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REVIEW ARTICLE

Valuing nature: A comprehensive review of ecosystem services in India

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Abstract

The concept of ecosystem services (ES) has garnered global recognition due to its substantial impact on human well-being. Biodiversity loss, driven by both direct and indirect factors, has led to a decrease in the lifespan of ecosystems and their ability to offer ecosystem services. On a global scale, ES assessments are increasingly utilised by academicians to develop sustainable and environmentally focused policies. In India, ES-related research has been steadily expanding to capture the various benefits, both tangible and intangible, provided by numerous ecosystems. This study analyses 71 research articles to evaluate the increasing trend of ecosystem research and examine their methodological approaches. The gaps in existing research and literature have been extensively examined. The study reveals that while ecosystem services obtained from woods have been extensively studied, blue water ecosystems have not been adequately researched. Additionally, there is a lack of research on both the immediate and long-term impacts of global warming and other environmental concerns on the availability of ecosystem services. A comprehensive evaluation of environmental sustainability necessitates the integration of interdisciplinary approaches. Future ES assessments should incorporate both conventional and indigenous knowledge systems within the evaluation framework to develop practical and long-lasting policy recommendations.

Keywords: ecosystem services; provisioning services; regulating services; supporting services; cultural services; economic valuation; India

Introduction

Ecosystem services are essential for building resilience against global challenges such as climate change and biodiversity loss. Forests, for instance, play a pivotal role in CO_2 sequestration, capturing approximately 7.6 billion metric tons of CO_2 each year, which accounts for about a third of global emissions. Similarly, wetlands, despite covering only 6 % of the earths' surface, store 35 % of terrestrial carbon. Pollinators, critical to global food production, contribute to crops valued between $235 billion and $577 billion annually. With nearly one million species at the verge of extinction, safeguarding ecosystems is vital for maintaining climate balance, protecting biodiversity and securing a sustainable future.

However, human interferences are causing degradation in ecosystems, resulting in habitat loss, biodiversity loss and the proliferation of exotic species. The degradation is primarily driven by the rising demand for resources like food, water, timber, fibre and fuel (1). The overexploitation of these resources is anticipated to pose a growing threat to human well-being (2). Around 60 % of the services vital for life on Earth are either deteriorating or being used unsustainably, potentially leading to more severe repercussions in over the next 50 years (3). Currently, around 2000 M ha of land are degraded, with an annual increase of 5-7 M ha (4).

Ecosystem services encompass the benefits that ecosystems provide, which are directly linked to the well-being and survival of humans (5, 6). Ecosystems lend a variety of essential commodities and services that are vital for human welfare. These services encompass the provision of food and raw materials, air and water purification, biodiversity preservation, aesthetic and cultural advantages (7). Additionally, they contribute to coastal protection, water supply and carbon sequestration, serving as natural buffers against environmental hazards (8). The Millennium Ecosystem Assessment (MEA) framework, published in 2005, categorizes ecosystem services into four main categories: supporting, regulating, provisioning and cultural services (9). This framework emphasises the intricate relationships and interconnections between the ecosystems, administration and human well- being, as well as the difficulties in prioritising and assessing various ecosystem services (10).

Comprehensive evaluations that consider the costs and benefits associated with the use of ecosystem commodities and services are crucial for informed decision-making and policy formulation (11). These evaluations account for the convolutions between ecosystem services and their impact on economic, social and cultural development (12). The total economic value (TEV) conceptual framework encompasses the cumulative worth of both direct and indirect value. Direct-use values arise when resources are directly consumed, whereas indirect values refer to non-consumptive and non-extractive benefits derived from ecosystem regulation, such as pollution control, climate regulation, or recreational value. Various methodologies have been developed to identify and quantify the hidden and intangible components of ecosystem services (13, 14). These approaches include Direct Market Valuation, Revealed Preference and Stated Preference approach.

Direct market valuation relies on market-based data to determine the cost, price and quantity of different ecosystem products and services that can be traded. Market price-based technique focuses on the market value of commodities, focusing on the price at which they are exchanged. Cost-based technique assesses the expenses involved in replacing a natural ecosystem service with artificial alternatives, while production functions-based approach analyses the connection between ecosystem services and the creation of marketable goods (6).

Revealed preference approaches rely on individual's behavioural patterns to infer their valuation of ecosystem services. This category includes two primary techniques. The Travel Cost Method (TCM) and Hedonic Pricing (HP). TCM estimates the recreational value of ecosystems by analysing the costs individuals are willing to incur to access these natural environments. HP, on the other hand, assesses how consumers value specific environmental attributes of goods. This method is particularly useful for assessing property prices near woods or other peaceful backdrops (15).

In contrast, Stated Preference methods are particularly beneficial for determining non-use values of ecosystem services. These methods often employ surveys to elicit respondents' preferences and trade-offs. Two primary approaches in this category are contingent valuation (CV) and choice modelling. CV involves individuals stating their willingness to pay (WTP) for a specific ecosystem feature or services, or their willingness to accept (WTA) compensation for negative environmental impacts, through structured questionnaires and other elicitation methods. Choice modelling, on the other hand, involves individuals selecting alternatives, associated with common features of environmental services being assessed (16).

