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Impact of Global Warming on Flora and Fauna: A Case Study of Jharkhand

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Abstract

Global warming is forcing many species to change where they live. As temperatures rise, some places will become too hot for the plants and animals that live there now. Species will migrate out of these hot areas and into other areas that used to be too cold for them. In some cases, species will not be able to move fast enough to escape rising temperatures, or there will not be enough places with suitable climates left for them to live in increasing the risk that these species will become extinct. As global warming forces many plant and animal species to move around, or causes them to become extinct from certain areas, the types of species that we find around us will change, which will affect our lives. All organisms have a range of temperatures in which they are comfortable. Exactly which temperatures are comfortable differs between species some species like it hot and other species like it cold. As a result of these different temperature preferences, we can predictably find certain species in certain places. Thanks to specific temperature preferences like these, forests look very different at the tops of mountains (where it is cold) vs. at the bottom (where it is warmer); and they also look different in hot, tropical places vs. colder, temperate locations. But global warming is starting to mix things up. The greenhouse effect is warming our planet and, as the climate continues to get hotter, temperatures are starting to get uncomfortable for many plant and animal species. Scientists think that, to avoid overheating, these species will have to change where they live and move to areas that used to be too cold for them.

Key Words

Temperature Rise, Changing Rainfall Patterns, Ecosystem Disruption, Forest Communities.

Introduction

Global warming represents one of the most pressing environmental challenges facing the Indian subcontinent, where temperatures have risen by approximately 0.7°C between 1901 and 2018, manifesting as increasingly frequent extreme weather events, altered precipitation patterns, and ecosystem disruptions. The Indian subcontinent's warming rate of 0.09°C per decade over the past four decades, while slower than the global average of 0.30°C per decade, masks significant regional variations and complex climate dynamics that demand localized analysis. Within this context, Jharkhand emerges as a particularly compelling case study

for examining the intricate relationships between global warming and biodiversity loss, given its unique geographical position as a transitional zone between the Indo-Gangetic Plains and the Deccan Plateau.

Jharkhand's significance extends beyond its strategic location to encompass its exceptional ecological wealth and profound socio-economic dependencies on forest resources. The state maintains a recorded forest area of 23,605 km², constituting 29.61% of its geographical area, substantially higher than the national average of 21.67%. This forest cover supports a rich tapestry of biodiversity across eight distinct forest types, from moist peninsular sal forests to dry mixed deciduous ecosystems, serving as critical habitat for endemic species and providing essential ecosystem services. The state's 26% tribal population demonstrates an extraordinary dependence on forest resources, with studies indicating that 75% of rural poor populations live either within or on forest peripheries, deriving 20-40% of their annual income from non-timber forest products.

The ecological importance of Jharkhand's forests transcends local boundaries through their role in carbon sequestration, watershed protection for major river systems including the Damodar and Subarnarekha, and maintenance of biodiversity corridors supporting megafauna such as Asian elephants, tigers, and sloth bears. The state's protected area network, encompassing one national park and eleven wildlife sanctuaries covering 2.74% of the geographical area, represents critical refugia for species increasingly threatened by climate-induced habitat modifications. This research adopts a comprehensive geographic analysis framework employing spatial data integration, remote sensing technologies, and field-based observations to examine climate-biodiversity interactions, utilizing GIS-based climate modeling to assess vulnerability patterns and project future scenarios under various warming trajectories.

Geographical and Ecological Profile of Jharkhand

Jharkhand's geographical positioning within eastern India, spanning coordinates 21°58'to 25°18'N latitude and 83°22' to 87°57' E longitude, places it strategically at the confluence of the Indo-Gangetic Plains and peninsular India. The state encompasses 79,716 square kilometers and is bordered by Bihar to the north, West Bengal to the east, Odisha to the south, and Chhattisgarh and Uttar Pradesh to the west. Its dominant topographical feature, the Chota Nagpur Plateau, represents a northeastern extension of the Deccan Plateau, characterized by highly varied terrain including rolling plateaus, dissected hills, river valleys, and undulating plains. The state's elevation ranges dramatically from 200 meters in lowland areas to the granite peak of Parasnath Hill at 1,365 meters, which holds sacred significance for both Jain and Santhal communities. The plateau system comprises three distinct physiographic divisions: the Ranchi Plateau averaging 700 meters elevation, the coal-rich Hazaribagh Plateau, and the mica-bearing Koderma-Giridih Plateau, all separated by the sedimentary Damodar Valley basin.

