



REVIEW ARTICLE

The Eastern Ghat of India: A review on plant ecological perspectives

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 OPEN ACCESS

ARTICLE HISTORY

Received: 09 April 2024
Accepted: 10 July 2024

Available online
Version 1.0 : 22 July 2024
Version 2.0 : 31 July 2024



Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

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CITE THIS ARTICLE

Behera S, Pattanayak SK, Bhadra A. The Eastern Ghat of India: A review on plant ecological perspectives. *Plant Science Today*. 2024; 11(3): 441-449. <https://doi.org/10.14719/pst.3684>

Abstract

The Eastern Ghats, a discontinuous range of mountains spanning Odisha, Andhra Pradesh, Telangana, Tamil Nadu, and Karnataka has a humid tropical monsoon climate with moderate to high temperatures and heavy rainfall. The Eastern Ghats offer a diverse range of flora and fauna, including endemics. The vegetation is classified into various forest types, including moist deciduous, dry deciduous, dry evergreen, evergreen, semi-evergreen, scrub jungles, and savannah. Eastern Ghat reflects the healthy carrying capacity of the ecosystem. The Eastern Ghats boasts a diverse plant community, with over 3200 flowering plant species, largely due to geographic factors, high seasonality, and elevational variations. The Eastern Ghats, a significant biodiversity granary in India, has been the subject of numerous taxonomic and quantitative surveys. The eastern coast of India's eastern forest (Eastern Ghats) is facing a decline in plant diversity due to overexploitation, habitat destruction, and rampant grazing. This has led to species loss and extinction. The forest cover has also decreased due to anthropogenic pressures. However, there is a lack of significant research on plant species population dynamics, soil surveys, soil chemistry, geomorphology, geobotany, pedology, edaphology, and phytochemistry. To address this, modern science and technology approaches, such as geomorphometry and geobotanical studies using Remote Sensing and GIS techniques, are the need of the hour.

Keywords

Climate change; Eastern Ghat; ecology; ecosystem; plant diversity

Introduction

The Eastern Ghats extend over 2000 km in the peninsular India with an average width of about 100 Km. The hill ranges remain within 11° 30' to 21° 00' N Latitude and 77° 22' to 85° 20' E Longitude. It covers an elevation range from sea level to 1572 m a.s.l. and is enshrined with diverse physical features, which provide an opportunity to host rich flora and fauna. It is dissected into discontinuous blocks along the east coast of India through erosion by west-to-east flowing major Indian rivers like Mahanadi, Godavari, and Krishna and their tributaries. From south to north, the Ghats is spread over Tamil Nadu, Karnataka, Andhra Pradesh, and Odisha states with a general trend of South South-West to North North-East (SSW-NNE) and cover a total estimated area of 75000 Km². In Odisha, the Eastern Ghats covers 36% of the total land area of the state (1). The vegetation belongs to different forest types like moist deciduous, dry deciduous, dry evergreen, evergreen, semi-evergreen, scrub jungles and savannah etc. The Eastern

Ghats is phytogeographically unique and hosts rich flora (2) and fauna. It is juxtaposed between Nilgiris in the south and Vindhyan in the north. Many plant species of the Himalayas and North-Eastern states are found in high altitudes of the Eastern Ghats. On the other hand, some Western Ghat plants are also found on the Eastern Ghats. Eastern Ghats harbours about 3200 plant taxa. The economic and ecological importance of the Eastern Ghat forests has been realized since ancient times. However, this ecosystem is under stress and multiple threats due to the alarming rate of deforestation-induced degradation. Therefore, adequate conservation measures are the need of the hour to help sustain this pristine ecosystem.

Materials and Methods

The studies on Eastern Ghats were carried out through field surveys and sampling methods. For example, Kadavul and Parthasarathy (3) carried out a study by the following methods on the tropical semi-evergreen forest of the Shervarayan hills within the Eastern Ghats. Four 1-ha square plots were subdivided into 10m×10m quadrants, and all living trees and lianas were identified and measured for girth at breast height (GBH). Voucher specimens were used for species confirmation. The study used Shannon, Simpson's, Hill diversity, and Hierarchical richness indexes to calculate species diversity and evenness. Relative density, frequency, dominance, and importance value index (IVI) were calculated. Distribution patterns were determined using Morisita's index.

Reddy and Ugle (4) worked on the tree species diversity and distribution patterns of the R.V. Nagar range, Visakhapatnam which falls in the domain of Eastern Ghats. The study used a random sampling method to collect tree data from 50 plots of quadrant size 20m×20m in the Madras and Visakhapatnam districts. The study evaluated phytosociological characteristics of tree communities, including frequency, density, abundance, basal area, and IVI. Species diversity was determined using the Shannon-Weiner index (Shannon and Weiner, 1963), and the ratio of abundance to frequency by Whitford methods (Whitford, 1949). Tree species were grouped into five frequency classes based on Raunkier's law (4).