Ecosystem services are elemental to achieving Sustainable Development Goals (SDGs), especially those concerning resource management, environmental sustainability and the welfare of communities and ecosystems. Progress towards SDGs concerning resources and the environment, including responsible consumption and production (SDG 12) and climate action (SDG 13) has shown positive outcomes in various regions due to the contributions of ecosystem services (17). The suggested techniques are projected to influence the delivery of six ecosystem services, directly contributing to SDGs 15, 2, 14 and 11 (life on land, Zero Hunger, Life Below Water and Sustainable Cities and Communities, respectively) (18).

India, with its vast population exceeding 1.3 billion, is one of the 17 megadiverse nations, home to a wide range of ecosystems, including forests, grasslands, deserts, wetlands and coastal and marine environments. These ecosystems sustain approximately 8% of global biodiversity and provide habitats for numerous endemic species (19). Yet, a significant portion of India's biodiversity, including unpopularized Ramsar sites (Kazhuveli coastal wetland) with international significance was not been fully documented or thoroughly examined. India's biodiversity faces significant threats from human activities like deforestation and excess harvesting, in addition to global issues like climate change.

As environmental concerns increase, there is an increasing recognition of the need to prioritise ES assessment research in the country. It is crucial to examine the rapport between ES valuation at the global level and ES literature at national and regional scales. There is a lack of research on the quantitative assessment of all the services offered by ecosystems, as compared to distinct types of ecosystem services. Identifying research that specifically examines the approaches used in valuing ecosystem services is particularly challenging. Hence, the study aimed to examine quantitative ES assessment studies conducted in India in between 2013 to 2024. This study focussed on two key research questions: 1) to examine the primary advancements and patterns in current research through a systematic review of existing ES studies and 2) to highlight the constraints of present ES studies and offer recommendations for the future trajectory of ES research.

The TEV framework categorises ecosystem services based on two primary values -Use and Non-use value. The employment of the TEV framework in ecosystem services helps understand the categorization of distinct types of services that need to be prioritised.

Materials and Methods

In this study, we explored journals and papers published between 2013 and 2024. An exhaustive search was conducted in digital repositories, specifically Scopus and Google Scholar, between July and August, 2024. The study utilised keywords such as "Ecosystem Services AND India," "Provisioning Ecosystem Services AND India," "Regulating Ecosystem Services AND India," "Supporting Ecosystem Services AND India," and "Cultural Ecosystem Services AND India." Additionally, for subcategories of provisioning, regulating, supporting and cultural services, specific ecosystem services viz. "pollination," "air pollution control," "ecotourism," and "sacred groves" were utilised as keywords to find relevant studies. Furthermore, supplementary review publications and their referenced sources were analyzed to ensure a comprehensive assessment. These sources were verified and quantitative data on ecosystem valuation in India were systematically compiled. The research methodology is outlined in Fig. 1.

During the first round of data collection, 1517 studies were acquired. Due to the broad and diverse nature of the ecosystem services (ES) concept, numerous comparable studies were conducted in neighbouring countries such as Nepal, Bangladesh and Pakistan. This is largely due to shared geographic and ecological features, including trans boundary landscapes such as the Himalayas and the Sundarbans. To ensure relevance, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed

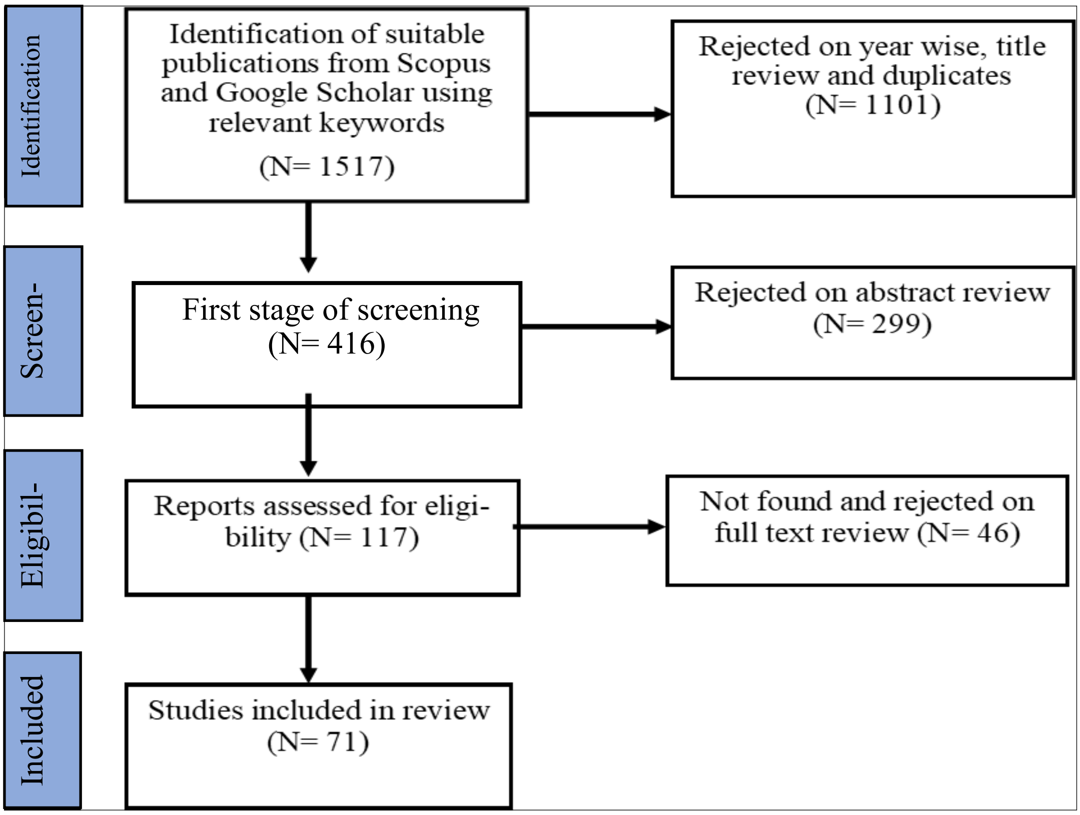

Fig. 1. Flowchart depicting the methodology for identifying studies included in the systematic review.

to determine the inclusion and exclusion criteria for publications (20). The PRISMA framework enhances the transparency and reliability of systematic reviews and meta-analyses by employing a four-phase flow diagram, which delineates the identification, screening, eligibility and inclusion stages.

To maintain a focused approach, our study was confined to research conducted within India's geographical boundaries, thereby excluding studies from neighbouring countries and duplicate records (N = 1,101). In the second phase, 416 studies underwent detailed examination. Research papers with a well-defined methodological approach and substantial contributions to the literature on ES assessment were selected, while opinion pieces and subjective investigations were excluded. This screening process resulted in the selection of 117 studies.

In the final stage, the selected research was further refined to align with our review methodology, prioritizing quantitative studies that explored emerging trends, innovative technological applications such as GIS-based models, land-use ES assessments, comparative analyses and other relevant aspects. Several key case studies and reports were incorporated into the framework due to their comprehensive and detailed investigations of ecosystem services in India, particularly those with implications for policy-making. A limited number of review papers were also included, specifically those offering a consolidated analysis of critical but underexplored ecosystems, such as wetlands. Based on these criteria, our final dataset comprised 71 relevant research publications and additional pertinent sources specific to India.

The collected literature was systematically categorized according to the broader ES classifications established by the Millennium Ecosystem Assessment (MEA) (21): Provisioning Services, Regulating Services, Supporting Services and Cultural Services.

Results and Discussion

Valuation methods for ecosystem services in India

Interest in ecosystem service assessment in India is growing, with increasing research focused on various habitats such as forests, grasslands, mangroves, wetlands and coral reefs. Various methodologies are used to calculate the values of ecosystem services in the territory, including the Contingent Valuation method (22-25), Benefit Transfer method (26-28), Travel cost method (29, 30) and Market price method (31). Notably, there is a rising trend in integrating modelling techniques into ecological evaluation research. For instance, one study extensively utilised the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model in a landmark assessment of ecosystem services in tiger reserves across India (32). Additionally, GIS-based approaches have been increasingly adopted in recent studies to assess variations in ecosystem services at the regional level (33-39).

Several authors have conducted comprehensive assessments of the Total Economic Value (TEV) of ecosystem services across India and its key ecosystems. In 2011, the TEV of ecosystem services in India was estimated at USD 1.8 trillion per year (40). Further, research also uncovers the presence of TEV at both regional and state levels. For example, the value of nine ES in the Terai Arc landscape was estimated to be ₹390 billion in 2015–2016 (41). Similarly, the TEV of forest in Arunachal Pradesh was determined to be approximately ₹1518 billion annually (42).

Provisioning services

Provisioning ecosystem services greatly contributes to India's economic growth. The services provided involve supplying fuelwood, silage, leaves, wild delicacies, medications and other resources that help increase households' annual revenues. In 2012-13, the overall value of marine ecosystem services in India was projected to be around ₹1.9 trillion (in Purchasing Price

Parity [PPP] terms) (43). The direct market valuation method highlights the economic importance of provisioning services of Ladakh, particularly grazing and fodder, which were valued between USD 482346.43 and USD 1458,099.04 annually (44).

In Karnatakas' wetlands, the economic value of fisheries provisioning services was estimated at C8.6 million annually (45). A study on the Brahmaputra River in Assam calculated the value of fishing as one of the provisioning services offered by the river to be at least ₹47.8 crores per year (46). Additionally, the estimated value of ecosystem services in the Mazandaran Forest Reserve ranged between 14.2 to 14.8 million USD ha^{-1} (47).

Non-timber forest products (NTFPs) play a key role in enhancing food security and generating income for deprived socio-economic groups in developing nations. The average annual household income from NTFPs in hamlets of Bundu Block, Ranchi district, Jharkhand is ₹4791.16 (48). The collection of NTFPs also significantly contributes to the income of tribal communities residing inside and around the Similipal Tiger Reserve, Odisha (49).

