corolla.

This shrub, belonging to the Acanthaceae family, was found abundantly about ten years ago in areas with water accumulation, such as ditches, ponds, small reservoirs, riverbanks, or roadside pits formed by soil and gravel removal. It also grew profusely in low-lying plots outside cities and in waterlogged barren areas.

However, in the past decade, due to urbanization, seasonal changes, reduced rainfall, and loss of moisture in its natural habitat, as well as increased developmental activities such as road construction, the natural growth of Hygrophila schulli has gradually declined, and its habitat range has become limited.

Currently, this plant still grows well in regions of Madhya Pradesh, Chhattisgarh, and Maharashtra, mainly as a weed in paddy fields. It also grows satisfactorily in Andhra Pradesh, Odisha, Bihar, and West Bengal.

Regarding its medicinal properties, it is observed that although there has been no systematic Ayurvedic or scientific research on its ingredients or pharmacological properties, Hygrophila schulli is traditionally known for its therapeutic potential.

According to Kirtikar and Basu (1935) and Singh & Gomez, this plant has significant medicinal value, being used for the treatment of anemia, inflammation, liver protection, and regulation of blood sugar levels. Its seeds are also considered aphrodisiac (tonic in nature) (Sailejan, 2005).


Land scape
Slopes.
And basaltic rock
original place 2006, fly
sculii
near view of flowering
hygrophila sculii

Neglected but Precious Plant – Hygrophila schulli (Kokilakshi)

This neglected yet invaluable plant species faced the threat of extinction due to rapid urbanization and developmental activities. To ensure its protection and propagation, a conservation and proliferation project was undertaken at Burdwan University (West Bengal) by Pal and Aferin, focusing on the study of its reproductive biodiversity.

During their research, scientists observed that the plant commonly reproduces both sexually (through seeds) and vegetatively (through rootstocks and other mechanisms). However, while studying the species in regions such as Paschim Medinipur, Hooghly, and Burdwan, Pal and Aferin noticed an interesting variation — some shrubs of Hygrophila schulli (Kokilakshi) bore white flowers instead of the usual blue-violet flowers.

In the paddy fields and lateritic soil areas of Paschim Medinipur, and along the edges of small ponds, white-flowered Kokilakshi plants were found in abundant quantities. In contrast, in the Burdwan and Hooghly regions, such white-flowered varieties were found in very limited numbers. Although the soil and climatic conditions across these regions were almost identical, the blue-violet variety of Hygrophila schulli predominated, similar to what is seen throughout the country. Occasionally, a few white-flowered shrubs appeared amidst them, and both varieties were restricted to the edges of paddy fields.

Morphologically, both plant types looked identical in structure, with the only difference being the color of the corolla — one blue-violet, the other white.

Further surveys and studies (Awdhiya, 2001) conducted in Chhattisgarh habitats revealed distinct differences in the growth habits of the two floral types. The white-flowered Kokilakshi shrubs were found to be shorter, more branched, and had a denser bushy appearance due to the presence of numerous lateral branches, which often spread over the ground during later stages of growth.

Experimental studies confirmed that the blue-violet–flowered Kokilakshi plants were capable of producing viable seeds, which could germinate into new plants through sexual reproduction. The process of seed formation and dispersal is the primary propagation mechanism in this variant, though vegetative propagation (through roots) also occurs.

In contrast, the white-flowered Kokilakshi (Hygrophila schulli) plants were found to be incapable of producing seeds through sexual means. Their reproduction occurs only vegetatively, through rootstocks.

According to the research of Almeida and Paul, this phenomenon demonstrates a naturally occurring variation endowed by nature itself, highlighting an important aspect of the species' evolutionary and ecological adaptation.

Observation on Reproductive Mechanism in Hygrophila schulli (Kokilakshi)

The permanent foot set (base structure) does not function uniformly across all forms and varieties of the species. At the macroscopic level, both flower types — blue-violet and white — appear identical in external morphology, particularly in the structure of the ovary, where no significant difference is observed.

However, microscopic studies revealed that both flower types contain four to eight ovules per ovary. In a comparative analysis, the ovules of the white-flowered plants were found to be smaller than those of the blue-violet–flowered plants.

In the white-flowered variety, the anthers appear well-filled with numerous pollen grains, but an abnormality was detected in their development. Even in fully mature flowers, the dehiscence (opening) of anthers does not occur normally. During this partial dehiscence process, a small slit forms at the lower part of each anther lobe, but the slit remains very narrow and incomplete, preventing the release of pollen grains.

As a result, the unreleased pollen grains remain accumulated in mass below the anther cavity. To determine the viability and staining behavior of these pollen grains, the Hauser and Morrison (1964) method was employed.

In this procedure, fresh pollen grains from newly opened flowers were collected and treated with a 0.8% aniline blue–lactophenol solution. The samples were then observed under a microscope to examine any changes or viability. After 24 hours, none of the pollen grains showed any staining reaction, indicating that the pollen was non-viable.

This experiment clearly demonstrated that in the white-flowered variety of Hygrophila schulli, the failure of pollen grain viability is

the primary cause behind its inability to reproduce sexually and form seeds.

In a subsequent stage of experimentation (conducted at Kharangana Forest Department Nursery, Wardha, 2007), the white-flowered plants were grown among blue-violet–flowered plants. However, even in this mixed plantation, the white-flowered variety did not produce any fertile seed set.

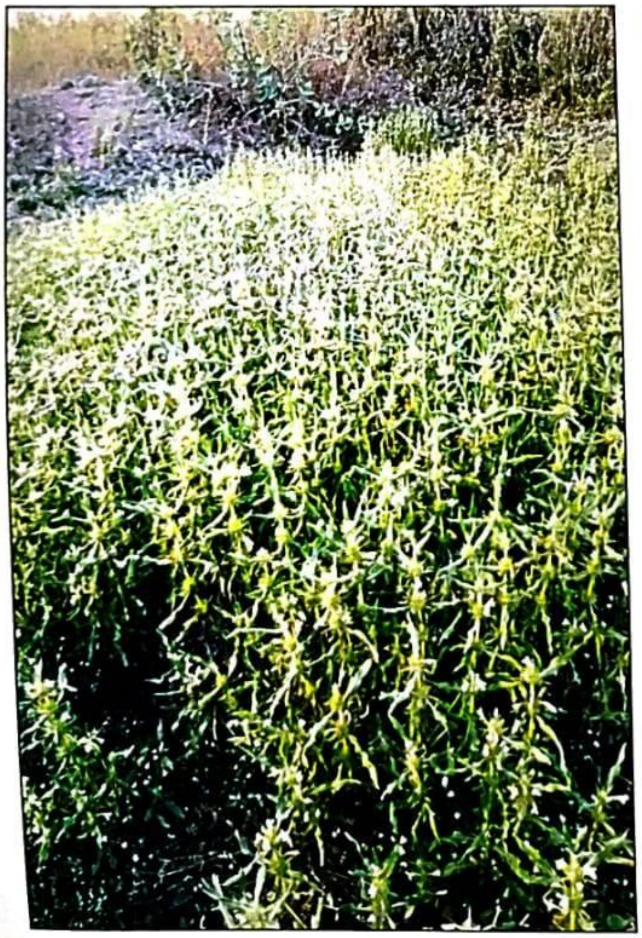
Further observations made during 2008–2009 at Kharangana Nursery (by Raut and A. Ghasle) and later during 2019–2020 (under the supervision of P.A. Kharangana and V.R. Shri Tambade), confirmed that from 2007 to 2020, the white-flowered plants never produced a complete seed set.

From these long-term studies, it was concluded that the two flower types — blue-violet and white — though occurring in close proximity in nature, represent two distinct and stable forms of Hygrophila schulli.

According to Almeida and Pal, these two forms are naturally co-existing variants within the same species, each representing a distinct shrub type with different reproductive mechanisms and growth behavior.

If the blue-violet–flowered form is considered the normal type, then the white-flowered form can be referred to as the white shrub variety of Hygrophila schulli. This was the interpretation proposed by the researchers.


forest officer ghasie
and
hygrophilla spinosa



Ecological and Functional Description – Habitat of the Plant

During 2002–2003, at the Forest Department Grass Research Centre, Chondani (Taluka Arvi, District Wardha), Mr. Ambadas Pakojwar and Mr. Nehare were working in the Forest Research Wing, Chondani. At the same time, my observational studies on medicinal plants in the Chondani forest plot and the pond area within the forest land were ongoing.

While residing in Chondani, I collaborated with Mr. Ambadas and Mr. Nehare to document the various medicinal plants growing in the area and to collect related ecological data.

At that time, I began examining the medicinal properties of the blue-violet–flowered Hygrophila schulli plants, in consultation with local traditional healers (Vaidus) who lived nearby. Together, we conducted field visits to study the plants in their natural habitats.

South of Chondani village, there is a small percolation pond constructed by the government. During one of our surveys near this pond, we noticed that inside the partially dried pond, there were thousands of shrubs of Hygrophila spinosa. Interestingly, instead of the usual blue-violet flowers, these shrubs bore pure white flowers.

The white-flowered plants were found abundantly (in thousands) all around the edges of the pond. Their presence surprised me greatly. I inquired with the local herders who grazed their buffaloes there, but none could provide any definite information about the plants.

At that time, I was uncertain whether these white-flowered plants were a result of environmentally induced phenotypic mutation or represented a natural variety. Therefore, I recorded them as a "white-flowered Kokilakshi", describing them as similar in medicinal properties to the blue-violet–flowered type.

However, at that stage, I did not conduct any taxonomic or reproductive studies on these plants.