The study conducted a vegetation analysis from March 2007 to December 2009 in a tropical dry deciduous forest stand and enumerated the floral composition and its diversity. Trees with a girth of ≥ 15 cm were sampled through quadrants (20m × 20 m), while shrubs through (5m×5m), herbs, climbers, and saplings were sampled through (1m × 1 m) quadrants. Herbarium specimens were prepared and species were identified using regional flora. The dispersion pattern was studied using various indexes. The study also analyzed the population structure of tree species and their threat to medicinal plants. The study analyzed tree species' abundance, frequency, density, basal area, importance value index, Shannon-Wiener index (Shannon and Weaver, 1963), and Simpson's index (Simpson, 1949) to study their dispersion patterns. The population structure was analyzed across five girth

classes, and the status and threat of medicinal plants in their natural habitat were classified according to the Red Data Book categories by the IUCN (5).

Results and Discussion

A study by G.S. Rawat (1997), at Eastern Ghat of Tamilnadu through Andhra Pradesh to the south part of Odisha known for its tropical forests and biodiversity. However, the effectiveness of protected areas (PAs) is often questionable. A survey was conducted to assess the forest's ecological status and the impact of current forest practices. The survey found that Srisenkateshwara National Park, Gundlabrahmeshwaram Sanctuary, and some regions of Srisailam-Nagarjunasagar Tiger Reserve had the least degraded forest coverage because of their PA status. Bamboo cutting must be prohibited in the core zones as well as reduced in buffer zones. The diverse flora of Gudem Maripakhala Sanctuary is vulnerable because of extensive 'podu' cultivation (6).

Kadavul and Parthasarathy (3) carried out a study on the tropical semi-evergreen forest of the Shervarayan hills within the Eastern Ghats. The study focused on the diversity of species, their density, the dispersion patterns of trees, the population structure, and the lianas. The study found that the forest stands had a majority of the growing population. There were revealed variations of basal area distributions among the different plots. The study also found that species richness and stand density decreased following an increase in the girths of trees. The study suggests that variation in plant abundance and diversity is related to site attributes and anthropogenic impacts (3).

Brahmam *et al.* (7) worked extensively on the different aspects of Eastern Ghats and composed it as "This is Orissa and its Eastern Ghats". The physiography of the ghats is characterized by steep mountains, broad valleys, dissected highlands, plateaus, plains, and river valleys (Table 1). The gneiss rocks are the principal range makers of the topography. The topography of the Ghats is predominated by the round hummocky hills covered with laterite formed from the khondalite rocks. The Charnockites and gneisses have given rise to more rugged hills with steep slopes. The maximal spatial spread of the Eastern Ghats is within the average elevation of 500m a.m.s.l., however, isolated peaks rise upto 1672m in some areas. Most of the hills in the Ghats harbour dense forests hosting a rich gene pool of plant species. Some of the plateau tops of the hills are still covered with fascinating forests but many of them have become seriously degraded due to the tropical effect of weathering and erosion. North-East to South-West trending Gandhamardan hills in Odisha is a part of the Eastern Ghats, which cover an elevation range from 300 to 1050m a.m.s.l.

Chittibabu and Parthasarathy (8) highlight the research work in the Kolli hills within the Eastern Ghats. They found that disturbed sites had lower species richness but greater density than undisturbed sites. The study found that 27% of species were in common to all the four

Table 1. Physiographic Characteristics of the Eastern Ghats.

Sl. No.	Location	Physiographic section & sub-sections	Important mountain and peaks with their altitude (m)	
1	Between Subarnarekha and Brahmani	Similipal massif, Nilagiri Hills, Baitarani uplands, Keonjhar plateau, Gangpur basin, Biramitrapur hills, Dhenkanal uplands	Malayagiri	1187
			Meghasini	1165
			Mankadanacha	1117
			Amjhuri	1082
			Daitari	875
			Badampahar	832
			Nilagiri	545
2	Between Brahmani and Mahanadi	Sundargarh hills, Bamra and Bonai hills, Tikarpara range and Kanaka hills	Nrusinghanath	986
			Panchadhara	915
			Tikarapara	901
			Bonai hills	769
			Bamra hills	761
			Kapilas hills	636
3	Between Mahanadi and Rushikulya	Khondamal hills, Nayagarh hills, Khurda upland and Rushikulya basin	Murali soru	1223
			Kotrabori hills	1184
			Doda soru	1157
			Khundabola	949
			Goaldei	764
4	Between Rushikulya and Nagavali	Maliyas, Mahendragiri hills, Vanshadhara and Niyamgiri hills	Singaraju hills	1516
			Niyamgiri	1515
			Mahendragiri	1501
			Devagiri	1382
			Chandragiri	1269
			Subarnagiri	1257
			Kotangi soru	1172
			Kirimbathali	1100
			Giridabadi	1036
Rayagara hills	881			
5	South of Tel and West of Nagavali	Kondan hills, Machkund plateau, Koraput plateau, Kalahandi basin	Deomali	1672
			Sinkarak Gutta	1620
			Turiakonda	1598
			Karnapadikonda	1487
			Hatimali	1391
			Tangri Dongar	1229
			Karlapat	1213
			Kondamali	1077

sites studied, with the majority of herbs about 40% constituting the community. The study also found that 28 species were annuals, and 6 species were weeds. The study focuses on the need for effective forest management and conservation strategies in disturbed forest sites with weed invasion, as 31% of economically important understory plants and their reduced richness in the disturbed forest sites are reflected by weed invasion.

