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Review Article

Impact On Climate Change on Medicinal Plants and Their Potency

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ABSTRACT

Climate change has emerged as a critical global challenge, profoundly influencing ecosystems and biodiversity. Medicinal plants, integral to traditional and modern medicine, are particularly vulnerable to the shifting climatic conditions. This study explores the impact of climate change on medicinal plants, focusing on alterations in their geographical distribution, growth patterns, and phytochemical composition. Rising temperatures, changes in precipitation, and increased carbon dioxide levels affect not only the yield of these plants but also their potency and efficacy as natural remedies. Furthermore, the loss of specific habitats threatens the survival of rare and endemic species with unique medicinal properties. The study underscores the urgent need for sustainable conservation strategies and adaptive measures to protect medicinal plant resources. By addressing these challenges, we can safeguard the health benefits these plants provide for future generations while promoting ecological balance.

INTRODUCTION

Climate change is reshaping global ecosystems, posing a significant threat to medicinal plants, their distribution, and their therapeutic potency. Shifts in temperature, precipitation patterns, and atmospheric carbon dioxide concentrations have been shown to directly affect the growth, survival, and phytochemical profiles of medicinal plants. For instance, higher temperatures and drought stress have led to decreased yields in species like *Withania somnifera* (Ashwagandha) and altered the concentration of bioactive compounds critical for medicinal efficacy (Patwardhan et al., 2020). Furthermore, habitat loss due to rising sea levels and deforestation has endangered species such as *Taxus baccata* (source of paclitaxel) (Smith et al., 2018). Such changes compromise not only biodiversity but also the global availability of essential medicines derived from plants. This paper highlights the urgent need for sustainable conservation strategies and climate-adaptive agricultural practices to mitigate these effects. By preserving medicinal plant diversity and potency, we can ensure the resilience of traditional and

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modern healthcare systems in the face of climate change.

Climate: Climate is the long-term weather pattern in a region, typically averaged over 30 years.[1][2] More rigorously, it is the mean and variability of meteorological variables over a time spanning from months to millions of years. Some of the meteorological variables that are commonly measured are temperature, humidity, atmospheric pressure, wind, and precipitation. In a broader sense, climate is the state of the components of the climate system, including the atmosphere, hydrosphere, cryosphere, lithosp here and biosphere and the interactions between them.[1] The climate of a location is affected by its latitude, longitude, terrain, altitude, land use and nearby water bodies and their currents.[3]

From the ancient **Greek origins of the word (klíma, "an inclination or slope"—e.g., of the Sun's rays; a latitude zone of Earth; a clime**) and from its earliest usage in English, climate has been understood to mean the **atmospheric conditions** that prevail in a given region or zone. In the older form, clime, it was sometimes taken to include all aspects of the environment, including the natural vegetation.

In geography, climate is the average weather conditions of a specific location over a long period of time, such as months, years, decades, seasons, or even millions of years. The World Meteorological Organization (WMO) uses a 30-year period to determine a region's average climate.

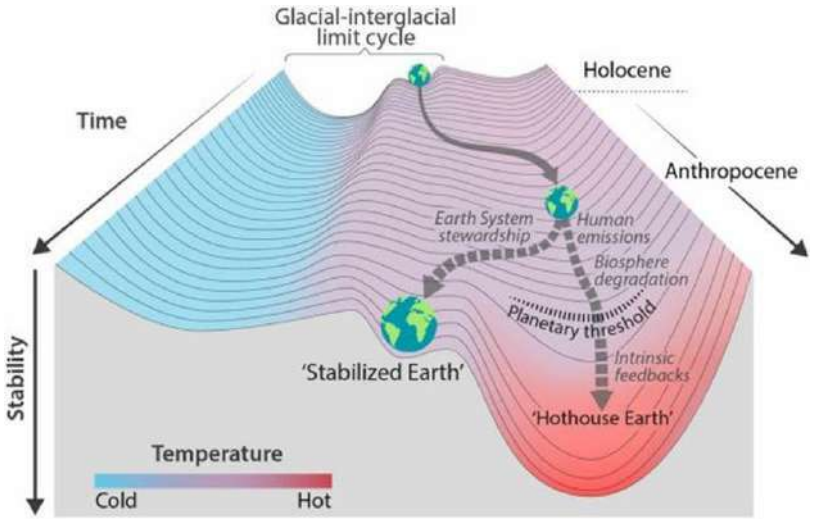


Fig. Diagram from the "Hothouse Earth" Trajectories paper, illustrating their hypothesised Earth system stability landscape in which an alternative Hothouse stable state requires consistent human intervention against in order to remain in a semi-stable Stablised state instead. Credit: Steffen et al (2018), PNAS

Climate is different from weather, which refers to short-term changes in the atmosphere. Weather can change every day, week, or even hour, while it takes about 30 years to determine a region's climate.