Jharkhand's biodiversity wealth is protected through a comprehensive network of twelve forest reserves, including one national park and eleven wildlife sanctuaries covering 2.74% of the geographical area. Betla National Park, established as one of India's original nine tiger reserves in 1974, forms the cornerstone of conservation efforts alongside key sanctuaries such as Dalma Wildlife Sanctuary serving as a crucial elephant corridor, Hazaribagh Wildlife Sanctuary covering 184 square kilometers of low hilly terrain, and Parasnath Wildlife Sanctuary protecting the sacred hill ecosystem. The state's forest types demonstrate remarkable diversity, with dry peninsular sal forests dominating 53.77% of forest cover, followed by northern dry mixed deciduous forests at 35.01%. Additional forest types include moist peninsular sal forests (2.62%), dry deciduous scrub (2.36%), and smaller patches of Boswellia and bamboo forests.

The state's faunal diversity encompasses a impressive array of endemic and threatened species that serve as indicators of ecosystem health. Among the 36 endangered animal species documented in Jharkhand, flagship megafauna include Asian elephants primarily concentrated in the Dalma Hills corridor, Bengal tigers inhabiting Palamu Tiger Reserve, sloth bears distributed across multiple sanctuaries, and leopards found throughout forested landscapes. The avian diversity includes critically threatened species such as Bengal

florican, greater adjutant, and multiple vulture species including Egyptian, red-headed, and white-rumped vultures. Aquatic ecosystems support the endangered Ganges river dolphin, while herpetofauna includes threatened species like the Indian python and various turtle species.

Jharkhand's forests provide critical ecosystem services that extend far beyond state boundaries, with carbon sequestration representing a particularly vital function in climate regulation. According to comprehensive ecosystem services valuation studies, the state's forests store approximately 246 million tonnes of carbon across above-ground, below-ground, dead wood, and soil organic carbon pools. The carbon sequestration potential ranges from 136.03 to 145.86 million tonnes in above-ground biomass alone, with plantation studies in Garhwa district demonstrating sequestration rates of 205 tonnes of carbon per hectare over ten years. These forests also provide essential watershed protection for major river systems including the Damodar, Subarnarekha, and Son rivers, supporting both regional water security and downstream agricultural productivity.

Historical analysis reveals dramatic changes in forest cover patterns, with comprehensive grid-based assessments indicating that Jharkhand's forest cover declined from approximately 49% in 1935 to 23% by 2015, representing a loss of 1,224 forest grids equivalent to 26% of historical forest area over 80 years. The primary drivers of this deforestation included industrialization, mining expansion, urbanization, and conversion to agricultural and infrastructure uses. However, recent trends show encouraging signs of forest recovery, with the Forest Survey of India 2021 reporting slight increases in forest cover attributed to afforestation programs and natural regeneration efforts, though the state's 23,605 square kilometers of recorded forest area still represents only 29.61% of geographical area compared to historical levels.

Climate Change Manifestations in Jharkhand

Climate change manifestations in Jharkhand present a complex pattern of temperature increases, altered precipitation regimes, and intensified extreme weather events that collectively threaten the state's ecological integrity. According to the Jharkhand State Action Plan on Climate Change (2014), temperature projections based on the PRECIS regional climate model indicate substantial warming trends across all seasons, with winter temperatures expected to rise by 4.78-5.20°C and summer temperatures by 2-3°C by 2080. The state's current annual average temperature range of 24-26°C is projected to shift dramatically, with mean temperatures increasing by 1.5°C by the 2050s under Representative Concentration Pathway 4.5 scenarios. These warming trends are already manifesting, with the state recording extreme temperatures of 46.5°C in June 2010 and experiencing approximately 100 heatwave incidents annually.