In August 2007, I came across the research of Paul and Arefin on Hygrophila schulli, in which they reported that the white-flowered variety represented a distinct form of the species. They concluded that this variety propagates only through vegetative mechanisms and does not reproduce through seeds, as it fails to form viable seed sets.

In my book, Medicinal Plants of Wardha District, I included a description of the medicinal properties of Hygrophila schulli and also mentioned the white-flowered variety. However, at that time (September 2007), my focus was descriptive rather than research-based, and no experimental or analytical study was conducted regarding its taxonomic distinction or reproductive behavior.

Along with Mr. Raut and Mr. Ghasle from the Forest Department, Mr. Nehare (research watchman), some local villagers, and the Chandni Forest Guard, I visited the site where Kokilakshi (Hygrophila schulli) plants were previously found.

For the past four years, I had not visited the pond area. In that period, the biogeographical landscape had changed significantly. The Hygrophila shrubs that

once grew abundantly all around the pond were now found only in a small section below the eastern embankment.

The white-flowered Hygrophila colonies that earlier thrived along all four edges of the pond had completely disappeared. The main reason for this loss was the illegal excavation of hard clay (murum) from the pond bed by tractors and trucks.

From February–March to May, the pond no longer retains water. Even when a little water remains, the bankwater zones dry up quickly. During this dry phase, tractors were used for illegal excavation of murum, which led to the destruction of the Hygrophila colonies that once spread across the pond interior.

The hard clay extraction, carried out during April and May, drastically altered the biological landscape that I had observed in 2002–2003. The entire pond margin (shoreline area) that once hosted Hygrophila shrubs had been completely wiped out.

In January 2008, during another field visit, we found a few surviving plants inside a small pit (6m × 20m) formed as a result of the excavation within the pond. Under the guidance of Mr. Raut (A. Kharangana Range) and Mr. Ghasle (R.O., Kharangana), with the help of forest guards and research staff, these surviving Hygrophila plants were replanted in the same pit area.

The objective of this transplantation was to observe and monitor whether the white-flowered Hygrophila could survive environmental disturbances such as:

Anthropogenic interference, Grazing pressure, Temperature fluctuations, Water-level variations during monsoon, and possible contamination from pesticides carried into the pond through runoff from nearby agricultural fields.

These factors were suspected to have caused toxicity in the pond water, which may have damaged the white-flowered Hygrophila population. Hence, a change of habitat was attempted to monitor its adaptability.

The newly transplanted plants were placed along the edge of the small pit, which contained accumulated runoff water from a larger reservoir.

In the same ecological zone but at a different site, Hygrophila (white-flowered) saplings were planted and observed by Mr. Raut, Mr. Ghasle, and me. The objective was to study the plants' growth behavior, soil adaptability, and response to various climatic factors such as moisture, temperature, and soil type.

Later, these plants were also transferred to the Kharangana Forest Nursery for further observation and comparative study under controlled conditions.

In August 2009, before the small white-flowered saplings began to bloom, several planting beds were prepared. The soil was mixed with hard murum (soft basaltic soil) brought from the Chaudani Reservoir area.

Upon observation in February 2010, it was found that the number of saplings increased rapidly at both sites. However, the saplings at both sites were unable to produce seeds. Their propagation occurred only through root and shoot regeneration.

By 2011, the saplings in the Forest Department nursery had disappeared, mainly due to lack of care and attention. The planting beds were destroyed, and the area was reused by the department to stack seed bags and sow new tree species for propagation.

During 2012–2013, renowned taxonomist Mr. Ramesh Acharya—my mentor in this research—and Mr. Zhanwar, Principal of Postgraduate Science College, Wardha, continuously guided me in this work. They inspired me, an ordinary science graduate, to reach a level where my experimental research could achieve success.

Both of my respected mentors often visited the site with me, conducted field observations and quarry inspections, and explained ecological systems in detail. Their mentorship was truly a blessing, enabling me to understand environmental changes and their consequences with scientific depth.

Together with Mr. Raut and Mr. Ghasle from the Forest Department, we had earlier transferred white-flowered saplings naturally from the reservoir to a small artificial pond. These saplings later developed healthy root colonies. However, the last remaining colony inside the reservoir was eventually completely destroyed.

Outside the reservoir, within the small pond, a large number of white-flowered plants had successfully developed. Scattered colonies were also found along Compartments 265 and 266, as well as near revenue land areas, where small streams and drains flowed through rocky terrains. These plants were a sign of their continued survival, and their spread—though limited—extended over some distance.

During reservoir overflow, the flowing water carried these plants downstream through the drains and rivulets. Since the plants did not reproduce by seeds, they relied entirely on their rootstocks for propagation. Even though they appeared

sparsely, their dispersal capability gained momentum. I have recorded instances of their natural establishment along forest drains and streams—a remarkable example of natural plant dispersal.

This natural adaptation and survival process stands as a fine ecological model for understanding the resilience and regeneration of Hygrophila species in disturbed landscapes.

If favorable conditions prevail, the Hygrophila plants will continue to reproduce naturally, forming colonies along forest streams, and upon entering larger water flows, they may disperse over long distances, leading to a wider expansion of the white-flowered Hygrophila population.

Under the guidance and personal support of Dr. Ramesh Acharya, during the COVID-19 period (2019), the saplings developed in the small pond were transplanted under different environmental conditions. With the assistance of Range Forest Officer Abhay Talhan, Forest Guard Tambale, and other forest staff, the white-flowered Hygrophila plants were transplanted into large prepared beds in the Kharangana nursery area. In these beds, the plants spread primarily through root propagation.

Two species were planted in the same plot:

Blue-flowered Hygrophila

White-flowered Hygrophila

In 2020, seed-based propagation was observed only in the blue-flowered variety (brought from a different location), while the white-flowered plants collected from the pond showed propagation exclusively through root systems.

Conclusion

For over 18 years, I have continuously observed and studied the changing ecological conditions of the Chaudani Reservoir and monitored the white-flowered Hygrophila population using scientific methods.

The decline of this plant species can be attributed mainly to two major reasons:

Human Activity (Excavation of Murum Soil):

During the summer months, tractors excavated and removed hard red murum soil from inside and around the reservoir. This process uprooted the Hygrophila plants, which were then carried away along with the excavated soil. Since the murum was transported and used elsewhere, the root fragments failed to regenerate in the new landscape. Evidence of this transported murum was later observed at several locations, confirming that no further spread occurred.

Grazing Pressure:

During the dry season, when some moisture remained in the reservoir, grass growth occurred, attracting domestic livestock. These animals grazed in the dried and excavated zones of the reservoir, trampling and destroying any remaining Hygrophila saplings.

Climatic Irregularities (Rainfall Variability):

Over the past 15 years, irregular rainfall patterns have also contributed significantly to the disappearance of this species. The unstable hydrological and ecological balance in the reservoir area disrupted the microhabitat necessary for Hygrophila survival. In certain years, the reservoir

overflowed excessively, while in others, it remained completely dry, creating unfavorable ecological conditions.

Consequently, due to climatic fluctuations and human interference, the white-flowered Hygrophila population has been pushed toward local extinction.

Emergence of a Possible New Subspecies

According to Pal and Arefen from Burdwan University (2007), the white-flowered Hygrophila has been classified as a single distinct variety under scientific nomenclature. However, given the observed morphological and ecological variations over time, there remains a possibility of subspecific differentiation—a subject worthy of further taxonomic and genetic study.

It has been proposed earlier that within the general population of blue-violet flowered Hygrophila plants, a few white-flowered individuals occasionally appear in limited numbers. However, my research (conducted in 2007) documents something entirely different — the emergence of a distinct ecological setting consisting exclusively of white-flowered plants, completely devoid of blue-violet forms, forming a separate and stable landscape.

Therefore, I reject the theory proposed by Pal and Arefen, which treats the white-flowered form merely as a minor variant. In this landscape, over the course of 18 years, I have observed the appearance of a wild ecotype of Hygrophila schulli, which has established itself as dominant in the area.

Although I lack the tools and resources to conduct genetic-level investigations, my long-term observations clearly indicate morphological and phenotypic changes, growth stability, and distinct developmental sequences that support the presence of a separate and stable form.

Moreover, due to minimal interference from blue-flowered Hygrophila populations in this region over the last 18 years, it can be reasonably inferred that a subspecific evolution may have occurred. Hence, while I do not claim to have confirmed a new subspecies genetically, I strongly assert that this unique ecotype deserves comprehensive scientific study and ecological protection.

Conocarpus erectus – between myth and science: The tree that divides opinions

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Introduction

The Rise of an Urban Green Icon

In the last two decades, the *Conocarpus erectus*popularly known as buttonwood or "Dubai tree"has found a home in the green belts of many Indian cities, including Hyderabad, Bangalore, Mumbai and many other urban landscapes (Rehman*et al.*, 2022). It's fast growth, dense evergreen canopy, and tolerance to drought, salinity, and air pollution made it a favorite among urban planners (Tauqeer*et al.*, 2019). In the Gulf countries, particularly in Kuwait, Qatar, and the UAE, *Conocarpus* was extensively planted to combat desertification and urban heat. The same promise attracted municipal bodies in Indiatrees that grow quickly, withstand harsh summers, and offer thick shade even in polluted corridors seemed an ideal choice for greening drives (Tauqeer*et al.*, 2019; Amiri*et al.*, 2019).

However, as the species became ubiquitous, public debate followed. Newspaper headlines claimed that *Conocarpus erectus* "causes allergies," "drains groundwater," and "emits toxic substances harmful to crops and humans." Some municipalities even moved to restrict its planting. But how much of this controversy is based on science, and how much on speculation?