Climate is described by statistics such as:

- Average and extreme temperatures
- Average and extreme precipitation
- Intensity, frequency, and duration of weather events
- Amount of sunshine
- Average wind speeds and directions

- Number of days above freezing
- Weather extremes

Climate change: Climate change is a broad term used to refer to changes in the Earth's climates, at local, regional, or global scales, and can also refer to the effects of these changes. In recent decades, the term 'climate change' is most often used to describe changes in the Earth's climate driven primarily by human activity since the pre-Industrial period (c. 1850 onwards), particularly the burning of fossil fuels and removal of forests, resulting in a relatively rapid increase in carbon dioxide concentration in the Earth's atmosphere.[3][4]

Causes of Climate Change: [5][6][7]

Climate change refers to significant and lasting changes in the Earth's climate, primarily caused by human activities and natural factors. Below are the main causes:

1. **Greenhouse Gas Emissions**

- **Carbon Dioxide (CO_2):** Released from burning fossil fuels (coal, oil, and natural gas) for energy, deforestation, and industrial processes.
- **Methane (CH_4):** Emitted during agriculture (especially rice cultivation and livestock digestion), landfill decomposition, and natural gas extraction.
- **Nitrous Oxide (N_2O):** Comes from agricultural fertilizers, burning of organic matter, and industrial processes.
- **Fluorinated Gases:** Synthetic gases used in industrial applications like refrigeration and air conditioning.

2. **Deforestation:** Forests act as carbon sinks, absorbing CO_2. Their destruction for agriculture, logging, or urban development reduces this capacity and releases stored carbon back into the atmosphere.

3. **Industrial Processes:** Manufacturing and chemical processes release CO_2, CH_4, and other pollutants that trap heat in the atmosphere.

4. **Agriculture:** Practices such as livestock farming, use of synthetic fertilizers, and wetland rice farming emit high levels of methane and nitrous oxide.

5. **Urbanization and Land Use Change:** Urban sprawl leads to increased energy demand, deforestation, and heat island effects in cities, contributing to global warming.

6. **Natural Factors:** Although minor compared to human activities, natural causes such as volcanic eruptions, variations in solar radiation, and ocean currents can influence the climate.

7. **Energy Production:** Coal-fired power plants, oil refineries, and natural gas production contribute significantly to emissions.

Medicinal Plants: The term medicinal plants were first used in 1967 in the context of the study of hallucinogenic plants. A medicinal plant is that species of the plant kingdom, whose parts (flowers, leaves, roots, stems, fruits, or seeds) are directly used or used in some preparation as a medicine to treat a condition or disease. Knowledge of the beneficial properties of medicinal plants to treat diseases represents a valuable resource to preserve the biological and cultural diversity of different ethnicities (Heinrich et al., 2017).[8]

Humans and medicinal plants: The bond between humans and medicinal plants is ancient and symbiotic. Since the dawn of civilization,

medicinal plants have played a crucial role in human health and survival. This relationship encompasses cultural, medicinal, ecological, and economic dimensions.[9][10][11][12]

Historical Context: Medicinal plants have been used in traditional healing practices for thousands of years. Ancient civilizations, such as those in Egypt, Mesopotamia, India, and China, documented the use of plants for treating diseases. **The Atharva Veda (1500–1200 BCE)** and the **Charaka Samhita (300 BCE–200 CE)** are prominent Indian texts that highlight the medicinal properties of plants. Similarly, the Huangdi Neijing (China) and the Ebers Papyrus (Egypt) are other notable works.

Cultural and Spiritual Significance: In many indigenous cultures, plants are not only medicinal but also sacred. They are used in rituals and ceremonies, symbolizing the interconnectedness of nature and human life. For example, Tulsi (*Ocimum sanctum)* is revered in Hindu households for its therapeutic and spiritual importance.

Medicinal Uses: Plants are a primary source of bioactive compounds used in pharmaceuticals. These compounds include alkaloids, flavonoids, tannins, and glycosides, which have antibacterial, antiviral, anti-inflammatory, and anticancer properties. Some notable examples include:

- **Aspirin:** Derived from the bark of the willow tree (*Salix alba*).
- **Quinine:** Extracted from the bark of the cinchona tree, used to treat malaria.
- **Artemisinin:** Obtained from *Artemisia annua*, a key treatment for malaria.