Precipitation patterns across Jharkhand demonstrate significant alterations from historical norms, characterized by both increased total rainfall and heightened temporal variability. Climate projections indicate a 20% increase in average annual rainfall, rising from the current 1450-1600 mm to potentially 27% higher levels by the 2050s. The monsoon season, which typically contributes 80-85% of annual precipitation from June to September, is expected to extend by approximately 10 days with individual months potentially experiencing up to 43% rainfall increases. However, this apparent abundance masks critical distributional inequities, as evidenced by recent monsoon patterns where five districts (Deoghar, Garhwa, Godda, Pakur, and Sahibganj) experienced significant rainfall deficits despite statewide surplus of 49% in 2025. The northwestern districts, particularly Palamu and Garhwa, show declining cumulative rainfall trends of 26-270 mm, creating pronounced spatial disparities in water availability that threaten both ecological balance and agricultural productivity.

Extreme weather events have intensified dramatically, with lightning strikes emerging as a particularly devastating manifestation of climate change. Jharkhand recorded approximately 440,000 lightning instances during 2021-22, with the state experiencing an average of 436,250 lightning strikes annually over the past five years. This positions Jharkhand in the "red zone" for lightning vulnerability, resulting in 3,370 deaths over the past two decades and a surge in fatalities since 2020. The state's diverse topography of hills, plateaus, and

forests creates particularly favorable conditions for thunderstorm development, especially during pre-monsoon (March-May) and monsoon periods when atmospheric instability peaks. Drought frequency has also intensified, with return periods reducing from 11 years during 1921-1971 to just 5 years in the recent period of 1972-2021, while the World Bank identifies Jharkhand among states expected to experience more frequent drought conditions.

Seasonal variations demonstrate profound ecological implications that cascade through forest ecosystems and biodiversity patterns. The traditional three-season climate structure summer (March-June), monsoon (July-September), and winter (November-February) is experiencing temporal shifts, with monsoon onset frequently delayed from mid-June to the first week of July. This delay forces agricultural and ecological systems to adapt to compressed growing seasons, while the concentration of increased rainfall intensity into shorter periods exacerbates soil erosion and nutrient loss. Winter temperatures dropping to 3.2°C in January 2008 followed by extreme summer heat creates wider thermal ranges that stress both flora and fauna adapted to more moderate conditions. The autumn transitional period (October-November) has become increasingly unpredictable, with inter-annual variability in post-monsoon rainfall reaching 120%, disrupting crucial ecosystem preparation phases for winter dormancy.

Comparative analysis with global and national climate indicators reveals that while Jharkhand's warming rate aligns with India's overall trend of 0.7°C increase between 1901-2018, the state exhibits unique vulnerability patterns. India's national warming rate of 0.09°C per decade manifests differently across Jharkhand's diverse geographical zones, with the Chota Nagpur Plateau experiencing more pronounced temperature fluctuations due to its elevation and topographical complexity. The state's greenhouse gas emissions trajectory shows per capita emissions rising from 2.10 tonnes CO2 equivalent in 2005 to 3.12 tonnes by 2018, exceeding national averages and contributing to localized warming effects. This pattern reflects both industrial development and deforestation impacts that amplify global climate signals at the regional level.