The Eastern Ghats region in India studied by Rao (9) is home to diverse flora and fauna and is facing deforestation and shifting cultivation practices, limiting dense forests and threatening wildlife species like the cheetah and tiger. This has drastically reduced species richness among plants, animals, and habitats. They have an average elevation of 1150 m and support moist and deciduous vegetation. Vegetation is classified into three strata: upper canopy, intermediate stories, and scrub-covered ground.

The index-based study conducted by Pitchairamu and Muthuchelian (10) in i) two disturbed areas (Nehru Park and foothill); ii) two moderately disturbed areas (Vannar Iruppu and Alaguchokkan); and iii) two undisturbed areas (Veerappan kovil and Dharga area) in the tropical dry deciduous Piranmalai forest in Eastern Ghats, revealed a progressive reduction trend in diversity with increase in disturbance. They documented a total of 82 plant species (16 trees, 21 shrubs, 28 herbs, and 17 climbers), and observed that the tropical dry evergreen forest ecosystems in six different study sites in Piranmalai forest are distinct from each other even though, all six sites receive about the same rainfall within 7Km radius and form a continuous section of tropical forests ranging from 200m upto 800m altitude. They attributed the changes in community characteristics to the increased grade of disturbance that led to plant diversity loss. This study revealed that the community organization is significantly changed in terms of flora composition,

species density, and tree population structure. This disturbance leads to thinning of the woody layer, and drastic change in the forest microclimate. These changes impair the tree species regeneration potential and simultaneously help in the colonization and establishment of shade-intolerant shrubs and annuals. Such studies provide pathways for the conservation of the forests undergoing degradation and help improve the condition of the environment and the economic status of the local people. Therefore, species density and tree population structure study carry importance in stabilizing ecosystem integrity with future socioeconomic security (10).

Sandhyarani (11) explores the significant region of Eastern Ghats with 560 tree taxa, comprising 262 genera and 80 families. The richest families are Rubiaceae, Euphorbiaceae, Lauraceae, Moraceae, Rutaceae, Mimosaceae, Meliaceae, Verbenaceae, Cordiaceae, Fabaceae, Ebenaceae, Oleaceae, and Tiliaceae. The genera of dominance include *Ficus*, *Grewia*, *Acacia*, *Diospyros*, and *Terminalia*. The region's geology, topography, vegetation, climate, floristic analysis, and tree distribution pattern are provided.

Sankar *et al.* (12) explored the threatened plants of Javvadh hills in the Eastern Ghats, which spread over the Krishnagiri, Tiruvannamalai, and Vellore districts of Tamil Nadu. At an altitudinal region of 800m a.m.s.l., the hills form an undulating plateau with small valleys. This region harbours around 800 taxa of which many are endemic and threatened. The litho units of these hills are highly ferruginous and minerals like hornblende and feldspar dominate in the matrix. Hot tropical dry climate dominates in the region, which has a characteristic average minimum temperature of 19°C, maximum temperature of 32°C, and annual rainfall of 1075mm. The hill range hosts 4 critically endangered, 16 endangered, 34 vulnerable, and several endemic species (Ravikumar and Ved, 2000). Four species need immediate attention for conservation *Brachystelma brevitulatum* (Bedd.) Gamble, *Panicum fischeri* Bor, *Barleria pilosa* Wall. ex Nees and *Premna latifolia* Roxb. var. *henryi* D. Naras belong to families of Asclepiadaceae, Poaceae, Acanthaceae, and Verbenaceae, respectively (12).

In the Eastern Ghats region, there are few isolated evergreen forest patches developed under typical geomorphological and habitat conditions. Pragasan *et al.* (13) compared the species of the southern part of Eastern Ghats with that of the Shola forests of Western Ghats. The evergreen Shola forests of the Southernmost Eastern Ghats occur towards the top of the hills in the elevation region of 750-1649m a.m.s.l.

The Charnockite-gneiss-varied metamorphic association characterizes the hills. In this region, important plant taxa for conservation priority are *Memecylon parvifolium* Thwaites (Melastomaceae), *Memecylon madgolense* Gamble (Melastomaceae), *Cinnamomum malabratum* (Burm. F.) Blume (Lauraceae), *Antiaris toxicaria* (Pers.) Lesch. (Moraceae), *Myristica dactyloides* Gaertn. (Myristicaceae), *Dimocarpus longan* Lour. (Sapindaceae), *Meliosma pinnata* (Roxb.) Maxim. ssp.

arnottiana (Wight) Beus. (Meliosmaceae), *Canarium strictum* Roxb. (Burseraceae), *Diploclisia glaucescens* (Blume) Diels (Menispermaceae), *Embelia basaal* (Roem. Ex Schultes) A. DC. (Myrsinaceae), *Entada pursaetha* DC. (Mimosaceae), *Capparis shevaroyensis* Sund.-Ragh. (Capparaceae), *Rhaphidophora laciniata* (Burm.f.) Merr. (Araceae) and *Gymnema tingens* (Roxb.) Wight & Arn. (Asclepiadaceae).