Rice farms in Odisha offer provisioning services by providing food and by-products like straw (50). In addition, they offer ancillary services, including soil formation, hydrological flow regulation and nutrient cycling. They also perform regulatory functions such as bio-pest control, the flow of carbon and fixing nitrogen. The benefit of these services ranges from ₹90533 to ₹123441 ha^{-1} per year. Similarly, studies in the Western Himalayas have quantified the amount of leaf litter collected for forest-dependent agriculture (51).

A study in the Western Ghats region assessed the economic value of ecosystem services, such as water provisioning at USD 612 million in 2021 (52). The average net present value of cost-saving estimates for a 30 % enhancement in water quality over 30-year period ranged from 2.7 million to 16.6 million USD for the Western Ghats region (53).

Organic agriculture methods, which depend on natural resources like fuelwood and timber, offer both ecological and economic benefits. In the upper Kedarnath valley, almost 95 per cent of household's depends on fuelwood and leaf litter for their energy needs, underlining the dependence of hill residents on these resources (54). Furthermore, genetic diversity is crucial for maintaining wildlife, plant and microbial genetic resources, enabling populations to adapt to different conditions and supports a range of ecosystem functions (55).

Regulating services

Regulating ecosystem services in India play a crucial role in soil conservation, carbon sequestration and storage, groundwater replenishment and the regulation of air quality, temperature, humidity and hydrological cycle (56, 57). However, there is a paucity of studies specifically addressing these regulating services, with existing research primarily focusing on air pollution control, carbon sequestration and pollination. The absence of standardized methodologies to quantify the benefits derived from these ecosystem services presents a significant challenge. Additionally, the role of ecosystems in storm protection remains inadequately explored (58). Air pollution is a growing concern globally, with India experiencing particularly severe conditions. Numerous studies provide strong evidence supporting the role of vegetation in improving air quality in urban areas (59, 60) . In Nagpur city, zones with less vegetation exhibited higher levels of sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) compared to zones with denser vegetation cover (61). Urban timbers are significant in capturing dust particles and regulating particulate pollution (62).

The economic impact of floods in India was estimated at approximately 2 % of the nations' GDP between 2005 and 2015, during which 71426 individuals died (63). The thick woods of Uttara Kannada provide a total benefit of ₹ 217872 ha^{-1} through natural hazard reduction and flood protection (64). The estimated value of soil conservation services provided by Indian forests was USD 535.6 M, with an average of USD 4.40 ha^{-1}. The Tropical Dry Deciduous Forests contribute the largest share, valued at 294.18 M US$ for soil conservation services and an average maximum value of USD 28.91 ha^{-1} from Littoral and Swamp Forest (65).

Uncontrolled human activities have led to an alarming increase in greenhouse gases (GHGs), particularly CO_2, in the Earth's atmosphere (66). According to the Forest Survey of India (FSI) 2021 report, India's forests store an estimated 7204 million t of carbon, with soil organic carbon accounting for 56.18 % of this total. A study conducted in Madhya Pradesh found that tropical forests in Damoh, Raisen, Katni and Sagar districts contain surface biomass ranging from 3.99 to 53.90 t ha^{-1}, while carbon stock ranges between 1.89 and 25.6 t ha^{-1} (67). In 2018, the overall carbon density of trees in Central India was estimated to range from 48.97 to 214.97 mg C ha^{-1} (68).

In recent years, there has been a significant decline in the global population of pollinators, particularly honey bees, which is a major cause for decline in agriculture production (69). The estimated economic value of insect pollination for vegetables, oilseeds, condiments and spices are ₹19498.20 crores, ₹ 43993.08 crores and ₹ 10109.43 crores respectively (70). However, there is limited literature establishing a direct causal relationship between the reduction of bees and other pollinators on agriculture and ecosystems in India.

Furthermore, some studies suggest that watersheds in India provide moderating ecosystem services valued at ₹ 34113 ha^{-1}, with water recharge contributing for 60 % of this value (71). Agro-ecosystems in India offer water-regulating services, like groundwater recharging, evapotranspiration and soil erosion prevention, which can be effectively analysed through agro-ecosystem models.

Cultural services

Cultural ecosystem services play a crucial role in shaping human well-being by fostering cultural traditions, spiritual beliefs and social connections. Ecosystems provide various cultural services, including diverse cultural expressions, spiritual and religious significance, knowledge systems, educational value, inspiration, aesthetic appreciation, social cohesion, cultural heritage, recreation and ecotourism (72). A study mapping six intangible landscape values in 65 places across the Sundarbans delta identified spiritual, recreational, heritage, aesthetic, educational and negative values, with environment degradation diminishing the aesthetic, recreational and other intangible values that people derive from it (73).

In the Indian context, research on cultural ecosystem services mostly focuses on aesthetic value, green tourism and traditional means of livelihood. Nevertheless, there has been limited investigation into the influence of natural environments on the mental and physical health of urban individuals (74).