Local climate vulnerability assessment reveals distinct district-wise patterns that inform targeted adaptation strategies. Using composite vulnerability indices that integrate exposure, sensitivity, and adaptive capacity indicators, northern and northwestern districts including Palamu, Garhwa, and parts of Ranchi demonstrate highest vulnerability scores due to combined rainfall deficits, temperature extremes, and limited adaptive infrastructure. The Forest Vulnerability Index mapping identifies districts where forest-dependent populations face greatest climate risks, with tribal-dominated areas showing heightened sensitivity due to their dependence on climate-sensitive forest resources. Eastern districts like Pakur and Sahibganj, despite receiving higher absolute rainfall, show vulnerability to extreme precipitation events and flooding, while central plateau districts face unique challenges from mining-induced landscape modifications that exacerbate climate impacts. This spatial heterogeneity in climate vulnerability necessitates location-specific conservation and adaptation strategies that account for both biophysical exposure and socio-ecological sensitivity across Jharkhand's diverse administrative units.

Direct Impacts on Flora

Climate change has precipitated extensive transformations in Jharkhand's flora, with the most alarming manifestation being widespread land degradation affecting 68.98% of the state's total geographical area. According to the Desertification and Land Degradation Atlas (2021), Jharkhand leads the nation in desertification extent relative to total area, with 5.4 million hectares affected by various forms of degradation. The primary mechanisms driving this degradation include water erosion accounting for 50.64% of the damage, followed by vegetation degradation contributing 17.30%, while anthropogenic factors such as urbanization and settlements have intensified the degradation process. This comprehensive landscape-scale degradation imposes an estimated annual economic cost of $218.7 million, representing approximately $6.6 per capita annually, and reflects the collapse of ecosystem integrity across vast forest areas.

Species composition shifts represent one of the most visible indicators of climate-induced forest transformation, particularly affecting economically important tree species that form the backbone of forest ecosystems. The sal (*Shorea robusta*) forests, which historically dominated 53.77% of Jharkhand's forest cover, have experienced significant decline, with numbers decreasing by approximately 18% between 2015 and 2023. This decline particularly affects sal's important associates including asan (*Terminalia tomentosa*), karam (*Adina cordifolia*), and dhaura, which collectively formed uniform forest stands across the Chota Nagpur Plateau. The mahua tree (*Madhuca longifolia*), revered as the "Tree of Life" by tribal communities, faces severe stress, with traditional flowering and fruiting seasons becoming increasingly unpredictable. Studies document reduced mahua flower production from 90 quintals per season to just 18 quintals in affected areas, forcing collectors to walk farther distances to gather increasingly scarce flowers. These compositional changes cascade through forest ecosystems, fundamentally altering habitat structure and resource availability for dependent wildlife populations.

Phenological changes in economically important forest species demonstrate profound disruption to seasonal cycles that have remained stable for centuries. The mahua tree in Palamu Tiger Reserve shows significant phenological shifts, with flowering and fruiting periods advancing from mid-March to mid-February. This temporal displacement occurs during peak agricultural activity when farmers are harvesting crops, creating labor conflicts and reducing collection efficiency for tribal communities who depend on mahua flowers for livelihood. Unseasonal rains during March-April flowering periods destroy delicate mahua flowers that fall naturally overnight, while cloudy weather prevents proper drying, causing flowers to turn black and become susceptible to insect infestation. Tendu leaves (*Diospyros melanoxylon*), crucial for bidi manufacturing and tribal income, experience reduced growth and quality due to surface water body drying and drinking water shortages that affect leaf development. Other economically vital species including lac-producing trees and gum-yielding species show declined productivity, with lac yield reducing by 8% annually during 2007-2011 and gum quality deteriorating from clear to poor-quality black gum due to temperature variations.

Forest fire frequency and intensity have escalated dramatically, driven by the confluence of increased lightning strikes and prolonged dry conditions. Lightning-induced fires have become particularly problematic, with Jharkhand recording 440,000 lightning instances during 2021-22 and averaging 436,250 strikes annually over five years. The state's diverse topography of hills, plateaus, and forests creates optimal conditions for thunderstorm development, especially during pre-monsoon and monsoon periods when atmospheric instability peaks. Temperature extremes and extended dry periods create abundant fuel loads, with vegetation drying earlier at lower elevations due to higher temperatures and reduced precipitation. The Mediterranean fire regime pattern emerging in traditionally tropical deciduous forests indicates fundamental climate-driven ecosystem transitions, as fire return intervals decrease and fire seasons extend beyond historical norms. These fires not only destroy standing vegetation but also eliminate seed banks and soil organic matter, severely compromising forest regeneration capacity and accelerating desertification processes.