Reddy and Ugle (4) worked on the tree species diversity and distribution patterns of the R.V. Nagar range, Visakhapatnam which falls in the domain of Eastern Ghats. Phytosociological analysis reveals that the most frequent species of the region are *Pterocarpus marsupium* Roxb., *Schleichera oleosa* (Lour.) Oken., *Mangifera indica* L., *Syzygium cumini* (L.) Skeels, *Bauhinia vahlii* Fern.-Vill., *Mallotus philippensis* Muell. Arg and *Grewia tilifolia* Vahl. The species are distributed in the semi-evergreen, moist deciduous, and savannah types of forests. Among 120 species recorded in this study, 107 showed regular, 12 showed random and one showed a contiguous pattern of distribution. Shannon-Wiener index of diversity was highest e.g., 5.5 for moist deciduous forests followed by a value of 5.27 for semi-evergreen and 3.71 for savannah forests.

Rao *et al.* (14) studied the vegetation types of the degraded Eastern Ghats Mountain ecosystem using techniques of remote sensing. The Eastern Ghats is an important biogeographic region of India and is a major center of plant diversity with high endemism. Their work discussed the presence of six different tropical forest types in these hill ranges viz. i) evergreen forests; ii) moist deciduous forests; iii) dry deciduous forests; iv) mixed dry deciduous forests; v) Scrub forests; and vi) dry evergreen forests (14). The Ghats, covering an area of 75000 Km² approximately, host about 3000 angiospermic plant species of which nearly 100 species are endemic namely *Boswellia ovalifoliolata* N.P. Balakar & A.N. Henry, *Cycas beddomi* Dyer., *Pimpinella tirupatensis* Bal. & Subr., *Pterocarpus santalinus* (Linn. F.), *Shorea tumbuggaia* Roxb. and *Terminalia pallida* Brandis are endemic to these hills. Many species of these Ghats have a narrow distribution and, therefore, any unusual change in the habitats can reduce their population (15, 16). The exploitation of native species in reserve forests of this region, despite protection measures, suggests the continuing loss of a gene pool, which might be valuable.

Saxena *et al.* (17) in their report on the proposal of Orissa Mining Corporation (OMC) relating to bauxite mining in Niyamgiri hill of northern Eastern Ghats apprised the Ministry of Environment and Forest that the hill constitutes the biotic province 6C in accordance to the Biogeographic Classification proposed by Wildlife Institute of India (WII); this province is similar to zone 6 of the Deccan plateaus in Western Ghats. In the hill, the proposed mining area occurs towards the upper part of the plateau covered with dense forest with floral and faunal richness. Some twenty Orchid species occur in the adjacent regions. The mining area is largely grassland surrounded by sal forests being an edaphic climax. Under the forest

ecological classification scheme of Champion and Seth the forest in the proposed mining area is classified as 3C i.e. "North Indian Tropical Moist Deciduous Forests-C2e (i) - Moist Peninsular High-Level Sal". Ecological communities found on the hills are: i) tropical evergreen forests, ii) tropical moist deciduous forests, iii) dry deciduous mixed forests, iii) moist peninsular sal forests, iv) dense bamboo forests, v) scrub woodlands and vi) open grasslands. Besides, tropical semi-evergreen forests are present in the neighbourhood of stream courses. The people belonging to the Dongaria Kondh tribe use the plant resources for medicinal purposes like treating acidity, arthritis, asthma, bone fracture, cholera, diarrhoea, dysentery, eczema, malaria, menstrual disorders, paralysis, rheumatism, sores, stomach disorders, tuberculosis, tumours, wounds, and scorpion and snake bites. Niyamgiri Hill provides a link between Kandhamal forests with the hills of Kalahandi, Koraput, and Rayagada regions. The forest of Niyamgiri also provides a link between Karlapat and Kotagarh wildlife sanctuaries occurring towards its Northwest and Northeast, respectively. Therefore, Niyamgiri helps maintain an uninterrupted forest corridor, and thereby, plays an important role in the ecological functioning of the region. The survival of two native communities namely Dongaria and Kutia Kondh solely dependent on the Niyamgiri ecosystem; these communities regard this hill as a sacred grove. Any activity related to mining would severely disturb the wildlife habitat causing major ecological damage. On the other hand, the mining operations on the plateau top would also paralyze active perennial springs as well as Vamsadhara River creating a hydrological imbalance in the region. Thereby, mining activity on the hill may impair the livelihoods of the primitive tribal groups (17). In the Malayagiri hill ranges of Eastern Ghats in Odisha, Sahu, and Dhal (5) enumerated the floral composition and its diversity. They also defined the status of threatened medicinal plants of this hill range. The population structure of trees was observed to be reverse J-shaped, suggesting the expansion of the population, which demands special protection and maintenance. This study highlights the presence of threatened medicinal plants that require *in-situ*, *ex-situ*, or biotechnological approaches (e.g. gene bank development) for their conservation and propagation. Unsustainable utilization of medicinal plants like *Gloriosa superba* L., *Oroxylum indicum* (L.) Vent., and *Uraria picta* (Jacq.) Desv. ex DC should be checked (5). Further, Sahu *et al.* (18) recorded 1063 individuals of 57 tree species with a mean density of 443 trees/hectare and a basal area of 13.73m²ha⁻¹. *Shorea robusta* Gaertn. f. was the dominant species. Other significant species present in the area are *Anogeissus latifolia* Roxb., *Diospyros melanoxylon* (Roxb.), *Madhuca indica* JF Gmel, and *Terminalia alata* Hyene ex Roth. The girth class of trees was negatively correlated with stem density and species richness suggesting the presence of a less matured tree community. Fifty-two and five tree species were contiguously and randomly distributed, respectively. Good species diversity in the plant communities was indicated by the Shannon-Wiener Index (H') value of 3.38 and