India, with its diverse cultural heritage, has long upheld nature conservation and biodiversity preservation as integral to traditional beliefs. A study on the Adi tribe of Arunachal Pradesh highlighted their indigenous survival strategies and community-based forest management, including the 'Kebang' institution and gender-specific harvesting techniques, which significantly contribute to sustainable resource management (75). Similary,the Baiga clan of Madhya Pradesh, via their extensive traditional wisdom and customs, plays a vital role in preserving ecological diversity and overseeing the management of forest resources (76). Numerous studies also document the environmental stewardship of other indigenous communities, such as the Gond, Aka, Tangkhul, Soliga and Kattunayaka tribes (77, 78).

The recreational value of both natural and human-altered ecosystems has been extensively studied. The travel cost method estimated the recreational value of Rajaji National Park at ₹24.86 crores in 2011 (79). Similarly, Kaziranga National Park in Assam was valued at ₹ 21 million per year, Biological Park in Itanagar at ₹ 3.88 crores ha^{-1} annually, and Dachigam National Park at ₹338 million per year. There is growing interest in studying the aesthetic significance of urban green spaces, which provide ecological, health, and social benefits. For example, the mean per capita availability of leisure green spaces in Nagpur is 3.65 m^2, though this varies across different regions of the city (80). The Vellayani Lake in Thiruvananthapuram, Kerala, has an estimated yearly leisure worth of ₹55.83 lakh (81).

Ecotourism, a nature-based leisure activity, integrates ecological, social, cultural, and economic sustainability while ensuring wildlife conservation and supporting local communities. Over the past two decades, ecotourism in India has gained significant popularity (82). Several studies confirm its substantial socio-economic benefits (83). Sacred Natural Sites (SNS), such as sacred groves, are acknowledged as significant cultural locations that offer various ecosystem services, notably cultural benefits (84). A study conducted on sacred groves in the Central Western Ghats identified 144 tree species, including 15 endemic species.. These groves demonstrated Indias' highest recorded carbon sequestration potential, estimated at 196.43 tonnes ha^{-1} (85). Additionally, studies have explored the attitudes of indigenous communities towards the preservation of sacred forests in the Kasargod and Kodagu regions of Kerala (86).

Supporting services

Supporting ecosystem services encompass essential processes for maintaining ecosystem functions such as primary production, soil formation, nutrient cycling, and oxygen production (87). In the context of India, the total Net Primary Productivity (NPP) from 1981to 2006 was valued at 1.42 Pg of carbon, while the Net Ecosystem Productivity (NEP) during the same period was approximately 20 Tg of carbon. Notably, significant temporal fluctuations have been observed in both NPP and NEP, varying across different years (88). A study conducted in Kaziranga National Park, Assam, utilised the Leaf Area Index (LAI) and meteorological data to calculate the Gross Primary Productivity (GPP) at 2.11 kg C/ m^2 annually (89).

Nutrient cycling in agro-ecosystems, such as agricultural fields and agroforestry systems, has attracted considerable scholarly attention in various researches (90, 91). For instance, a study conducted on bamboo plantations in three ravine systems in India found that bamboo plantations can increase soil carbon levels by ₹365.90 to ₹ 2927.24 t^{-1} of carbon. Additionally, the nutrient value of soil was estimated between ₹ 2126 and ₹ 5555 ha^{-1} (92).

Assessment and identification of gaps

This research aims to identify and highlight the most significant academic publications on ES in India published in between 2013 to 2024. A year-wise analysis of these publications is shown in Fig. 2A. In terms of individual ecosystems (Fig. 2B), ES derived from wetlands, urban ecosystem, rivers, and marine environments have been widely studied (15 studies each), followed by agricultural ecosystems (14 studies) and natural forests (12 studies). The number of studies addressing all four ecosystem services is 21, with a notable emphasis on regulating ecosystem services (Fig. 2C). Among specific ecosystem services, regulating services were the most frequently examined (16 studies), followed by research on cultural services (15 studies) and provisioning services (13 studies). The fewest publications were found on supporting services, with only 6 studies.

The distribution of studies across different sub- services within the four main ecosystem services categories, as defined by the MEA, 2005, is illustrated in Fig. 3. Fig. 3A shows that the majority of studies on provisioning services focus on direct-use services (49 %) followed by clean water (26 %), food and wood (10 % each), with the least research on fibre and fuel (5 %). In the regulating services (Fig. 3B), studies on overall regulatory services dominate (43 %), followed by research on water regulation (23 %), erosion control (13 %), and studies on climate regulation and protection from natural hazard studies (10 % each).

For cultural ecosystem services (Fig. 3C), studies on overall cultural services represents the largest proportion (62 %), followed by education (16 %), recreation (11 %), aesthetic value (8 %), and spiritual significance (3 %). Fig. 3D presents the analysis of supporting services, where general studies account for 40 %, followed by habitat provision and biodiversity conservation (20 % each). The remaining studies focus on nutrient cycling (12 %) and soil formation (8 %).