The Forest College and Research Institute (FCRI), Mulugu, Telangana, has embarked on a scientific investigation to separate myth from reality evaluating both the positive ecological functions and perceived negative impacts of *Conocarpus erectus* in Indian conditions.

The Green Virtues: Environmental and Economic Benefits

A Natural Pollution Filter

Studies from industrial regions of Iran and Pakistan have revealed that *Conocarpus erectus* efficiently accumulates heavy metals such as lead (Pb), copper (Cu), cadmium (Cd), and nickel (Ni) in its leaves and bark (Yasmeen *et al.*, 2023; Amiri *et al.*, 2019). This metal-accumulation capacity makes it a valuable biomonitor and phytoremediator in polluted environments (Tauqeer*et al.*, 2019). In Karachi and Abadan, *C. erectus* trees planted along highways significantly reduced airborne particulate matter and toxic metal loads in roadside dust (Yasmeen*et al.*, 2023; Amiri*et al.*, 2019). This ability to sequester contaminants in its tissues helps mitigate urban air pollutionan urgent need in India's growing cities.

Carbon Capture and Climate Resilience

A 2020 study published in *Plant Physiology Reports* demonstrated that *Conocarpus*

erectus exposed to elevated CO_2 concentrations showed over 70% higher biomass, improved photosynthetic efficiency, and better water-use performance. This indicates that the species could play a strong role in carbon sequestration and urban climate mitigation, offering substantial CO_2 absorption per unit area. Its evergreen habit ensures year-round photosynthetic activity (Sekhar*et al.*, 2023).

Soil Improvement through Vermicomposting

One of the concerns about *Conocarpus* residues was its allelopathic effectits leaves releasing chemicals that inhibit the germination of neighboring plants. However, a 2022 *Sustainability* study found that when its biomass was processed through vermicomposting, these toxic effects were neutralized, transforming the litter into a nutrient-rich organic fertilizer that enhanced mung bean growth and soil health. Thus, its leaves once considered a problem can become a solution for sustainable organic farming **(**Alsharekh*et al.*, 2022; Rehman*et al.*, 2022**)**.

Potential for Phytoremediation of Polluted Soils

Research in *Ecotoxicology and Environmental Safety* (Tauqeer*et al.*, 2019) revealed that *C. erectus* can phytoextract lead (Pb) while phytostabilizing chromium (Cr), nickel (Ni), and cadmium (Cd), making it one of the few multipurpose species capable of handling multi-metal contamination. With India's rising industrial pollution and fly ash deposition, this feature could be highly valuable in reclamation of contaminated lands and degraded mining sites.

The Criticisms: Myths, Misunderstandings, and Evidence

The Allergy Debate

Several news reports have accused *Conocarpus erectus* of triggering respiratory allergies and asthma. But two major clinical studies from Iran tell a different story.

- A 2022 *Grana* study found that 58% of allergy patients showed mild skin reactivity to *Conocarpus* pollen (Ramezani*et al.*, 2022).
- However, a subsequent 2023 *Allergo Journal International* investigation concluded that only 17% exhibited weak positive reactions, with mean wheal diameters far smaller than those caused by common weeds and grasses (Ramezani*et al.*, 2022; Rehman *et al.*, 2022).

The authors emphasized that *Conocarpus* pollen has low allergenic potential and is unlikely to cause widespread asthma or rhinitis. Hence, allergy concerns appear exaggerated and likely influenced by local conditionssuch as dust, pollutants, or other co-occurring species.

Draining Groundwater and Harming Crops

Media articles frequently allege that *Conocarpus* consumes excessive groundwater or releases harmful chemicals into the soil. Scientifically, the tree's water use is comparable to other evergreen species like *Ficusreligiosa* or *Azadirachtaindica*.

Yes, its allelopathic properties caused by phenolic compounds like gallic, ferulic, and caffeic acids can suppress the germination of

certain herbs and weeds. But these effects are mostly short-term and localized, and vanish when the litter decomposes or is composted. The vermicomposting studies proved that these compounds can be effectively neutralized, turning potential "toxins" into soil nutrients (Sekhar*et al.,* 2023; Tauqeer*et al.,* 2019; Alsharekh*et al.,* 2022; Rehman*et al.,* 2022).

Harmful to Humans and Birds

Another popular belief is that *Conocarpus* releases toxic volatiles harmful to humans and birds. No scientific study has detected any harmful gaseous emissions from the species. On the contrary, biochemical analyses show high levels of antioxidants, phenolics, and flavonoids in its tissues compounds often used in herbal medicine (Sekhar *et al.,* 2023; Tauqeer*et al.,* 2019). Extracts from *C. erectus* have demonstrated antibacterial, antifungal, and anticancer properties in multiple studies, suggesting potential pharmacological applications rather than toxic hazards (Yasmeen*et al.,* 2023).

Hence, further studies are needed to clearly understand the ecological and environmental impacts of Conocarpus species, especially in urban and semi-arid regions. Although these trees are widely planted for landscaping and roadside plantations, their effects on groundwater levels, soil properties, and native biodiversity require systematic scientific evaluation. Long-term and region-specific research is essential to assess both the potential benefits and possible negative consequences of large-scale planting. Such studies will help policymakers and urban planners make evidence-based decisions regarding the sustainable use of Conocarpus trees.

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Aesculus indica (Indian Horse chestnut): A multipurpose himalayan tree supporting livelihoods and biodiversity

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Introduction

Forests serve as vital ecological and economic resources, providing habitat for diverse species, supporting livelihoods, and maintaining environmental balance. Among the various valuable tree species, *Aesculus* plays a significant role. Among the genus, *Aesculus indica* is distributed across cooler climates of eastern Asia, eastern and western North America, and Europe. In India, *A. indica* is native to the northwest Himalayas that occur on the mountain slopes in the moist and shady valleys in the northwestern Himalayas at elevations ranging from 1000 to 3000 m elevation. *A. indica* belongs to the family Sapindaceae, referred to as Indian Horse chestnut, Khanor, Bankhor, Tatwakhar in Himachal Pradesh and Hanudun in Kashmir (Mohapatra et al., 2023). In Himachal Pradesh, it is found in the forests of districts Chamba, Kangra, and Kullu, Mandi, Solan, Sirmour and Shimla.

Taxonomy	
Kingdom	Plantae
Phylum	Tracheophyta
Class	Magnoliopsida
Order	Sapindales
Family	Sapindaceae
Genus	*Aesculus*
Species	*indica*

Morphology

The tree is a medium to large-sized deciduous tree which typically reaches an average height 25 - 30 m with cylindrical trunk diameter of approximately 2.5m. The bark is smooth -grey and exfoliates in narrow bands when it ages. The trees produce flowers from April to May, and fruiting occurs from September to November. Leaves are obovate in shape, ranging seven to nine in numbers and are opposite to sub-opposite in arrangement. The leathery fruits are smooth, shiny dark chocolate to brown in color, having smooth ovoid seeds. The seeds are glossy, chocolate-colored, distorted and oval-shaped weighing approximately 11-21g each in weight (Sood and Mishra, 2014). The best quality of the seeds and fruits are harvested from late September to early November. At lower elevation, the species is often mixed with *Pinus roxburghii* and other broadleaf species, while at higher elevation, it is associated with *Quercus leucotrichophora* and *Quercus floribunda* in the forest (Singh and Mittal, 2019).

Utility

It is an attractive tree *i.e.* known for its ornamental value, with its vibrant multi-colored blossoms and beautiful foliage, therefore is becoming popular as an avenue tree. It is fast growing and yield timber used

for packing cases, water troughs, planking, tea-boxes, mathematical instruments and shoe heels etc. Due to its beautiful blossom, it helps pollination of orchards in the hills. The tree has significant high medicinal value, as oil from the seed is applied externally in the treatment of skin diseases and rheumatism. The seeds contain β-aescin, a compound with antiviral properties, which has been shown to control cucumber mosaic virus with an efficacy of up to 94% (Majeed et al., 2010). Saponins found in the seed are used as a soap substitute. *A. indica* contains various nutrients and minerals and has exhibited significant biological activities which reflects its ethnomedicinal importance (Madhavi et al., 2023). The trees shoots and leaves serve as fodder, collected for the winter when there is a scarcity of green fodder as it contains high nutritional value. After processing, the seeds are used to make edible porridge (*seek*) which is taken as non-cereal food during religious fasting days by local villagers. Indian horse chestnut provides many direct and indirect benefits for the ecosystem and local communities.

Figure: Morphological characteristics of *Aesculus indica* showing leaf, bark, fruit and seed

Establishment and Silviculture

Direct seeding is the simplest and most economical method for establishing Aesculus indica compared to nursery raising and transplanting, as it preserves the deep taproot system.

Seed Collection

Seeds are collected from healthy, mature mother trees between October and December depending on altitude. Fruits are yellow capsules containing large shiny seeds (3–4 cm diameter; ~10 g weight). Mature trees can produce about 60 kg of seeds annually.

Seed Handling

After collection, fruits are shade-dried for two days for easy extraction. Excess drying should be avoided because the seeds lose

viability quickly. Damaged, wrinkled, and diseased seeds are discarded. Seeds should ideally be sown within 10–20 days, as viability declines after 2–3 months of storage.

Site and Planting

The species grows well in moist, well-drained soils between 1,000-3,000 m elevation, especially along streams and riverbanks. Direct sowing is done from November to January before snowfall. Seeds are dibbled in small pits (6-8 cm deep), placing 1-2 seeds per pit and covering with loose soil. Germination begins after snowmelt in March-April.