Simpson's index (C) value of 1.

A study by P.C. Panda *et al.* (19) confined to the northern portion of Eastern Ghats located in Odisha state covers the districts of Kandhamal, Ganjam, Bolangir, Boudh, Cuttack, Nayagarh, and Angul. The temperature range varies season-wise and this region is observed with 4 major soils entisols, alfisols, vertisols, and inceptisols. The study recorded 882 species from 532 genera and 129 families, including 263 tree species, 78 shrubs, 138 climbers/twinners, and 403 herbs. Tree species were predominantly from *Diospyros melanoxylon* (Roxb.), *Lannea coromandelica* (Houtt.) Merr., *Madhuca indica* J.F. Gmal. and *Shorea robusta* Gaertn. f. with Euphorbiaceae, Rubiaceae, Fabaceae, and Combretaceae contributing to maximum species richness, stand density, and basal area (19).

Naidu and Kumar (20) analyzed the diversity of trees in the Eastern Ghats of northern Andhra Pradesh, through five districts Visakhapatnam, Srikakulam, West Godavari, Vizianagaram, and East Godavari which have semi-evergreen, tropical thorny-scrub vegetation, tropical dry-deciduous, tropical dry-evergreen, and tropical moist-deciduous forest. It recorded 270 species, with 141 common, 78 occasional, and 51 rare. The dominant family was Fabaceae, with *Ficus*, *Diospyros*, *Albizia*, *Grewia*, *Acacia*, and *Bauhinia* being the most abundant. The study highlights the need for conservation (20).

Kumaraguru *et al.* (21) analyze the floral diversity of the Tiruchirappalli forest division, revealing 417 species from 89 families. The predominant families are Euphorbiaceae, Poaceae, Cesalpinoideae, and Mimosaceae, with other 38 families having 1 species each. The study provides baseline information on the vegetation in the Eastern Ghats' tail-end region, making it crucial for further study. The diversity of plants reflects the carrying capacity of the ecosystem.

Alam *et al.* (22) explore the Eastern Ghat located between 11° 30' and 22° N Latitude and 76°50' and 86° 30' E Longitude in a North-East to South-West direction in Tamil Nadu. Approximately 2600 pteridophytes, gymnosperms, angiosperms, and 160 plants of cultivation are recognized in the Eastern Ghats region. Habitat destruction in Eastern Ghats, despite its lush green vegetation and diverse habitats, often leads to the extinction of bryophytes due to their sensitivity to environmental change. To protect these species, it is crucial to assess their bryophytes, identify changes in habit, habitat, growth rate, and pattern, and classify them under threatened plant categories.

Naidu and Kumar (23) investigated tree species distribution, density, and population structure in Visakhapatnam district in Andhra Pradesh, India, and it is experiencing rapid vegetation changes due to anthropogenic forcings such as thermal power generation, mining, and hydroelectricity projects. The study aims to assess the change in tree diversity of the Eastern Ghat of India using biodiversity indices. The study found high abundance and diversity of tree species in the Visakhapatnam district forest, with Shannon-Wiener

values ranging from 0.81 to 4.1. An effective and prospective method of forest management is required to conserve dominant tree species and maintain ecological balance. The findings of this study are useful to conservationists as well as forest managers for effective conservation planning (23).

A study highlights the uniqueness and potential for ecosystem conservation in the study region in East Godavari district, Andhra Pradesh, but highlights overexploitation due to cultivation, firewood, fencing, and wood use. Medicinal plant collection, forest fires, and grazing cause rapid forest decline. People's participation is crucial for the most effective conservation, and this study will help understand threats and drive conservation policies (24).

The study by Dash and Misra (25) on plant diversity in tribal village ecosystems in Orissa, reveals that these resources meet tribals' basic needs for sustenance. Out of 249 species, forty-three are used for food, sixty-one for medicine, eighteen for timber, three for stimulants, Sixteen for fuel, and seventeen for sacred plants.