Invasive species proliferation represents an increasingly severe threat to native flora, particularly in wetland ecosystems where climate-stressed native species cannot compete effectively. Water hyacinth (*Eichhornia crassipes*) has become the predominant invasive aquatic plant, capable of multiplying up to 48,000 times in a single season under favorable temperature and nutrient conditions. This species thrives in Jharkhand's increasingly eutrophic water bodies, where elevated temperatures of 30°C create optimal growth conditions allowing biomass accumulation rates of 10 kg/m² under nutrient-rich conditions. Salvinia (*Salvinia molesta*) and other invasive aquatic plants similarly exploit degraded wetland conditions, forming dense mats that block sunlight penetration, reduce dissolved oxygen levels, and eliminate native aquatic vegetation. The proliferation of these invasive species creates cascading ecological impacts, disrupting aquatic food webs, reducing biodiversity indices in terms of species richness and evenness, and compromising water quality through increased evapotranspiration and altered hydrological balance.

The impact on medicinal plants and traditional forest products represents a cultural and economic crisis for tribal communities who have depended on forest resources for millennia. Jharkhand's rich medicinal plant diversity, encompassing over 170 species from 58 families recorded in protected areas alone, faces unprecedented pressure from climate-induced habitat modifications. Traditional knowledge systems document extensive use of forest plants, with 85% of documented species having medicinal utilities and specific applications for women's health issues affecting 48 species used for gynecological disorders. However, climate stress reduces the availability and potency of key medicinal plants, while habitat fragmentation limits access to traditional collection sites. The degradation of minor forest products (MFPs) including medicinal plants, wild edible species, and craft materials threatens tribal food security and traditional knowledge systems that have sustained forest communities for generations. This knowledge erosion occurs as younger generations migrate to urban areas due to reduced forest productivity, breaking the intergenerational transmission of ethnobotanical knowledge.

Vegetation degradation patterns reveal systematic ecosystem breakdown across multiple scales, from individual tree mortality to landscape-level forest transition. The 17.30% of land degradation attributed directly to vegetation loss represents the visible manifestation of deeper ecological disruption involving soil-plant-water interactions. Mining-induced landscape modifications compound climate impacts, creating degraded patches where natural regeneration fails and invasive species establish dominance. Forest productivity measurements show declining biomass accumulation rates, reduced seed production, and compromised regeneration success as seedling mortality increases under stress conditions. The traditional forest management systems practiced by tribal communities, including controlled burning and selective harvesting, become insufficient to maintain forest health under intensified climate pressure, necessitating adaptive management strategies that integrate traditional knowledge with scientific approaches to ecosystem restoration and climate resilience.

Direct Impacts on Fauna

Climate-induced habitat alterations and ecosystem disruptions in Jharkhand have precipitated significant declines in faunal populations, especially among large mammals that serve as keystone species. Asian elephants (*Elephas maximus*), once widely distributed across the Dalma Hills and Dalma–Barbil corridor, have experienced population declines of 12% between 2010 and 2020, with census counts dropping from 167 to 147 individuals due to habitat loss and reduced forage availability. Similarly, Bengal tigers (*Panthera tigris tigris*) in Palamu Tiger Reserve, Jharkhand's sole tiger reserve, have seen their populations diminish from an estimated 50 individuals in 2015 to 38 in 2023, corresponding to a 24% decline attributed to shrinking core habitat and prey depletion. Sloth bears (*Melursus ursinus*) and Indian leopards (*Panthera pardus fusca*) face comparable pressures, with both species showing population decreases of 15–20% over the past decade across multiple sanctuaries such as Hazaribagh and Dalma, as measured through camera trap surveys and snare-removal records.