Aftercare and Protection

Young seedlings are highly susceptible to grazing, fire, and damage by rats and porcupines. Covering seed spots with leaf litter or grass straw and selecting fenced sites reduces losses. Weeds should be removed to ensure proper growth.

Growth and Maturity

Seedlings grow about 40-60 cm annually and reach ~30 cm height within the first season. They remain vulnerable for 3-4 years and grow beyond grazing height in 6-7 years. Flowering begins at 7-8 years, and trees may live up to 300 years.

Major Constraints

The principal establishment problems are grazing, forest fire, and rodent damage, which can be minimized through proper site selection and community protection. *Aesculus indica* seeds often face dormancy and poor germination rates, which can limit the species' regeneration and cultivation efforts.

Conclusion

High yielding seed sources of higher nutritive value, must be selected to develop better strains to explore its wide utility for future breeding and multiplication programme. Genetic variability can be assessed by studying variations in seed sources and selecting the best provenances for optimal seed quality. Standing beside Himalayan streams, *Aesculus indica* supports pollinators, nourishes livestock, shelters communities, and can act as keystone species.

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Valeriana jatamansi: Protecting a Precious Himalayan Herbal Legacy

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Valeriana jatamansi Jones (Jatamansi), also known as Balchhari, Mushkbala, Sugandhbala, is a perennial, aromatic, medicinal herb belonging to the family Caprifoliaceae. The word valerian may come from Latin valere (to be strong or healthy) or from its earlier form of velo (a great medicine) (Bhatt et al., 2012). This herb has long been known as an aromatic and therapeutic product and serves as an important source of raw material for the pharmaceutical and perfumery industries. Taxonomically, *V. jatamansi* Jones is classified under the Kingdom Plantae, Phylum Tracheophyta, Class Magnoliopsida, Order Dipsacales, Family Caprifoliaceae, Genus *Valeriana*, and Species *jatamansi*. It is endemic to the Himalayas from Afghanistan to southwest China; also from India and Nepal and there are populations found in Bhutan and Myanmar. In India, it is found naturally at altitudes from 1,000 to 3,600 m; typically in wet, shady places that have soil with moisture like damp forests, moist grasses, or beside streams. In the Himalayan forests, ***V. jatamansi*** usually grows under the shade of trees like *Quercus leucotrichophora* (banj oak) and *Pinus roxburghii* (chir pine).

V. jatamansi is an erect, pubescent perennial herb that generally grows to a height of 30 to 80cm depending on the environmental conditions in which it is growing (Thakur et al., 2018). *V. jatamansi* has a gynodioecious breeding system with female plants growing taller (up to 80cm) than hermaphrodite plants (about 60cm) under Western Himalayan conditions. The economically important portion of *V. jatamansi* consists of thick elongated rhizomes with fibrous aromatic roots. The lower leaves of the plant are ovate to cordate, measuring 2–10cm long, while the upper leaves are smaller and often dissected. *V. jatamansi* develops flat-topped cymes with snow-white flowers, three stamens, and three-celled ovaries, with a flowering and fruiting period that extends from March to June. Another one of V. jatamansi's significant biological characteristics is that it has a *gynodioecious* breeding system, which means that there are separate male and female reproductive structures on different plants. The use of different plant species makes it possible for *V. jatamansi* to undergo cross pollination

and therefore maintain continual variation of traits, which results in creating considerable genetic diversity. In addition, Rani et al. (2015) discovered that there were many cytotypes (diploid, tetraploid, and octoploid with 2n=16, 32, 64) within the same populations within North-Western Himalayas, thus demonstrating the cytogenetic complexity of this species. The degree of heterozygosity and polyploidy will also facilitate genetic variability.

Valeriana jatamansi – Vegetative stage (left) showing basal rosette leaves; flowering stage (right) showing white inflorescence.

Agrotechnology, Propagation and Production Potential

Cultivating *V. jatamansi*, is necessary for both its conservation and the increasing worldwide demand for the plant. Sustainable harvesting and domesticating the plant type lowers the pressure placed on the wild plant populations and allows for a consistent supply of raw materials. Farmers can propagate this plant by using seeds, rhizomes, and tissue culture however, vegetative propagation is preferred because it creates a consistent plant population that matures earlier. When farmers use seed propagation they need to remember that seeds are tiny and light and require 0.5-1.00 kg of seeds per hectare and must be planted immediately after they have ripened. When using growth regulators to pre-treat seeds, germination rates are improved. When planting rhizoids or rootstocks of *V. jatamansi*, they are planted in June at the onset of monsoon season. A mother nursery must be used to produce healthy suckers as they grow. Tissue culture techniques are becoming a preferred choice for large-scale clonal propagation as well as the preservation of elite genotypes of *V.*

jatamansi. Purohit et al. 2015 have developed a process for multiplying plant types using a number of plant parts which include leaf and nodal segments, apical and axillary buds, petioles and rhizomes are therefore represented in this variety of planting techniques.

To prepare an appropriate growing area, it is essential to conduct three separate ploughing operations. The soil must be loose or friable and well-drained for successful crop production. The addition of Farmyard Manure (FYM) at a rate of 20 tons/ha while preparing the soil, will enhance its fertility. In order to achieve maximum biomass and crop yields, apply N: P: K (Nitrogen: Phosphorus: Potassium) fertiliser at 150 kg N, 75 kg P and 75 kg K/ha. This recommendation is especially important in India where many soils are low in nitrogen. Plant the seedlings (8–10 cm tall) in August at a spacing of 40-45 cm between rows and 30 cm between individual plants. As this crop is shade tolerant, it can be grown successfully as part of an agroforestry system under a nodal canopy of other forest trees. The second year yield of roots is significantly higher than the first year yield. The average site yield will range from 3.5-4.5 tons of rootstock per hectare in year one and 7.0-7.5 tons rootstock per hectare in year two; therefore, harvested year two is the preferred alternative from an economic perspective.

Phytochemistry, Traditional Heritage and Modern Therapeutic Value

Jatamansi's importance can be seen through its being cited in ancient texts like the Rigveda and Charaka Samhita. According to Dhiman ***et al.*** (2020), this plant has been widely used as a natural remedy for anxiety and as a calming (sedative) agent in Ayurvedic and Unani systems of medicine. Its rhizomes have been utilized to treat insomnia, anxiety, nervous tension, hysteria, epilepsy, hypertension dry coughs, jaundice, and wounds. A paste made from its roots is often applied to the forehead to help relieve headaches. The medicinal properties of Jatamansi are mainly due to the presence of important bioactive compounds such as valerenic acid and valepotriates, which are responsible for its calming and therapeutic effects. The essential oil derived from Jatamansi contains over 290 compounds, predominantly monoterpenes and sesquiterpenes (Jugran et al. 2019). The content of essential oils can be found at concentrations between 0.05 - 2.00 % and is impacted by the altitude, genotype, growing conditions, and age of the plants. Extracts from Jatamansi and its essential oil show promise as a therapy for the treatment of neurodegenerative diseases because they would be applicable to multiple levels of care for those with regards to their brain health. Jatamansi has great genetic diversity, resulting in variations of its phytochemical compounds amongst different populations.

Over-Exploitation, Constraints and Conservation Imperatives

V. jatamansi has great commercial and medicinal value; however, there are significant challenges with conserving this species. According to Tan et al., 2019, *V. jatamansi* can be classified as endangered in various areas due to excessive uprooting of its rhizomes from natural habitats. For

example, in the state of Himachal Pradesh, within the district of Chamba, there is an abundance of natural diversity (Purohit and Vyas, 2005); however, over-harvesting and habitat degradation have resulted in decreased populations of *V. jatamansi* (Maurya et al., 2017). The majority of the commercially available plants still come from plants that were collected in their natural habitats; therefore, the quality of the plants is inconsistent and their genetic resources have been depleted. The essential oil content of each plant also varies due to age of the plant, stage of harvesting, climate at the location of the plant, and the genetic make-up of the plant. Lack of standardized harvesting and processing methods also negatively impacts the quality of the essential oils. Therefore, multiple conservation strategies need to be used simultaneously (i.e. supporting the establishment of scientific farming and agroforestry systems, conserving the diversity of cytotypes/germplasm, developing standards for harvesting/post harvest handling of *V. jatamansi*, using biotechnological approaches for mass propagation of elite clones, and developing best management practices for sustainable harvest of *V. jatamansi* in the wild.

Conclusion

The plant *V. jatamansi* showcases an impressive alignment between traditional healing practices and potential pharmaceutical applications. Protecting the aromatic regional treasure of the Himalayan Mountains requires safe gardening methods; preserving genetic diversity; and managing resources in a sustainable way to guarantee ecological endurance, as well as future use as an herbal remedy and pharmaceutical product.

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Fundamentals of remote sensing in forest ecosystems

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Introduction

Forests are a substantial part of the Earth's biosphere. They occupy nearly 30% of the Earth's land surface and are at the core of many ecological cycles by providing the necessary habitats and stabilizing the global climate through carbon storage (Bonan, 2008; Pan et al., 2011; Gillespie et al., 2008). But the forests, which have significant ecological and economic value, are still being cut down at shocking rates. The chief cause of this has been unsustainable management and the results are habitat fragmentation and loss of biodiversity and degradation of ecosystems on a large scale (Canadell& Raupach, 2008; Schmitt et al., 2009). This drop necessitates the availability of accurate and real-time data about the health, structure, and functioning of forests globally.

In response to this demand, remote sensing has been identified as a revolutionary instrument. Essentially, it is a method for collecting data about Earth's surface from a distance without any direct contact (de Jong et al., 2004). We can consider remote sensing devices as an improvement of the human eye; however, while the latter is limited to the visible spectrum of light, the former can capture a much wider range of the electromagnetic spectrum, thus producing results that are beyond human perception.