The Eastern Ghats, spanning Andhra Pradesh, Karnataka, Odisha, Tamil Nadu, and Telangana, have a humid tropical monsoon climate with moderate to high temperatures and heavy rainfall). The region experiences a semi-arid rain shadow region to its south. Soil types include black, red, and alluvial, with high relative humidity during the rainy season. The Eastern Ghats' biodiversity, particularly plant diversity, is threatened by anthropogenic pressures and natural disasters. Natural competition, lack of pollination, and human activities like encroachment, mining, and illegal trade lead to habitat destruction and fragmentation, affecting the region's natural regeneration and seed formation. These Ghats are home to a wide range of angiospermic plants i.e. over 4000 flowering plant species. A total of 166 taxa of flowering plants are endemic in the Eastern Ghats. Some of the well-known endemic species found in this hill range are: *Acacia donaldii* Haines (Leguminosae: Mimosoideae), Human activities have significantly reduced the area of occupancy and occurrence of many endemic species in the Eastern Ghats region. *In-situ* and *ex-situ* strategies must be placed to ensure their long-term survival, and conservation through protection of natural habitats, strict forest encroachment bans, and awareness-raising efforts by State Forest Departments.

The hydrogeological and geophysical realms of the North Eastern Ghats Khondalitic terrain were explored by Rao (26). In this region, basement granitic gneiss is covered with metasedimentary Khondalitic rocks at the top of which occur the bauxitised laterites. The rock formations have undergone intense weathering, faulting, fracturing, and folding, and water is accumulated mainly in two aquifer conditions i) a weathered lateralised-bauxite layer and ii) a fractured layer; there is hydraulic continuity between these layers (26). Khondalite terrain, named after the 'Khonds' tribe of India living in the Eastern Ghats, covers about one-eighth of areas of the country covered with hard rock formations. The presence of iron

and bauxite deposits bears testimony to the concept of the origin of khondalites from alumina (27). The chondrites on interactions with water are altered into laterite on the surface and the subsurface kaolinite (28).

Below the streamlines, and low-lying areas most of the khondalite became kaolinized. This kaolinite zone is mostly clays and acts as a barrier preventing groundwater movement towards the stream. Thus, groundwater accumulates in the upland areas. The kaolinite zone becomes a groundwater potential zone wherever the formation is fractured and intruded with quartz veins opined that the Eastern Ghats terrain is dissected by well-developed river basins with many sub-basins (27). These basins have different groundwater potentials depending on the intensity of weathering and lithologic configurations. Also, the aerial photograph shows that the khondalite terrain has fractured zones (29). This character is behind the reason for the existence of groundwater potential zones at all elevational levels all through the Eastern Ghats despite having steep slopes. The khondalite formations are homogeneous and the weak planes in them are more or less uniform. Therefore, the dendritic pattern of drainage is prevalent in this terrain. A general trend of increase in total dissolved salt content in water is observed with the decrease in elevation in the Eastern Ghats (27). Generally, the quality of the groundwater of Eastern Ghats is suitable for drinking and irrigation purposes. However, in a few pockets, high levels of Fluoride and Nitrate are present.

Panda *et al.* (30) did a study on a reassessment of the status of endemic vascular plants of Eastern Ghats in Odisha and opined that the Eastern Ghats is rich in terms of plant diversity and harbors approximately 3500 wild plant species. They reported the existence of 136 endemic vascular plants within the Eastern Ghats. Sahu *et al.* (31) worked on the tree species distribution, diversity, and soil nutrient status along an altitudinal gradient (81m-450m) in the Saptasajya hill range, Eastern Ghats, India. They documented 368 individuals of tree species which belong to 48 species, 42 genera, and 27 families. Species occurrence gradually decreased from lower to higher elevations. The average tree species basal area was calculated as 30.64 m²/ha. Shannon-Wiener index of diversity was 2.19, 1.84, and 1.29 in Lower Elevation Forests (LEF), Middle Elevation Forest (MEF), and High Elevation Forest (HEF), respectively. On the correlation of soil parameters of three forest sites with tree species richness, diversity, and density, it was found that species richness and diversity indices were positively related to pH; tree density was negatively related to pH, phosphorous, and organic carbon. This study helps understand vegetation patterns about soil nutrients in the Eastern Ghats of India and gives a better conservation plan.

The study by Panda (32) explores the impact of ecosystem disturbance, climate change, and physiography on the richness of plant species in the Eastern Ghats. This study reveals a total of 1670 species, 737 genera, and 167 families, with 771 herbs and 451 trees being the dominant

groups. Fabaceae is the largest family, followed by Poaceae, Acanthaceae, Rubiaceae, and Euphorbiaceae. The most species-rich genus is *Crotalaria*, followed by *Ficus*, *Acacia*, *Grewia*, *Cyperus*, and *Indigofera*. It reveals that water-energy dynamics significantly regulate plant richness, with mean annual precipitation and temperature playing a significant role.