Ecological Significance: Medicinal plants support biodiversity and ecosystem stability. Forests and other natural habitats rich in medicinal plants act as reservoirs of genetic diversity, which is critical for ecological balance and human health.
Economic Importance: The global herbal medicine market is valued in billions of dollars. Countries like India and China dominate this sector due to their rich tradition of herbal medicine. Programs like **AYUSH** (Ayurveda, Yoga, Unani, Siddha, and Homeopathy) in India emphasize the integration of traditional knowledge with modern healthcare.

Challenges: Despite their benefits, medicinal plants face threats such as habitat destruction, overharvesting, and climate change. Sustainable harvesting and conservation efforts are essential to maintain this relationship for future generations.

Climate and medicinal plants: The relationship between climate and medicinal plants is deeply intertwined, as the growth, distribution, chemical composition, and potency of medicinal plants are significantly influenced by climatic conditions. [13][14][15][16]

1. **Growth and Distribution:** Climate determines where specific medicinal plants can thrive. Factors like temperature, rainfall, humidity, and sunlight are crucial for the germination, growth, and reproduction of these plants. For instance, Aloe vera thrives in arid and semi-arid regions, while plants like turmeric and ginger prefer tropical and subtropical climates.

2. **Chemical Composition:** The medicinal properties of plants are often linked to secondary metabolites (alkaloids, flavonoids, terpenoids, etc.) whose synthesis is climate-dependent. Variations in temperature, UV radiation, and water availability can affect the production and concentration of these bioactive compounds.

3. **Adaptation to Stress:** Plants in harsh climates (e.g., deserts or high altitudes) often produce higher concentrations of secondary metabolites as a defense mechanism against environmental stress, which can enhance their medicinal value. For example, ginseng grown in cooler climates contains more ginsenosides.

4. **Climate Change Impact:** Rising global temperatures, changes in precipitation patterns, and extreme weather events are altering the habitats of medicinal plants, threatening their availability and efficacy. Some species may become extinct, while others might migrate to new regions, disrupting traditional knowledge systems.

5. **Ethnobotanical Importance:** Indigenous communities often cultivate and use medicinal plants that are adapted to their local climate. Changes in climate may disrupt this balance, affecting both the communities and biodiversity.

Impact of Climate Change on Medicinal Plants: [17][18][19]

1. **Shifts in Distribution:** Rising temperatures and changes in precipitation patterns can cause medicinal plants to shift to new habitats, often higher altitudes or latitudes, threatening local availability. Example: Artemisia annua (used for malaria treatment) shows altered distribution due to temperature changes.

2. **Loss of Biodiversity:** Climate change exacerbates habitat loss and reduces biodiversity, endangering rare medicinal plants like Taxus baccata (source of anticancer drug paclitaxel).

3. **Alteration in Phytochemical Composition:** Changes in temperature, CO_2 levels, and UV radiation can influence the production of bioactive compounds in plants, affecting their medicinal potency. Example: Hypericum perforatum (St. John's Wort) produces lower concentrations of therapeutic compounds under stress conditions caused by climate change.

4. **Phenological Changes:** Shifts in flowering and fruiting times disrupt the lifecycle of medicinal plants and their pollinators, impacting plant reproduction and harvest.

5. **Increased Vulnerability to Pests and Diseases:** Warmer temperatures Favor pests and pathogens that attack medicinal plants, reducing their yield and quality.

Mitigation and Adaptation:

1. **Conservation Efforts:** Protecting natural habitats through afforestation and sustainable harvesting practices. Establishing seed banks and botanical gardens to preserve genetic diversity.

2. **Climate-Resilient Cultivation:** Developing and cultivating climate-resilient varieties of medicinal plants. Promoting agroforestry to integrate medicinal plants with sustainable land use.