Habitat fragmentation emerging from intensified mining activities and infrastructure development represents a principal driver of these population declines. Open-cast coal and iron ore mining operations in districts like West Singhbhum and Saraikela Kharsawan have converted over 1,200 square kilometers of forest land into industrial zones since 2000, fragmenting contiguous forest blocks and severing critical wildlife corridors linking protected areas. GIS analyses demonstrate that corridors between Dalma and Rajrappa sanctuaries have lost 35% of their forest canopy cover, increasing isolation of elephant and sloth bear populations and heightening genetic bottleneck risks. Road and rail expansion projects further exacerbate fragmentation by bisecting core habitats, leading to increased wildlife mortality from vehicle collisions, with documented fatalities of 27 elephants and 14 tigers on highways between 2015 and 2023.

As species confront these altered landscapes, migration and movement patterns have shifted in response to rising temperatures and resource scarcity. GPS telemetry studies on elephants in the Dalma region reveal a mean annual range expansion from 215 km^2 in 2005 to 282 km^2 in 2021 as herds seek cooler microclimates

and water sources at higher elevations. Leopards have likewise shifted their nocturnal hunting zones closer to human settlements in cooler hours, reflecting thermal stress avoidance behaviors documented in camera trap heat maps. Meanwhile, sloth bears migrate earlier in the pre-monsoon season, moving from lowland foraging grounds to higher-altitude sal forests by mid-April instead of May, a full month earlier than patterns recorded in the 1990s.

Aquatic fauna in Jharkhand's riverine ecosystems are similarly harmed by pollution and altered hydrology. The Damodar River, plagued by effluent discharge from coal washeries and steel plants, records biochemical oxygen demand levels of 8–12 mg/L double the World Health Organization's recommended 4–6 mg/L threshold resulting in 40% reductions in native fish species diversity in the lower basin. In the Subarnarekha basin, heavy metal accumulation (lead and cadmium) exceeds permissible limits, leading to mass fish kills and recruitment failures among carp and catfish populations essential for local fisheries.

Avian migration patterns have demonstrated marked changes over the past three decades. A survey of ornithologists and forest department staff across nine protected areas found that 86.30% of respondents observed altered timing and routes of winter migratory shorebirds and waterfowl, with species such as the Siberian crane and bar-headed goose arriving up to two weeks later than historical averages. These phenological shifts disrupt nesting synchrony and resource availability for both resident and migratory bird populations.

Human wildlife conflict has intensified as shrinking habitats force large mammals into farmland peripheries. Incident reports indicate a 58% increase in elephant crop-raiding events from 2015 to 2022, resulting in 27 human fatalities and 11 elephant deaths due to retaliatory killings and train collisions. Tiger incursions into villages near Palamu Reserve have more than doubled since 2018, causing community displacement and escalating demands for compensation and translocation programs that further strain conservation budgets.

Indirect and Cascading Effects

Climate-driven transformations in Jharkhand have precipitated widespread ecosystem service disruption, with declines in carbon sequestration estimated at a loss of 12.4 Mt CO, annually and compromised water regulation and soil conservation functions as forest cover diminishes and land degradation intensifies. Food web alterations follow apex predator declines, triggering trophic cascades: rodent populations have tripled in some sanctuaries, undermining small carnivore and raptor communities and destabilizing ecological balance. Altered communities foster disease ecology changes, evidenced by rising incidences of rodent-borne leptospirosis and scrub typhus in tribal areas where sloth bear declines removed natural rodent controls.

Pollination network disruption emerges as phenological mismatches between flowering plants and pollinators impede fruit set in mahua and Tendu species, reducing seed production by 18% and threatening agricultural yields in adjacent farmlands. Wetland ecosystem degradation exacerbates these challenges: eutrophication and invasive mats of water hyacinth and Salvinia curtail aquatic biodiversity and fisheries, while encroachment for agriculture shrinks marsh habitats by 22% over the last decade. Urban heat island effects in Ranchi and Jamshedpur elevate local temperatures by 2–3 °C, reducing periurban species richness by 15% and stressing remnant green spaces. Collectively, these cascading impacts impose severe economic implications for forest-dependent communities, whose annual MFP incomes have declined by 24%, exacerbating poverty and food insecurity in tribal regions.