The phytosociological study (33) examined the upper story vegetation layer in five districts of Odisha, including Kalahandi, Raygada, Ganjam, Khurda, and Satkosia (Angul), revealing a rich and diverse vegetation and flora. The region experiences summer temperatures ranging from 40 to 46.3°C and winter temperatures from 4.4 to 13.2°C. It has four major soil types: inceptisol, alfisols, entisols, and vertisols. Forest vegetation in the Eastern Ghats sub-division was quantitatively analyzed using a forest cover map, revealing higher frequency percentages in dense forest and open forest species like *Shorea robusta* Gaertn.f., *Terminalia alata* Hyene ex Roth, *Buchanania lanzan* Spreng., *Lannea coromandelica* (Houtt.) Merr., *Madhuca indica* J.F. Gmal., and *Syzygium cumini* (L.) Skeels. The study reveals the status of plant diversity, sal tree status, invasive species competition, and soil chemical properties in sal-dominated natural forests. It provides valuable data for researchers and policymakers to improve forest inventory and conservation strategies.

A study by Kanimozhi *et al.* (34) analyzed factors affecting biodiversity in the Eastern Ghats of Tamil Nadu, specifically in the Salem and Thiruvannamalai districts. 182 tribal respondents were selected and data was collected through personal interviews. Results showed decline in biodiversity is influenced by factors such as habitat destruction, land fragmentation, modernization of healthcare, introduction of exotic plant varieties, higher application of plant chemicals, and increased deforestation. To prevent the threat, communities should maintain diverse cropping patterns, avoid chemical inputs, use bio-friendly practices, grow traditional crops, and avoid mono and plantation cropping.

India's Eastern Ghats (EG) forests are rich in species but need to be explored and recognized despite their significant contribution to the region's endemism (35). The Index-based Atmospheric Purity research identifies trepidation in lichen flora, focusing on their priority and prosperity using alpha and beta diversity indexes. The Indian subcontinent has 3,005 lichenized and lichenicolous fungal taxa, with Sirumalai and Megamalai being major biodiversity hotspots with 96 and 101 species respectively. Kollimalai, a 1,300m-high hill station in Tamil Nadu, is a mystical region inhabited by Siddhas and tribals. The study examines lichen growth, metabolism, and habitat characteristics of the Kolli Hill, a habitat for various plants and animals, from March 2019 to April 2021, based on climate, growth intervals, and natural metabolism. The study identifies five lichen types, Pertisarioid, Usneoid, Ramalinoid, Arthonioid, and Cyanolichens, which are highly sensitive to pollution and anthropogenic activities. Scaly and Cyanolichens are found in tropical and high-humidity areas, while

Arthonioid, Usneoid, Scaly, and Ramalinoid types have the least diversity.

M.P. Verma *et al.* (36) conducted a study on the Eastern Ghats region in Andhra Pradesh, dividing it into Southern, Central, and Northern Ghats. This is home to floristic richness, endemic flora, and forest diversity. The Bodakondamma sacred grove study area is located in Chinthapalli Mandal of Visakhapatnam District, with dry deciduous vegetation and the annual jathara festival. This study reported 67 species of trees, 45 species of shrubs, 73 herb species, and 45 climber species at the sacred grooves. Sacred groves house rare, endemic, and endangered species. Local tribes rely on forests for resources, but younger generations' negligence threatens these groves. Conservation is urgent, and awareness is needed.

A study conducted by Behera (37) in the Tropical Moist Sal Forest of Eastern Ghats found a significant decline in tree and shrub diversity, species richness, basal area, and density along the gradient of disturbance. However, the index of Shannon-Wiener diversity increased considerably with increasing disturbance levels. The highest stem density was found in the tree diameter class of 10-30cm, with lower diameter classes having higher species richness. Disturbances impacted tree distribution patterns, with recurrent grazing, frequent forest fires, and poor soil seed banks contributing to poor regeneration. The study recommends adopting approaches encompassing sustainable conservation measures including local people and tribal involvement to control the biodiversity of the remaining Moist Sal Forests and prevent further degradation.

A study by Naidu *et al.* (38) at the Eastern Ghats region in India, part of the Deccan peninsula biogeographic zone, once sustained diverse habitats, flora, and fauna. However, forests are decreasing rapidly due to anthropocentric activities such as urbanization, modern infrastructure of roads, railways, and dam construction. Other reasons include natural calamities, invasion of secondary species, and weeds. The study was carried out in six regions (Galelu, Kodavatipuri, Subbaiahpalem, Sileru, Rajupeta, and Gadampalem) of Visakhapatnam district, Andhra Pradesh, revealing good species dominance, diversity, stand density and richness in comparison to other dry deciduous forests. Various forms of anthropogenic pressures, such as logging, illegal hunting, timber collection, and invasive species entry, have affected the region's ecological significance.