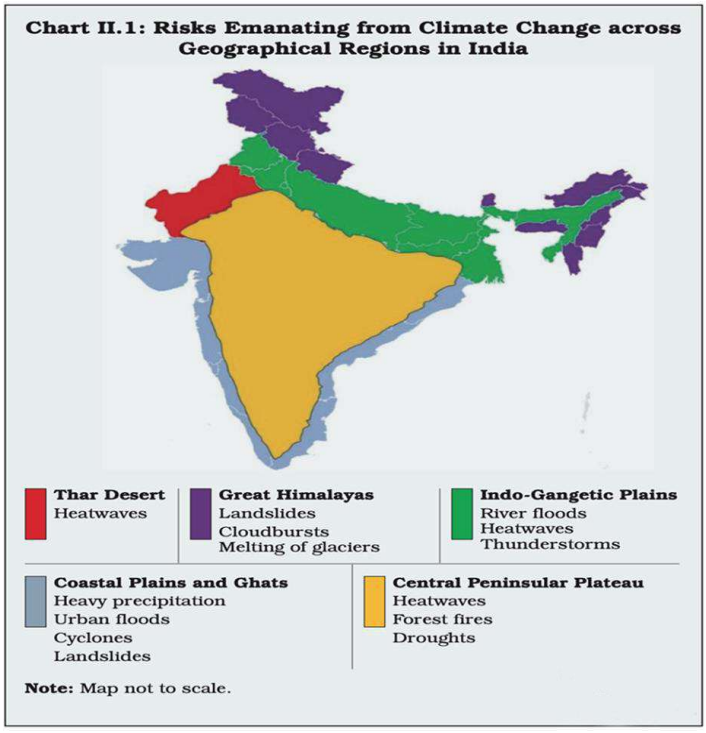
3. **Traditional Knowledge Integration:** Collaborating with indigenous communities to utilize their knowledge for sustainable harvesting and adaptation strategies**.**

Over the past decade, Central India has witnessed noticeable changes and a gradual decline in greenery, flora, and fauna, largely influenced by the growing impact of climate change. According to the India State of Forest Report (ISFR), while

states like Madhya Pradesh and Chhattisgarh continue to hold significant forest cover, subtle but continuous degradation is evident. Madhya Pradesh, for example, recorded a minor decrease of around 22.62 square kilometers of forest cover between 2011 and 2021, while Chhattisgarh experienced minor fluctuations despite an overall small net gain in tree cover, much of which is attributed to plantations rather than natural forests. These figures, though seemingly marginal, mask the larger issue of forest quality deterioration. Climate change, with its increasing temperatures, erratic monsoon patterns, prolonged droughts, and intense heatwaves, has led to the drying up of forest areas, greater susceptibility to wildfires, and the weakening of natural regeneration processes.

The flora diversity of Central India, known for its tropical dry deciduous forests dominated by species such as Sal, Teak, and Mahua, has been particularly vulnerable. Rising temperatures and changing rainfall patterns have stressed native species, leading to shifts in species composition, reduced flowering and fruiting cycles, and even localized extinctions of sensitive plant species. Similarly, the fauna in Central India, including key species like tigers, leopards, and herbivores such as chital and sambar, has been affected due to habitat fragmentation, scarcity of water sources, and shrinking prey bases, all indirectly linked to climatic stressors. Studies have shown that climate change is driving shifts in species distribution, pushing many animal populations to higher altitudes or denser forest patches in search of favorable conditions, thereby disturbing ecological balances.

Moreover, recurrent drought years have impacted the undergrowth and grasslands crucial for herbivores, creating a cascading effect on the food chain. The interconnection of these environmental stressors over the last decade suggests that while the absolute percentage declines in forest cover, flora, and fauna numbers might seem gradual, the qualitative degradation of ecosystems in Central India is severe. Biodiversity loss, coupled with the pressure of human expansion and agricultural demands, exacerbates these impacts, making the region's rich natural heritage increasingly vulnerable to ongoing and future climate instability.



Medicinal Plants Impacted by Climate Change in India:

Medicinal Plant	Geographical Region	Uses	Impact of Climate Change
Ashwagandha (*Withania somnifera*)	Central India (Madhya Pradesh, Rajasthan)	Stress relief, immunity booster	Reduced root yield, altered alkaloid content
Tulsi (Holy Basil) (*Ocimum sanctum*)	Pan-India (widely cultivated)	Antiviral, adaptogen	Decreased oil content, pest outbreaks
Neem (*Azadirachta indica*)	Dry regions (Rajasthan, Gujarat, UP)	Antibacterial, skin diseases	Drought stress, slower growth
Amla (Indian Gooseberry) (*Phyllanthus emblica*)	Central & South India (MP, Tamil Nadu, UP)	Vitamin C, digestion	Flowering/fruiting irregularities
Shankhpushpi (*Convolvulus prostratus*)	North India plains, Rajasthan, MP	Brain tonic, memory enhancer	Drying habitats, growth inhibition
Guggul (*Commiphora wightii*)	Rajasthan, Gujarat, MP (Arid zones)	Cholesterol, arthritis	Overharvesting & aridification
Arjuna (*Terminalia arjuna*)	Riverbanks (UP, Bihar, Odisha, Maharashtra)	Heart health	Riverine habitat drying up
Safed Musli (*Chlorophytum borivilianum*)	Gujarat, Rajasthan, MP	Vitality, aphrodisiac	Soil degradation, heat waves