Core Concepts and Principles

Remote sensing fundamentally involves the recording of the electromagnetic radiation that is either reflected or emitted by the Earth's surface (de Jong et al., 2004). The first satellite for civilian Earth observation, Earth Resources Technology Satellite-1 (ERTS-1), later called Landsat-1, was put into orbit in 1972. This satellite, which had a four-waveband multi-spectral scanning system, was the main contributor to giving remote sensing the worldwide recognition it now enjoys as a vital environmental technique (de Jong et al., 2004). Since then, the capabilities of sensor technologies have been highly selective, resulting in more precise and accurate data.Remote sensing in the forest sector has undergone a radical change from being a scientific "toy" to an "omnipresent technology" (Fassnacht et al., 2024). It provides a means to gather digital data over a wide range of levels in a time-efficient and synoptic manner, which is indispensable for forest monitoring, the most extensive ecosystems on the planet (Wulder, 1998). The digital method that is used makes it possible to carry out mapping on a large scale quickly and at the same time, it also provides for the determination of mapping accuracy and the integration of data with Geographic Information Systems (GIS) (Wulder, 1998; Iverson et al., 1989).

Remote Sensing Platforms and Sensors

Remote sensing platforms are the holders of sensors and the sensors themselves can be situated on the ground, in the air or in space. A basic difference in sensor technology is the division into passive and active systems.

Passive Sensors: The operation of these devices depends on the energy coming from outside; most of the time, this is the energy of the sun, which is used to illuminate the object under observation. The amount of light that the forest canopy reflects is what these sensors measure at various spectral bands of the electromagnetic spectrum. The main examples of the most suitable technologies are the Landsat Thematic Mapper (TM) and Multispectral Scanner (MSS) (Iverson et al., 1989; de Jong et al., 2004). Multispectral sensors get the data in a few large bands, like visible, near-infrared, and short-wave infrared, which are the most important for differentiating the kinds of forests and determining the vitality of the vegetation.

Active Sensors

These devices are engineered to carry their own power source, and as a result, they send out a beam of energy towards the Earth's surface, and then, they calculate the energy that is sent back. Therefore, they can collect data without the need for Sunlight. Examples are:

LiDAR (Light Detection and Ranging): This technology involves the use of a laser beam and the measurement of the time the light takes to reach the surface and back, is used to build the three-dimensional point cloud of the forest structure. The information can be very helpful in absolute terms to measure canopy height, the number of trees per unit area, and biomass.RADAR (Radio Detection and Ranging): These sensor types transmit microwave energy and gauge the energy reflected by the forest. RADAR has a feature that can be vital in certain situations such as when there is the presence of cloud or light rain and these can be the causes of the hassle of reliable monitoring inviteregs with persistent cloud cover, such as tropical rainforests (Patenaude et al., 2005).

Applications in Forest Monitoring

Remote sensing is the mainstay of various applications that drive forest monitoring to a great extent, delivering indispensable data to scientists and managers of the land.

Forest Inventory and Mapping

The primary application of the classification and the mapping of the forest kinds is one of the most essential uses. This is accomplished by the analysis of the spectral signatures of the image pixels. There are two main ways to accomplish this are Supervised Classification with this method, an operator is needed to identify and "train" the computer by giving examples of known land cover classes (e.g., hardwood forest, coniferous forest) with specific pixels. The algorithm then uses these training sites to classify the rest of the pixels based on statistical similarity (Iverson et al., 1989).Unsupervised Classification here, computer algorithms automatically categorize pixels that have similar spectral properties into classes without any human input. After the classification, an operator assigns a real land cover type to each class (Iverson et al., 1989).

Change Detection and Damage Assessment

Remote sensing through the help of satellite images can locate changes in forest cover which is a very effective way (Iverson et al., 1989). It helps a lot in monitoring the changes such as deforestation and reforestation which is very important in places that have few or no ground-based data (Williams & Stauffer, 1979; Woodwell et al., 1984, Iverson et al., 1989). Besides that, satellite sensors can pick up on the changes in the shapes of the trees and the leaves that are caused by drought, acid rain, or insect attacks by identifying changes in the canopy's spectral (Vogelmann & Rock, 1986).

Biophysical and Structural Assessment

Through the use of remote sensing, crucial life-related parameters of nature such as forest biomass and leaf area index are measured. Such measurements usually depend on image texture along with spectral data to get better results (Wulder et al., 1996, Wulder, 1998). Texture, which is the description of the changes in the area of a remote sensing image, can bring in more information to the forest structure that cannot be derived from just the spectral data (Wulder, 1998).

Biodiversity and Ecosystem Conservation

Remote sensing is turning to be more and more important in the conservation of biodiversity and ecosystems by providing accurate mapping and monitoring of the natural habitats and the species that are in danger of extinction. Satellite pictures help in conservation by locating and mapping the most important habitats for animals in forests, wetlands, and grasslands. Moreover, it locates the first signs of stress or degradation in marine and coastal ecosystems like coral reefs, mangroves, and seagrasses which help a lot in understanding ocean health and the effects of climate change. All these functions make remote sensing a very important instrument in the support and revival of those ecosystems that are at risk. (Chand, 2025)

UAV-Based Remote Sensing for Forest Fire Risk Assessment

Currently, the improvement of drone (UAV) technology has opened a great range of possibilities for the forest to be monitored in high resolution. The use of UAVs is the link between the standard satellite images and the on-ground surveys since they can deliver real-time, ultra-high-resolution data that is very important for the detection of the less visible vegetation stress, or forest health, variations (Abdusalomov et al., 2025; Hamzah et al., 2025).Abdusalomov et al. (2025) introduced a compact UAV-based method for locating fire-risk trees in the early stages in wild forests. Their method couples a MobileNetV3-Small backbone with a Single Shot Detector (SSD) head, which is streamlined for the real-time detection on edge devices such as Jetson Xavier NX. This work made use of more than 3000 annotated RGB UAV images representing healthy, partially dead, and fully dead trees to train the model and testing showed the precision to be 94.1%, recall 93.7%, and mAP 90.7%.This is just one example of the many ways AI-powered object detection is rapidly being adopted in forest ecosystem remote sensing. Through UAV photos, it is possible to pinpoint fire-causing woody material at the fine level, that

is, the one which due to lower moisture content and higher flammability most probably acts as ignition sources (Calderisi et al., 2025). In contrast to conventional satellite-based monitoring, the UAV system is capable of noticing not only the detailed phenotypic but also the structural changes, even in mixed and tightly wooded areas (Junttila, 2025).Local data processing is possible through the combination of UAV sensing and edge computing, thereby increasing the speed of data handling and reducing the need for the external communication links (Oliveira et al., 2024). Still, the problems of changing light, seasonal canopy changes and a limited number of species at the level of classification continue to be major issues (Abdusalomov et al., 2025). It is anticipated that future developments will feature multispectral and thermal sensors to advance fire-risk forecasting and ecosystem surveillance (Tezcan & Eren, 2025).In brief, the remote sensing technology employing UAVs is a revolutionary forest monitoring technology supply that can offer preemptive, data-driven insights for forest health assessment and wildfire prevention.

Multi-Source Remote Sensing for Forest Carbon Monitoring

Forests are the mainstay of the Earth's carbon cycle, as they hold nearly 45% of the carbon present on land and are responsible for taking out almost 3.5 petagrams of carbon from the atmosphere every year (Liang et al., 2025). Therefore, it is an absolute necessity to have a reliable monitoring system in place for forest carbon stocks if we are to successfully achieve global climate targets such as carbon neutrality and the objectives set in the Paris Agreement. Remote sensing, especially when used together with GIS for spatial analysis and data integration, offers a timely and large-scale solution to the problem of estimating forest biomass and carbon stocks (Liu et al., 2015; Patenaude et al., 2005).In their demonstration, the researchers have shown that the use of data from a variety of remote sensing sources leads to a sizable gain in the precision of forest carbon quantification. To be specific, Landsat and Sentinel-2 are two of the optical sensors that could provide detailed spectral data related to vegetation greenness and the general health of the canopy. At the same time, radar sensors such as Sentinel-1 and ALOS-2 are capable of structural data acquisition of forest stands as they can penetrate clouds and similar occlusions. LiDAR sensors such as GEDI or ICESat-2 facilitate the accurate vertical profiling of the forest and also the biomass distribution. The UAV-based platform, in this case, coordinates the data as it captures ultra-high-resolution images for the local calibration and validation process (Liang et al., 2025).The combination of several data sources that is commonly known as data fusion allows wood resources experts to extract more accurate and detailed information from biomass and carbon content. Liang et al. (2025) found that multi-sensor fusion resulted in biomass estimation accuracy with the R^2 value reaching 0.83 and the root mean square deviation (RMSE) being lower than 25 Mg/ha thus, single-sensor approaches were outperformed. The mentioned advancements in particular pave

the way to the INVENTORYs of measurement, reporting, and verification (MRV) systems necessary for international programs such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) to operate efficiently.Besides scientific uses, multisource remote sensing is a viable tool for the local and global carbon accounting initiatives. A case in point is Brazil's PRODES program, which uses optical and radar data to monitor deforestation; likewise, Congo Basin and Indonesia systems have adopted the use of