ES-related scientific research in India shows progress but is still behind other countries. A bibliometric analysis assessing Environmental Science publications from 1900 to 2018 showed that the United States had the highest number of print publications (596), followed by the United Kingdom(317), Australia (201), Germany (189) and China (163). The present study also highlights a lack of risk evaluation literature within the Indian atmosphere. While Indian scholars are currently examining the effects of global warming on ecosystem services (ES); however, additional assistance is required. There is an urgent need to expand research efforts on the impact of global warming on ecosystem services in different habitats, with a particular focus on urban and agricultural ecosystems.

A significant gap in interdisciplinary research remains, necessitating integration across multiple research models,

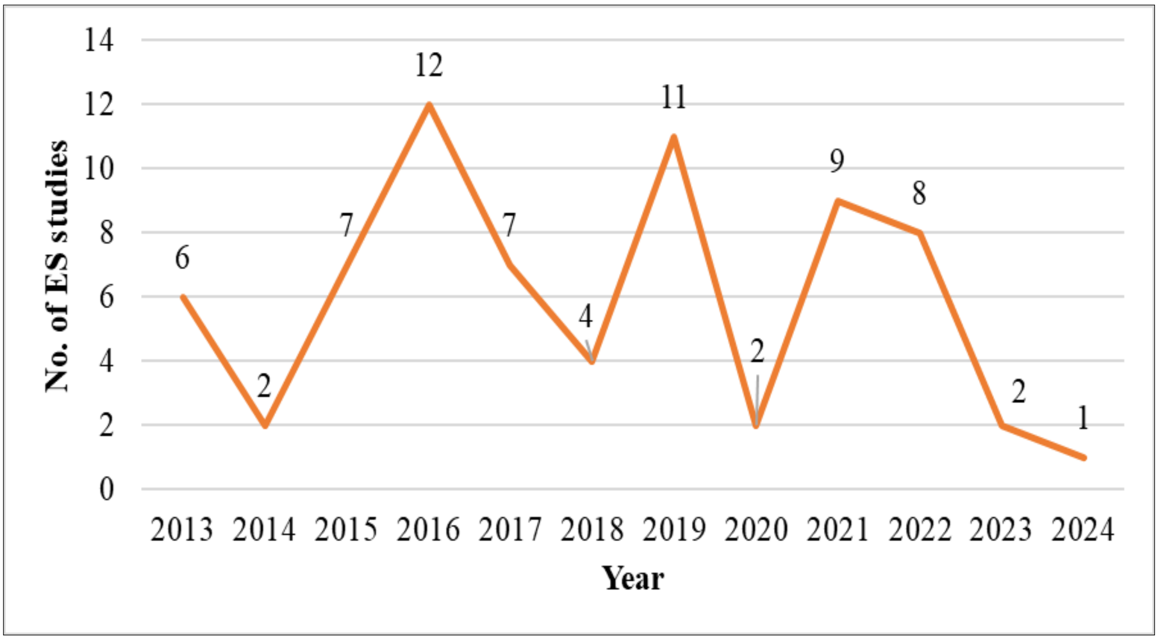

Fig. 2A. Number of ES studies published between 2013 and 2024 (N= 71).

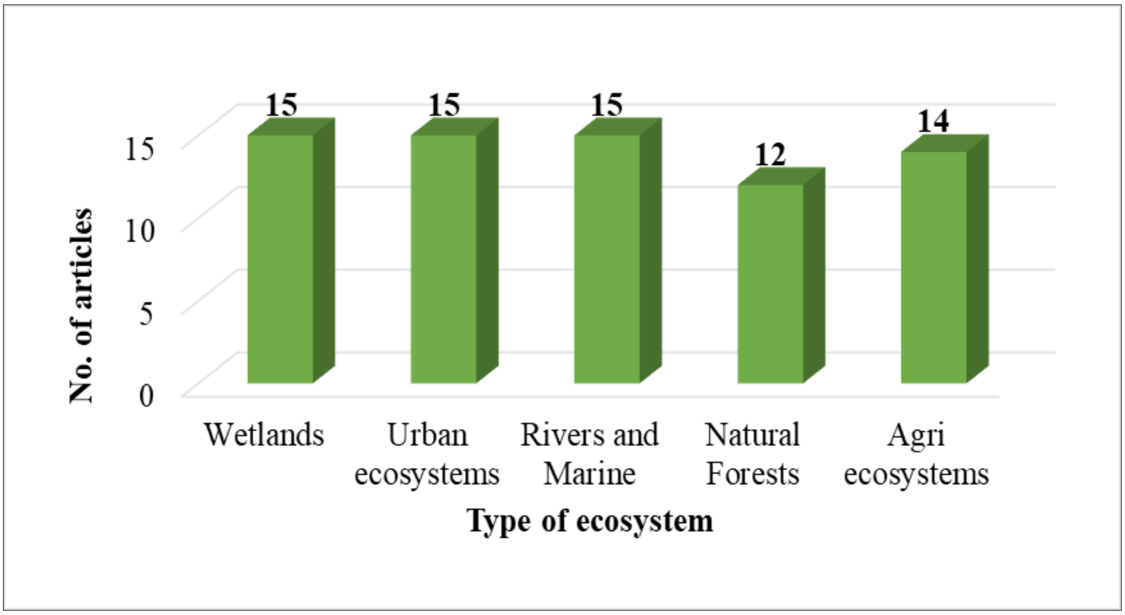

Fig. 2B. Distribution of studies according to type of ecosystem.