Affected Geographical Regions:

- Himalayan regions (Jammu & Kashmir, Himachal Pradesh, Uttarakhand): High-altitude species (Kutki, Jatamansi, Chirata) impacted by glacial retreat, warming, and habitat shifts.
- Arid and semi-arid zones (Rajasthan, Gujarat, Madhya Pradesh): Species like Guggul, Ashwagandha, and Safed Musli suffer from droughts and desertification.
- Western Ghats & Eastern Ghats: Moisture-loving species like Satavari and Brahmi are affected by erratic rainfall.
- Gangetic plains & riverine areas: Plants like Arjuna and Sarpagandha face flooding and habitat degradation.
- North-East India: Biodiversity hotspots experiencing shifting monsoon patterns affecting medicinal flora.

What we can do? Humans play a crucial role in conserving biodiversity and combating climate change. To protect our planet's rich variety of life, we must adopt sustainable practices such as reducing deforestation, protecting natural habitats, and promoting afforestation and reforestation. Switching to clean and renewable energy sources like solar and wind can significantly cut down greenhouse gas emissions. Sustainable agriculture, organic farming, and reducing chemical use help preserve soil health and support pollinators and other wildlife. Conserving water, reducing plastic use, and encouraging recycling can also reduce our environmental footprint. Additionally, protecting endangered species through conservation programs, enforcing wildlife protection laws, and supporting community-based forest management are essential. By raising awareness, promoting education, and involving local communities in conservation efforts, we can create a collective

movement toward a more resilient and biodiverse planet while actively mitigating climate change.

Human interventions are critical in mitigating the dual crises of biodiversity loss and climate change. One of the foremost actions is the conservation and restoration of natural ecosystems, including forests, wetlands, grasslands, and mangroves, which not only harbor rich biodiversity but also serve as significant carbon sinks. Afforestation and reforestation initiatives, especially using native and endemic species, can restore degraded lands while maintaining ecological balance. Sustainable land-use practices, such as agroforestry, organic farming, and crop rotation, can reduce dependency on chemical inputs, preserve soil fertility, and enhance habitat quality for native flora and fauna. Transitioning to renewable energy sources like solar, wind, and biogas reduces greenhouse gas emissions and curbs habitat destruction linked to fossil fuel extraction. Moreover, strengthening environmental governance, implementing policies that restrict habitat encroachment, and enforcing wildlife protection laws are vital. Community involvement through participatory conservation empowers indigenous and local communities, who often possess traditional ecological knowledge, to become active stewards of biodiversity. Urban planning must also integrate green infrastructure and promote climate-resilient cities through green belts, urban forests, and sustainable transportation. Finally, awareness campaigns, environmental education, and integration of climate and biodiversity concerns into school curricula can foster a culture of conservation from a young age. Collectively, these human-led actions form a multi-dimensional approach that addresses the root causes of biodiversity decline and climate change while promoting a more sustainable and resilient future.

SUMMERY AND CONCLUSION: This review highlights the growing threats posed by climate change to medicinal plant biodiversity in India. Key species such as *Withania somnifera* (Ashwagandha), *Picrorhiza kurroa* (Kutki), *Nardostachys jatamansi* (Jatamansi), and *Rauvolfia serpentina* (Sarpagandha), which have significant ethnomedicinal and pharmaceutical value, are facing altered phenology, habitat loss, and reduced secondary metabolite content due to rising temperatures, erratic rainfall, and habitat fragmentation. The geographical distribution of many species—particularly those native to the Himalayas, Western Ghats, and arid zones—is shifting, resulting in ecological imbalances and threatening traditional healthcare systems dependent on these plants. Research and case studies from various regions underline the urgent need for conservation strategies, sustainable harvesting practices, and scientific interventions to protect these vulnerable species. In the face of accelerating climate change, conserving medicinal plant diversity is not only an environmental imperative but also a public health priority. Integrated efforts involving habitat conservation, ex-situ cultivation, traditional knowledge preservation, and climate-resilient agricultural practices are essential to mitigate biodiversity loss. Human actions—such as reducing carbon emissions, restoring ecosystems, enforcing protective legislation, and promoting education—can significantly slow the degradation of biodiversity and support ecological balance. A coordinated approach involving policymakers, researchers, local communities, and conservationists is vital to ensure the sustainability of medicinal plant resources. Protecting these plants today is an investment in the ecological, cultural, and medicinal well-being of future generations.

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