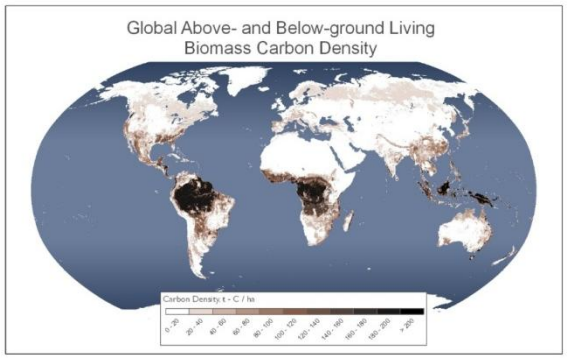

Fig.1. The distribution of carbon at a global level (Ruesch, 2000)

LiDAR and SAR data to determine carbon fluxes and ecosystem degradation (Saatchi et al., 2011; Harris et al., 2012). These programs create the framework for openness and reliability in the reporting of carbon emissions and removals and thus serve as a direct link betweenremote sensing and the implementation of climate policies

Change Detection in Forest Ecosystems

Change detection, alternatively known as multitemporal image assessment, is the basic scientific work of remote sensing that has made it possible to look at how forests have evolved over time. It basically means that one looks at the pictures depicting the same site but taken at different time periods so as to decide whether and how much forest cover, structure, or condition have changed. The main aim of this technology is to keep track of the natural and anthropogenic

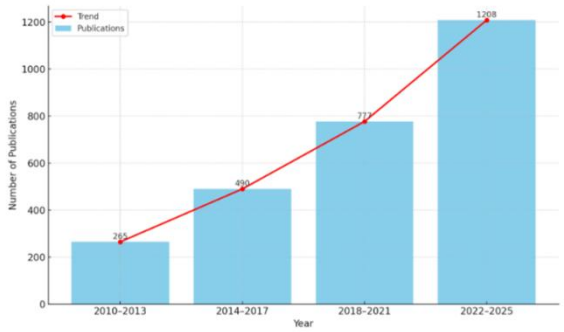

Fig.2. Publication trends on forest carbon monitoring and remote sensing, categorized by 4-year intervals from 2010 to 2025. Data obtained from Web of Science Collection using keywords: “Forest Carbon Monitoring” AND “Remote Sensing” (Liang, 2025)

processes like deforestation, regeneration, insect outbreaks, and forest degradation (Wulder, 1998).Only changes obtained from comparing images that are geometrically registered accurately and have been adjusted for radiometric consistency can be considered real. The differences can result from the use of classified thematic maps, spectral values, or spectral data transformations. If one works with thematic maps, then it is necessary to ensure that classification methods used in different dates are the same because the differences in the training data or the boundary location can cause classification errors. Lark (1995) asserted that the merging of various classifications may increase the number of pixels that have been incorrectly classified,

especially when the number of land cover classes is large.Spectral-based methods determine the changes that have occurred in the pixel values of the images which have been geometrically corrected and coregistered by means of image differencing or image ratioing. With image differencing, the pixel values of one date are taken away from those of another in order to get a difference image that shows the regions where significant change has taken place (Muchoney& Haack, 1994). On the other hand, image ratioing divides pixel values of one image by those of another with the aim of lighting up the proportional changes in reflectance. Olsson (1994) used spectral differencing for forest thinning assessment and noted that the reflectance decreased immediately after tree removal but then gradually increased as the vegetation recovered over time.There are also some other sophisticated methods for change detection like Principal Component Analysis (PCA) of multi-date imagery (Fung & LeDrew, 1987), Change Vector Analysis (CVA) (Lambin & Strahler, 1994) and techniques based on fuzzy logic (Gong, 1993). As an example, Leckie et al. (1992) studied a series of 13 Landsat MSS images over time to characterize temporal trends and to forecast future forest stand conditions on the basis of historical change patterns.

Challenges and Future Directions

Though extremely useful, remote sensing in forestry is not without challenges. One of them is the problem of the correlation between spectral data and forest structure, which can be quite different, thus resulting in inaccurate predictions at the single-pixel level (Iverson et al., 1989). The speed at which new remote sensing methods are introduced into day-to-day forestry operations is different from one region to another and is affected by factors such as existing workflows, traditions, and regulations (Fassnacht et al., 2024).Another major issue concerning data is that of their uncertainty. The significance of map and model validation is pointed out as being of utmost importance for raising the trust in remote sensing products and the willingness to adopt them (Fassnacht et al., 2024). The research community is of the view that more research works should be done so that remote sensing products can be compared against the conventional field methods so as to show their worth (Fassnacht et al., 2024). Research in the future should be directed at coming up with the most effective ways of validating these models and of generating metadata which will allow for a rigorous estimation of prediction variance. To overlook this uncertainty is not an option because this factor alone can be responsible for over 95% of the total variability in large-area estimations (Fassnacht et al., 2024).

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Bergenia ligulata (Pashanbheda): Ethnobotany, phytochemistry, pharmacology and conservation perspectives

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Medicinal plants are one of nature's greatest gifts to mankind and provide us with treatments for a large number of health-related conditions. *Bergenia ligulata* (Pashanbheda or stone breaker) is one of the major Himalayan medicinal plants used in traditional medicine. It is recognized as a threatened medicinal plant by the criteria established by the International Union for Conservation of Nature (IUCN); therefore conservation of *B. liglulata* is of utmost importance (Gohain et al. 2022). The rhizome of *B. ligulata* is highly treasured and used in many traditional medicines as a treatment for urinary stones, dysuria, inflammation, fever, jaundice and wound healing (Koul et al. 2020). The confirmation of *B. ligulata* traditional uses in modern medicine, mainly its ability to prevent kidney stones, has generated tremendous global scientific interest (Roychoudhury et al. 2022). However, excessive harvesting of *B. ligulata* from its natural habitat in the Himalayas throughout history has placed immense stress on its natural habitat, thus the need for sustainable farming practices and conservation methods is critical.

Taxonomy and Classification

B. ligulata is a species of plant belonging to the family Saxifragaceae, and is classified by taxonomists as follows: Kingdom Plantae, Subkingdom Tracheophyta, Division Magnoliophyta, Class Magnoliopsida, and Order Saxifragales. Within the genus Bergenia, several species of perennial rhizomatous plants exist; however, B. ligulata can be cited as being one of the most commonly used botanicals with medicinal value. Traditional Indian medicine recognizes B. ligulata as a medicinal resource for dealing with kidney stones via lithotripsy, and this relationship is noted throughout various Ayurvedic classic literature (i.e., Charaka Samhita, Sushruta Samhita, and Ashtanga Hridaya) under the vernacular name of Pashanbheda (Gurav and Gurav 2014). Additionally, B. ligulata has many other vernacular names including Pashana, Ashmabhid, Ashmabheda, Asmaribheda, Nagabhid, Parwatbhed, Upalbhedak, and Shilabhed (Chitme et al., 2010), demonstrating that it possesses a broad acceptance for use within diverse forms of traditional medicine throughout India.

Habit and flowering morphology of *Bergenia ligulata* showing fleshy, rounded

basal leaves and pink cymose panicles emerging from rocky soil habitat.

Morphology and botanical description

B. ligulata is an extensively-branched perennial herb with a strong and resilient growth form, adapted well to Himalayan rocky and temperate conditions. The root system of the plant is reddish, and likewise has a thickness of approximately 2-5 cm. The stem is short, stout, fleshy and procumbent. The leaf blades are large, fleshy and ovate, petiole is sessile, the terminal leaf margin is rounded and the edges have short hairs; thus, due to their leather-like texture and broad shape, B. ligulata is often referred to as elephant-ear or leather cabbage. The flowers are white, pink or purple; bloom from the months of April and May; are present in a cymose panicle; and measure 3 cm in diameter. The fruit is a drupe that has an orangish-reddish coloring. The rhizome is the part of the plant that is most commonly used for medicinal purposes; it is thick and fleshy.

Distribution and ecology

The Himalayan regions of both temperate and sub-temperate areas are the home of *B. ligulata*. From Kashmir to Nepal, Sikkim, Bhutan, and the northeastern states of India, as well as Pakistan and the surrounding areas, this is a plant with broad geographic distribution (Koul et al., 2020). The species typically occurs at elevations between 1,500 and 3,000 meters; however, it prefers the moist, rocky, shaded slopes of temperate/ subalpine areas. The nature of the plant's rock-dwelling sale is believed to relate to its stone-breaking properties in traditional medicine - a classic case of the doctrine of signatures in ethno-botany.

Ethnomedicinal importance and traditional uses

B. ligulata has an important role in both traditional medicines where it is well-known for its role in the breakdown of kidney and bladder stones, relief of dysuria and treatment of urinary tract infections (Koul et al. 2020). Its Sanskrit name Pashanbheda translates to breaker of stones, which is indicative of its long history of use for managing urinary stones and renal disorders. In addition to its role as a lithotripter, B. ligulata is viewed in traditional medicinal systems as having anti-urolithiatic, anti-inflammatory, anti-ulcer, anti-arrhythmic, anti-hepatotoxic, neuro-protective, anti-fungal, anti-diabetic, anti-nociceptive, immuno-modulatory, and potentially anti-HIV properties, and so it has broad use for a variety of ailments of the urinary system, the liver, the gastrointestinal tract, metabolic conditions, and inflammatory diseases. More recently, many studies have confirmed the traditional uses of B. ligulata based on its composition of phytochemicals (Roychoudhury et al. 2022; Koul et al. 2020), thereby supporting its importance in evidence-based herbal medicine.