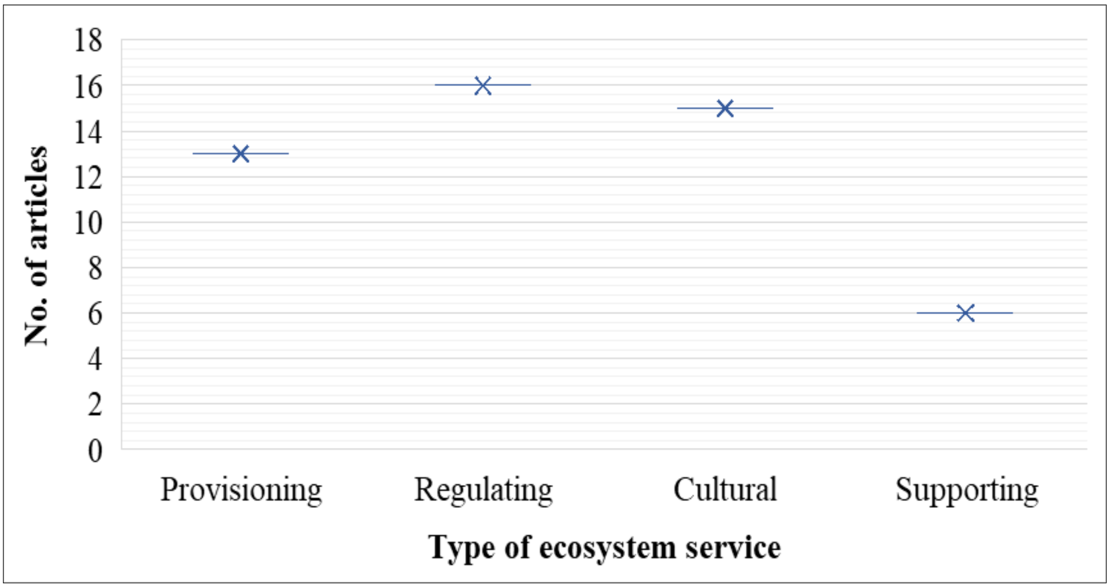

Fig. 2C. Distribution of studies according to type of ecosystem service.