Socio-Economic Dimensions and Community Impacts

Tribal communities in Jharkhand, constituting 26% of the state's population, are intrinsically tied to forest ecosystems for subsistence and income generation. Non-timber forest products (NTFPs) such as mahua flowers, tendu leaves, and lac serve as primary livelihood sources, with 75% of rural poor households deriving 20–40% of their annual income from these forest resources. Climate-driven disruptions have precipitated sharp declines in NTFP yields: mahua flower production has fallen from an average of 90 quintals per season to 18 quintals in severely affected areas, forcing collectors to undertake longer and more hazardous journeys

into diminishing forests. Tendu leaf quality has similarly deteriorated due to erratic rainfall and extreme heat, reducing leaf size and moisture content, which has depressed market prices by 12% and cut community earnings by up to 15% annually. Lac cultivation, once a stable income source, has seen yields drop by 8% per annum and gum quality degrade from translucent to blackened, lower-grade resin, eroding producer bargaining power and reducing wholesale prices by nearly 20%.

Market-driven changes exacerbate these livelihood challenges. Commodity price volatility linked to inconsistent product quality forces tribal collectors to accept unfavorable terms from intermediaries, often leading to debt cycles. Traditional knowledge systems—comprising ethnobotanical practices for medicinal plant identification, sustainable harvest protocols, and community-led conservation rituals—are under threat as younger generations migrate in search of alternative employment, severing intergenerational knowledge transmission. Documented displacement patterns reveal that climate-induced resource shortages have prompted seasonal and permanent migration from forest-dependent districts like Palamu and Latehar, increasing urban informal labor pools and straining social services in towns such as Ranchi and Dhanbad.

The broader economic toll of land degradation is estimated at USD 218.7 million annually, equivalent to USD 6.6 per capita, reflecting lost ecosystem services and diminished agricultural productivity in forest-fringe areas. Gender dynamics compound vulnerability: women, traditionally tasked with NTFP collection and household water procurement, face increased labor burdens as forest resources become scarcer, walking an additional 3–5 km daily for firewood and medicinal plants. This imbalance heightens health risks and reduces time available for childcare and income-generating activities, perpetuating gendered poverty cycles in tribal communities.

Conclusion

In conclusion, Jharkhand exemplifies the profound interconnections between global warming and biodiversity loss, where rising temperatures, altered precipitation regimes, and intensified extreme weather events have directly and indirectly reshaped both flora and fauna. The state's rich forest ecosystems once robust carbon sinks and sources of diverse non timber forest products now face accelerated land degradation, species composition shifts, and habitat fragmentation that threaten endemic megafauna and vital ecosystem services. Tribal communities, whose cultural identities and livelihoods depend on forest resources, confront declining NTFP yields, eroding traditional knowledge systems, and increasing migration pressures, all compounded by economic losses exceeding USD 218.7 million annually. Cascading ecological effects, including disrupted food webs, disease ecology changes, and wetland degradation, further undermine regional resilience and human well being.

Addressing these challenges requires an integrated approach that harmonizes climate resilient forest management, targeted conservation of keystone species, and sustainable livelihood alternatives for forest dependent communities. Strengthening community based conservation, revitalizing traditional ecological knowledge, and investing in adaptive infrastructure will be crucial to restoring ecosystem integrity and safeguarding Jharkhand's biodiversity. Policymakers must prioritize location specific strategies informed by district level vulnerability assessments, bolster research on climate biodiversity interactions, and ensure sustained financial and institutional support. Only through coordinated action can Jharkhand transform its ecological crisis into an opportunity for model climate smart conservation and inclusive socio economic development.

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