Phytochemistry: Bioactive compounds and their interconnection

B. ligulata contains high levels of secondary metabolite compounds including phenolics, flavonoids, terpenoids, glycosides, tannins and sterols, with its most popular active substance being bergenin, a C-glycoside of 4-O-methyl gallic acid, which is used as a chemical marker for establishing a standard for its quality (Roychoudhury et al., 2022). Arbutin, gallic acid, protocatechuic acid, chlorogenic acid, catechin, syringic acid, ferulic acid, β-sitosterol, stigmasterol, caryophyllene, 1,8-cineole, quercetin and reynoutrin are also constituents of this plant. All of these phytochemicals have a synergistic effect, with the phenolics and flavonoids responsible for their antioxidant and antiinflammatory properties; terpenoids and sterols providing an antimicrobial action; and the main ingredient being bergenin's involvement in its antiurolithic properties. Therefore, the therapeutic effects of B. ligulata are the result of a composite phytochemical system rather than that of an individual compound.

Agro-Techniques and cultivation practices

B. ligulata is well adapted to temperate and humid environments where the temperatures usually do not exceed 20°C. This plant prefers sandy or weakly acidic soils contain large amounts of humic organic material, but also survives in all soils from medium loamy to clay with the addition of manure, due to its hardy qualities. Although the plant is tolerant to complete sunlight, it has superior vegetative growth under partially shaded conditions. Vegetative reproduction consists primarily of pieces of the rhizome about 7.5 – 12.5 cm long with 2 - 3 nodes planted at a spacing of about 10 cm × 10 cm; this sequenced cropping reduces the cropping time by almost a year compared to seed reproduction. Seed production is not as effective because they are small and have poor germination rates; however, cold stratification for 15 days increases the germination rate, which may take from 60 to 90 days to germinate under greenhouse conditions, and then they are transplanted at the 2 - 3 leaf stage (Singh and Pandey 2019). The need for sustainable cultivation practices to relieve pressure on the remaining natural populations is essential.

Conservation concerns and future perspectives

The characteristics of curious, ground-based plants that are used for food have made them sought after by a growing number of people. This is resulting in a huge demand for *B. ligulata* and an increasing loss of natural populations across the Himalayan Region due to unregulated collection (Gohain et al., 2022). As it has been recognised as a threatened species, there is now a pressing need for the conservation of this plant through: 1) in situ conservation of natural habitats within the region, 2) ex situ conservation through botanical gardens and in vitro culture techniques and 3) the promotion of large-scale cultivation. It is essential to establish, develop and standardise protocols for sustainable harvesting and strict phytochemical quality control. In addition, the future of *B. ligulata* will be further supported as it gains more scientific credibility through integrated

molecular authentication and metabolomic profiling, and through the provision of well-designed clinical validation studies supporting the use of the plant in evidence-based phytomedicine.

Conclusion

B. ligulata is an exceptional Himalayan medicinal herb that has a long-standing traditional use as a stone breaker and is getting more attention from modern pharmacological research. *B. ligulata* phytochemical profile contains high concentrations of bergenin and phenolics that explain its antiurolithic, antioxidant, and anti-inflammatory activity and the increasing commercial demand has created an ecological strain on this species. The integration of traditional knowledge, phytochemistry, pharmacology, agrotechniques, and conservation biology is vital for the sustainable utilization of *B. ligulata*. Hence, *B. ligulata* not only serves as a therapeutic treasure of the Himalayas but also serves as an exemplary model for the integration of ethnomedicine, modern scientific validation and biodiversity conservation.

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Medicinal and aromatic plants of India: Integrating ancient heritage with modern science

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Abstract
India's medicinal and aromatic plants represent a rich botanical heritage rooted in ancient traditions such as Ayurveda, Unani, and Siddha, and increasingly validated by modern science. These plants are vital sources of bioactive compounds used in traditional and contemporary medicine, perfumery, and pharmaceuticals. Rising global demand, especially post-COVID-19, highlights the need for scientific cultivation, sustainable harvesting, and biodiversity conservation. Medicinal and aromatic crop cultivation offers economic opportunities, agricultural diversification, and environmental sustainability, particularly on marginal lands. Integrating traditional knowledge with modern research and cultivation practices can strengthen healthcare systems, conserve endangered species, and enhance rural livelihoods while meeting growing global herbal product demands.
Keywords: Medicinal plants, aromatic crops, traditional medicine, biodiversity conservation and sustainable cultivation.

Introduction

Medicinal plants have played a vital role in human health for millennia, providing essential therapeutic agents and forming the foundation of traditional healing systems worldwide.The use of medicinal plants is not just a leftover practice from the past, but an active and growing field that continues to shape both traditional and modern medicine. India's vast biodiversity and enduring cultural heritage have fostered the use of medicinal and aromatic plants for more than five millennia. Across generations, healing knowledge flowed through oral traditions, handwritten manuscripts, and classical treatises. The VinayaPiṭaka—one of the oldest Buddhist scriptures—reveals how deeply plants were woven into early Indian life. There are explicit mentions of the uses of turmeric (haliddā), garlic (lasuṇa), asafoetida (hiṅgu), and the trikaṭu formula—a combination of long pepper (pippali), black pepper (marica), and dry ginger (śuṇṭhī)—to treat stomach ailments and fever. Jaundice and skin diseases were treated with decoctions made from neem bark (nimba), kuṭaja bark (used for dysentery), and blue lotus (uppala).Classical Ayurvedic texts such as the CharakaSaṃhitā and SuśrutaSaṃhitā also provide detailed accounts of hundreds of medicinal plants, describing their nomenclature, methods of preparation, and therapeutic applications.In traditional medicine, plants were valued not only for their direct therapeutic effects but also for their holistic and spiritual properties. In systems such as Ayurveda and Traditional Chinese Medicine, these plants played an integral role in healing practices.Even today, these traditional systems—Ayurveda, Unani, and Siddha—remain alive, moving in rhythm with modern healthcare. Scientific research has begun to affirm what ancient

healers long understood. Turmeric reveals powerful antioxidant and anti-inflammatory effects; Ashwagandha demonstrates adaptogenic and hepatoprotective properties. Plants like *Catharanthus roseus* **(**Sadabahar), *Rauwolfia serpentina* (Sarpagandha), *Withania somnifera* (Ashwagandha), and *Asparagus* ***racemosus*** (Shatavari) now bridge tradition and technology, serving modern medicine in the treatment of cancer, hypertension, neurological disorders, and hormonal imbalances.

Distribution and Diversity of medicinal plants

Traditional knowledge systems across continents represent a living heritage of healing practices, deeply rooted in biodiversity and cultural traditions. Nigeria, one of the most biologically diverse countries in Africa, is home to a wide variety of medicinal plants and holds a rich body of traditional knowledge related to their use. However, much of this knowledge is passed down orally from generation to generation, making it vulnerable to loss due to cultural changes, urbanization, deforestation, and other environmental pressures.Traditional medicinal practices remain deeply integrated into the healthcare systems of nations such as China, India, Japan, Pakistan, Sri Lanka, and Thailand. Within India, medicinal plants are dispersed across an expansive array of natural habitats (S. Hassan, 2020). Approximately, 70% of the country's medicinal plantsare concentrated within tropical forests, with particularly high density in the Eastern and Western Ghats, the Chota Nagpur Plateau, the Aravalli and Vindhya ranges, and the Himalayan region (Mittermeier, 1999). As the world's highest mountain system, the Himalayas serve as a premier repository for this botanical diversity. The region's intricate topography and varied climatic gradients foster a multitude of ecological niches that sustain a vast array of specialized plant species. Geographically, this Himalayan corridor stretches from Jammu and Kashmir in the west to Arunachal Pradesh in the east. It is situated between latitudes 27°–38° N and longitudes 72°–89° E, encompassing a total area of roughly 236,000 km² (Valdiya, 1980).

A global legacy of medicinal plants

As the global demand for herbal medicines grows, there is a new responsibility to grow plants scientifically, harvest them sustainably, and protect biodiversity. By doing this, India not only preserves its natural ecosystems but also safeguards a rich legacy of plant knowledge that continues to benefit people. The connection between plants and human health goes back far beyond written history. Prehistoric societies often saw disease as a punishment from the gods and responded with prayers, rituals, and herbal remedies, known as JaduyiSharbat. Archaeological findings from 60,000-year-old Neanderthal burial sites in Iraq show the use of medicinal plants such as marshmallow and yarrow which are still used in traditional medicine today.Similar stories appear around the world. In Mexico indigenous communities used the peyote cactus for spiritual and healing purposes, a practice later confirmed by its antibiotic properties. Ancient Sumerian writings

mention the use of opium, thyme, mustard, and sulphur while Babylonian texts added senna, coriander, saffron, cinnamon, and garlic to their herbal medicines. In India plants were used not only to heal but also to please the senses. The Aromatic traditions especially in perfumery were highly developed. At Nawabi banquets guests were welcomed with attars and rosewater, creating a fragrant and elegant atmosphere. Also, the silver trays, ivory or silver attar containers shaped like mangoes or peacocks and lacquered boxes holding precious vials showed luxury and refinement. Cities such as Delhi, Agra, Kannauj, Lucknow, and Hyderabad became centres of fragrance, where the art of distillation reached perfection. From these cities, India's aromatic products travelled far—across Asia, Europe and Africa—carrying a culture where plants healed, scented, and connected people across civilizations.