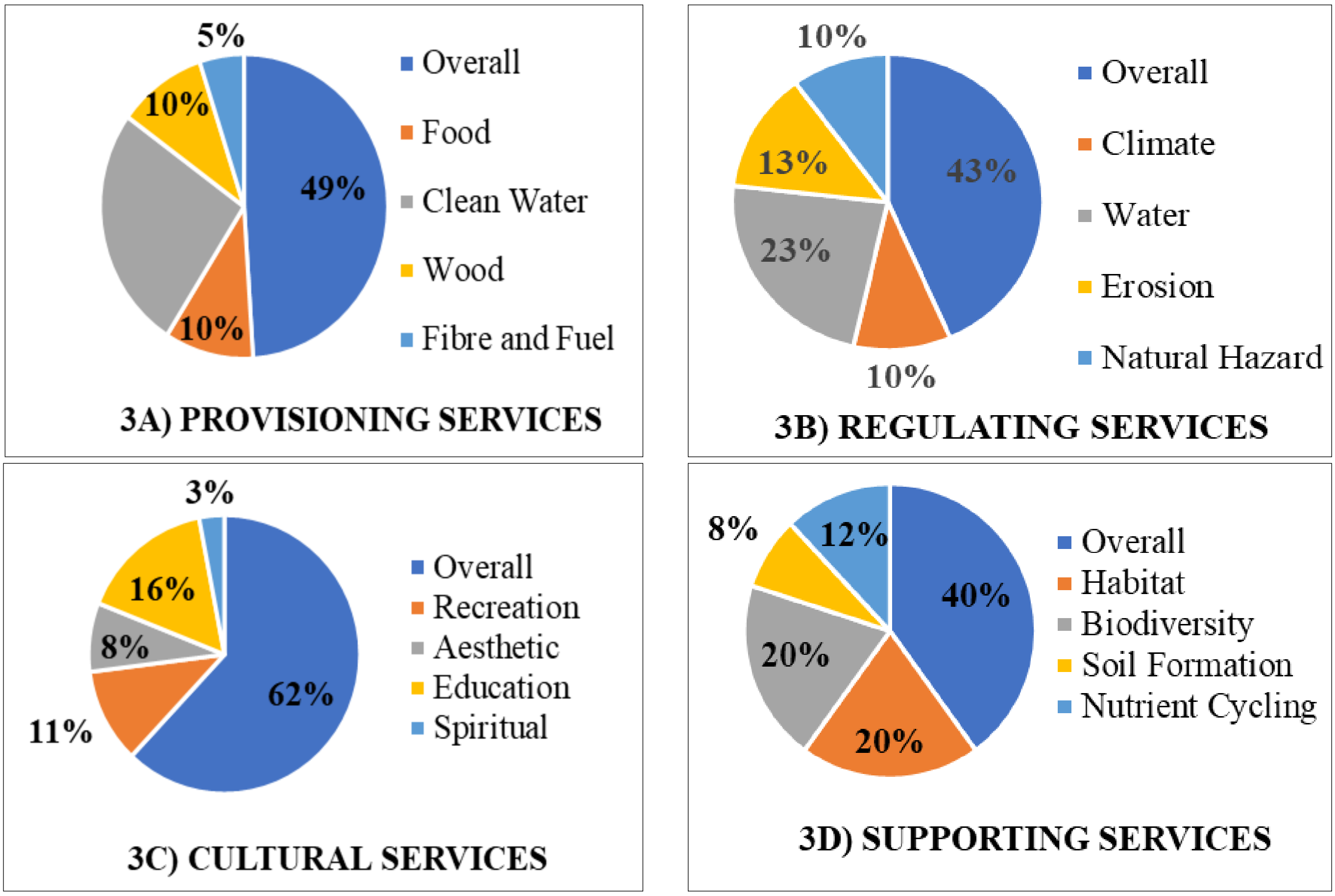

Fig. 3. Percentage on number of studies contributed by each sub- services to the four main categories of ecosystem services.

including economic and environmental data. ES trade-offs should be incorporated into spatial planning studies, and investigations into the effects of biodiversity loss on ES should be prioritized and systematically unified. Furthermore, greater emphasis is required on studies examining the regulation and maintenance of ES in India.

It is essential to explore the relationship between cultural ES and human well-being beyond merely recreational services. Empirical research is needed to assess the cultural impacts of developmental projects on ecologically sensitive regions, including the Himalayas, Western Ghats, coastal zones, island mangroves, and Northeast India, where forest cover loss has been significant. Additionally, studies on marine ecosystems are necessary, particularly concerning species on the brink of extinction. Integrating local communities into policy development and decision-making is equally crucial to ensure sustainable management of ecosystem services.

This review provides a comprehensive perspective on the evolution of ES research in India, outlining current trends, knowledge gaps, and methodological approaches. It traces the institutional origins of ES studies and identifies key research centers in India that have significantly contributed to ES assessment. This study is expected to aid researchers and policymakers in identifying underexplored ecosystems and prioritizing future research directions within the country.

Conclusion

Intensive efforts have been made to quantify the economic value of different ecosystem services in India. This study analysed 71 ecosystem services valuation studies, examining their origins, types of ecosystem services, ecosystems assessed, regional coverage, and existing research gaps. The finding indicates a geographical bias in the coverage of ES literature, with certain regions receiving much attention while others do not. A similar pattern in observed in under-researched ecosystem services, particularly grasslands, marine habitats, semi-arid regions, and desert landscapes. Addressing these gaps requires greater incorporation of ecosystem valuation in policymaking, especially concerning trade-offs arising from environmental degradation due to uncontrolled human activities.

Empirical studies demonstrating the impact of infrastructure development and urbanisation on ecosystem services can enhance environmentally conscious decision-making. We need to incorporate robust modelling tools into the ES assessment framework to predict future shifts, thereby aiding in model development and strategic planning, with a focus on sensitive areas. Given India's rich biological diversity, further research is needed to assess the regional correlation between biodiversity decline and its effects on ES. Additionally, empirical studies should be conducted to quantify the impact of environmental stressors, such as invasive species, pollution and climate change on ecosystems. It is also imperative to incorporate indigenous and traditional knowledge, along with cultural values, into ecosystem valuation frameworks. At present, much of the focus is directed toward recreational and tourism-related benefits, neglecting other crucial aspects of ES. At both regional and national levels, financial support and targeted incentive packages should be provided to promote research on ES, biodiversity, ecosystem features, and the consequences of ES loss. A multidisciplinary and integrative approach is essential to strengthen evidence-based techniques for conservation and restoration policies in Indias' diverse ecosystems. Greater funding is required for ecological infrastructure and the formulation of policies for smart-city programmes to guarantee long-term urban sustainability.

This study has certain limitations, as it is based on a critical review of a limited number of readily available ES studies. However, it contributes valuable insights into methodological approaches, regional disparities, and the origins of ES valuation research in India, thereby advancing the understanding of ecosystem service assessments in the country.

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Authors' contributions

HB was involved in designing the overall study, conducting the literature review, developing the research protocol, and drafting the initial manuscript. SK reviewed the manuscript and contributed to improving its scientific content. SV provided suggestions during the revision process and helped enhance the clarity of the manuscript. UK revised the manuscript and offered input on the structure and coherence of the content. BK contributed to the critical revision of the manuscript and improved the formatting and presentation. SD participated in reviewing and refining the manuscript to ensure quality and accuracy. All authors read and approved the final version of the manuscript.

Compliance with Ethical Standards

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

Ethical issues: None

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