Conclusion

The review of the literature shows that many taxonomic surveys and quantitative floristics works have been carried out in the Eastern Ghats. Few geological and botanical surveys have been carried out only on the Eastern Ghats during the prospecting of the bauxite deposits. However, no significant works on the aspects of plant species population dynamics, soil survey, soil chemistry, geomorphology, geobotany, pedology, edaphology, or phytochemistry have

been done on the Ghats (Fig. 1). The Eastern Ghats provide important ecosystem services like perennial stream water for drinking, agriculture, daily needs, medicinal plants, bamboo, fuel wood, non-timber forest products, timber, economical grasses for broom making, and above all the hill range controls the microclimate of the East Coast region of India (Fig. 1). Besides, Eastern Ghats is considered one of the most noted biodiversity granaries not only in India but also in the world. Therefore, modern approaches of science and technology like extensive geomorphometry and geobotanical studies using Remote Sensing and GIS techniques should be applied to ascertain: i) Plant taxonomic diversity of the Eastern Ghats, ii) Species-level population status with their conservation priorities, iii) The nature, extent and spatial distribution of landscape features on the Ghats, iv) Soil physicochemical characteristics on the Ghats, vi) Vegetation-geography-soil relationships through

landscape level analysis and interpretation.

Acknowledgments

Authors acknowledge the support from Centurion University of Technology and Management; and Sambalpur University.

Authors' contributions

SB formatted the article according to the 'Plant Science Today' Journal and did the revision, SKP contributed to Plagiarism compliance and checking; AB collected literature, and data, and wrote the article.

Compliance with ethical standards

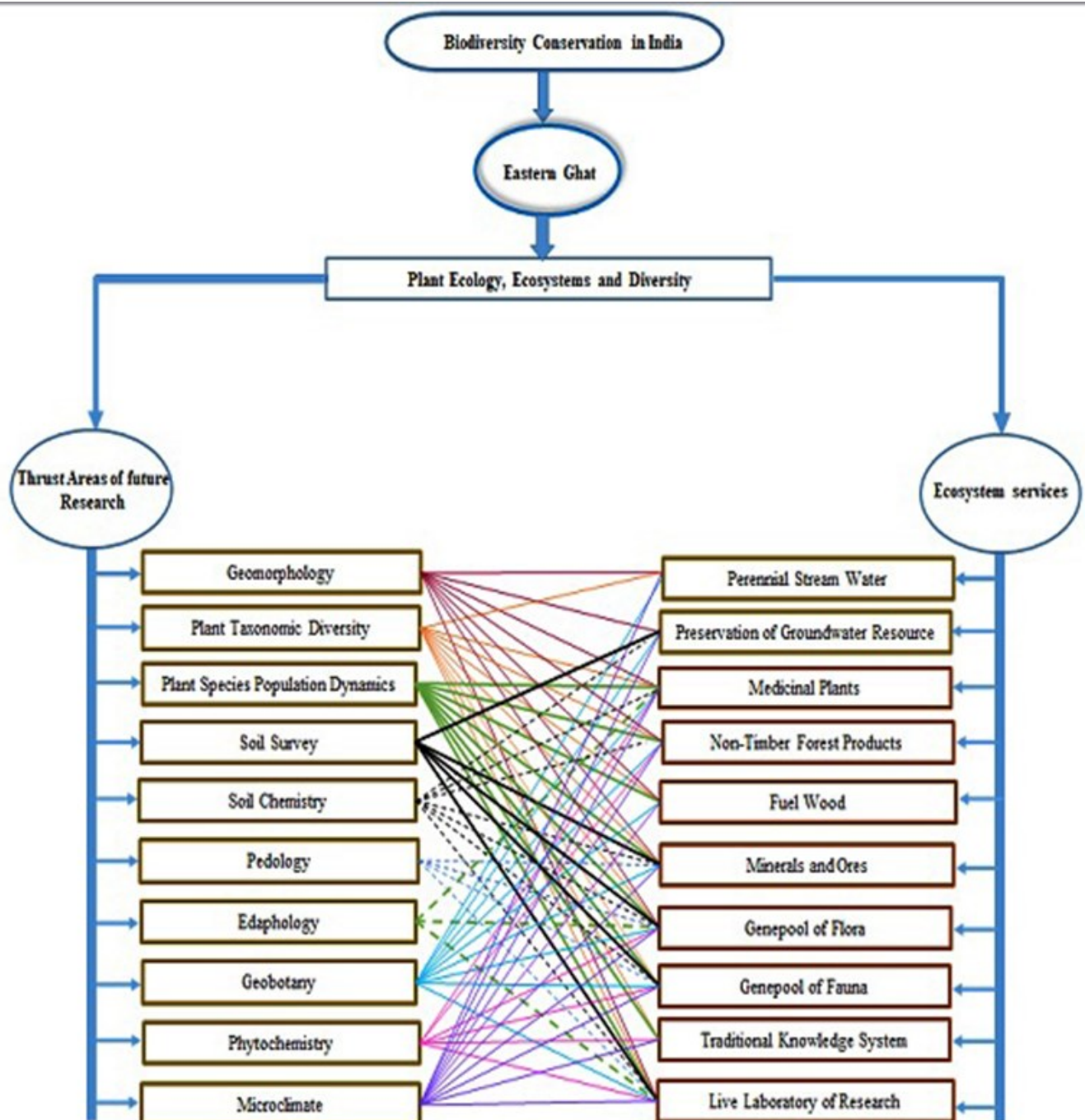


Fig. 1: Linking thrust areas of future research on the Eastern Ghat and available Ecosystem services

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None.

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