Current Scenario in India

India possesses immense medicinal plant diversity (6,000–7,000 species) yet it has struggled to develop internationally recognized and commercially viable phytomedicines. Despite a global market valued at 60–100 billion USD, India's share remains disproportionately low at only 0.1 billion USD (A. Subramoniam, 2014). Nearly 960 species are traded, with Uttar Pradesh and Rajasthan leading in production. Post-COVID, the demand for immunity-boosting herbs has increased significantly,emphasizing the role of medicinal plant cultivation and conservation, employment generation, export promotionand integration with traditional agriculture. Institutions such as Central Institute of Medicinal and Aromatic Plants (CIMAP), Lucknow have contributed by developing improved varieties and cultivation practices, while companies like PatanjaliAyurved and Dabur promote contract farming of crops like ashwagandha, aloe veraand Mentha. Out of about 3,000 medicinally important species, nearly 2,500 are used in traditional medicine but only around 100 are regularly utilized. India is the second-largest exporter of medicinal plants after China, with both countries accounting for over 70% of global demand. However, China has advanced significantly by documenting over 800 medicinal plants and developing 187,518 manufactured drugs and 1,489 patented herbal medicines (Pan et al., 2013). In contrastIndia has limited monographs and lower export performance (Kamboj, 2000). Traditional systems such as Ayurveda, Siddha, and Unani, though time-tested, often lack modern validation for safety, efficacy, and quality. Additionally, nearly 95% of raw materials are sourced from forestswith minimal cultivation. According to the National Medicinal Plants Board about 6,000 species are used, but only around 50 are cultivated. Although the global market is valued at ₹600 billion, India's share is just ₹5 billion. Challenges such as poor-quality planting material, inadequate technical knowledge, limited market access, low adoption of good agricultural practicesand minimal value addition continue to hinder the sector's growth. Scientific researches also nowvalidate these traditional practices in biodiverse regionsby systematically

investigating medicinal plants for their therapeutic potential, as depicted in Fig.1.

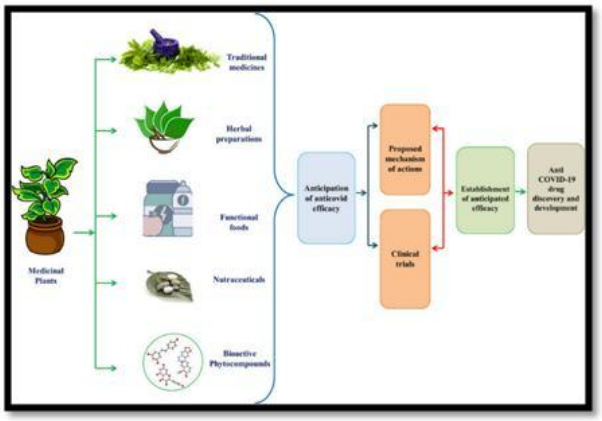

Fig. 1: Investigation process of drug discovery from medicinal plants

Importance of Medicinal Plants in Healthcare Systems

Medicinal plants have been used for healing since ancient times in many cultures. Plants contain many useful substances that help treat common problems like colds and stomach disorders and fight serious diseases like cancer, malaria, infections and long-term inflammatory conditions.In traditional systems like Ayurveda, medicinal plants are the main source of treatment.Prominent examples of such Ayurvedic herbs include Tulsi, Turmeric, Neem, Amla, Ashwagandha, and Ginger (Fig.2) all of which are traditionally valued for their ability to boost immunity and maintain overall wellness. Good nutrition is considered important for body growth, and healing is believed to occur through the balance of natural elements and body energy (Agni). Medicinal plants are prepared as teas, pastes, or extracts, and are given in proper amounts by skilled practitioners. Plants such as turmeric, Echinacea, and Cannabis sativa are now used in both traditional and modern medicines.Even with modern medical advances, about one-third of today's medicines come from plants and other natural sources. They are also used to produce essential oils, dyes, and vegetable oils.Many of these compounds originate as metabolic by-products that, while non-essential for the plant, have significant pharmacological effects on humans. Medicinal drugs can be obtained from various plant parts:

Fruits: Senna, Solanum viarum, Datura

Flowers: Butea monosperma, Bauhinia variegata

Leaves: Senna, Datura, Periwinkle

Stems: Liquorice, Ginger, Dioscorea, Garlic

Roots: Rauvolfia, Periwinkle, Ginseng

Seeds: Isabgol, Abrus

Bark: Cinchona

Fig 2: Some medicinal plants from the Ayurvedic system renowned for their immunity-boosting properties

Bioactive Constituents and Potential of Medicinal and Aromatic Plants

Medicinal and aromatic plants are rich sources of bioactive compounds—naturally occurring chemical substances that produce physiological effects in the human body. For

centuries, these compounds have been widely used in traditional medicine due to their diverse therapeutic properties, including antimicrobial, anti-inflammatory, antioxidant, and anticancer activities. Their strong pharmacological potential makes them valuable resources for modern drug discovery and development, as many serve as lead molecules for the design of new therapeutic agents. Understanding these compounds and their mechanisms of action has significantly contributed to integrating medicinal plants into modern healthcare systems.Medicinal plants contain a wide range of bioactive constituents such as alkaloids, glycosides, flavonoids, terpenoids, and phenolic compounds, which form the basis of disease prevention, diagnosis, and treatment in both traditional and modern medical practices. Aromatic plants, on the other hand, are rich in essential oils and fragrant compounds that are extensively used in pharmaceuticals, perfumery, cosmetics, food flavouring, and aromatherapy. Many plant species possess both medicinal and aromatic properties, making them highly valuable resources that link healthcare, industry, and sustainable agriculture. These plants play a vital role in traditional systems of medicine such as Ayurveda, Unani, and Siddha, while also serving as important raw materials for contemporary pharmaceutical and cosmetic industries.

Integration of Traditional and Modern Medicine

Despite early skepticism, traditional medicine remains widely practiced and is increasingly integrated with modern healthcare. Practitioners now combine Western medicine with naturopathy, complementary therapies, and Ayurvedic treatments. Modern research investigates the molecular and biochemical mechanisms of herbal compounds. For example, studies on Ashwagandharishta show upregulation of antioxidant enzymes (CAT, GPx) and downregulation of pro-inflammatory cytokines (IL-6), explaining its hepatoprotective effects.

Over 100 plant species contribute to modern pharmaceuticals. Examples include:

Catharanthusroseus (Sadabahar) – cancer therapy

Rauwolfiaserpentina (Sarpagandha) – hypertension

Withaniasomnifera (Ashwagandha) – vitality, stress, neurological disorders

Asparagus racemosus (Shatavari) – rejuvenation

Commiphoramukul (Guggul) – metabolic disorders

Bioactive compounds such as alkaloids, flavonoids, terpenoids, and phenolics are the main contributors to these medicinal effects.

Benefits of Medicinal and Aromatic Crop Cultivation

By-products can be effectively utilized to reduce production costs and increase profitability.

Efficient utilization of labour is possible through cultivation of these crops.

Foreign exchange can be earned through exports.

Integrated farming systems can generate higher net returns compared to traditional farming.

Incidence of pests and diseases is generally lower compared to conventional crops.

These crops can be grown on low-fertility and problem soils.

Medicinal and aromatic crops are farmer-friendly and environmentally sustainable.

Damage by stray animals and birds is minimal.

Products derived from these crops can be stored safely for longer periods.

Medicinal plant cultivation enables farmers to earn better profits. In recent times, particularly after the COVID-19 pandemic, people have increasingly turned towards natural medicines to improve immunity and overall health.India has a long tradition of using different parts of plants to treat diseases. It is recognized as one of the world's megadiverse countries, with many plant species found exclusively within its borders.According to a Government of India survey, about 8,000 plant species are used medicinally. Products derived from these plants have strong international demand, creating significant opportunities for farmers through medicinal plant cultivation.

Future Perspectives of Medicinal Plants in Healthcare-

Recent Developments and Innovations in Plant-Based Medicine:

As interest in plant-based therapies grows, several emerging trends are shaping the future of medicinal plants in healthcare. One major development is the increased use of phytochemicals—such as alkaloids, flavonoids, and terpenoids—for therapeutic applications, offering new opportunities for drug discovery, especially for diseases with limited treatment options. Advances in plant-based nanotechnology have also enabled the development of nanoparticles for improved drug delivery, enhancing bioavailability and targeted treatment while reducing side effects. Additionally, genetic engineering has made it possible to enhance the medicinal properties of plants, allowing for increased production of therapeutic compounds or the introduction of novel functions. This approach, known as pharming, highlights the potential of plants as both nutritional and medicinal resources. (Manisha et al., 2025)

Bridging Medicinal Plant Knowledge with Modern Biomedical Science

The integration of medicinal plants with modern biomedical research is driving the development of more effective and sustainable healthcare solutions. Researchers are increasingly employing advanced technologies, including omics approaches such as genomics, proteomics, and metabolomics, to investigate the mechanisms of action underlying plant-derived bioactive compounds. (Manisha et al., 2025)

Clinical Potential and Commercial Prospects

Medicinal plants show strong potential in treating cancer, neurodegenerative, and cardiovascular diseases through bioactive compounds with therapeutic benefits. Growing consumer demand is driving the global commercialization of plant-based products, though quality control and regulation remain essential. With increased pharmaceutical investment and technological advances, medicinal plants are

poised to play a larger role in modern and integrative healthcare (Manisha et al., 2025).

Conclusion

India's medicinal and aromatic plants are a priceless heritage linking ancient wisdom with modern science. They provide bioactive compounds essential for traditional and contemporary medicine, perfumery, and pharmaceuticals, while supporting rural livelihoods and environmental sustainability. Rising global demand emphasizes the need for scientific cultivation, sustainable harvesting and biodiversity conservation. Integrating traditional knowledge with modern research, advanced technologies, and good agricultural practices can enhance drug discovery, healthcareand export potential. By promoting cultivation and value addition, India can conserve endangered species, strengthen healthcare systems, boost the economy and meet growing international demand for high-quality herbal products.

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