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LEVERAGING REMOTE SENSING AND PARTICIPATORY GIS FOR ENVIRONMENTAL RESILIENCE: A SYSTEMATIC REVIEW OF GLOBAL COMMUNITY FORESTS

Jothiha K[1], N. Sriram[2]*, M. Senthilkumar[3], K. P. Ragunath[4] & R. Parimalarangan[5]

[1]Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India
[2*]Special Officer, Vigilance & Disciplinary Proceedings, Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India
[3]Directorate of Extension Education, Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India
[4]Centre for Water and Geospatial studies (CWGS) Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India
[5]O/o Directorate of Research, Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India
*Corresponding author Email: ns73@tnau.ac.in

ABSTRACT
Though forest cover nearly one-third of world cover, intensified human activities and inadequate management practices results in encroachment, human-wildlife conflict and forest degradation. Geospatial approaches, including remote sensing and participatory GIS, play a crucial role in monitoring community forests, strengthening land rights, safeguard stability and sustainability of natural resources. This systematic review maps the global landscape of geospatial methodologies used to scale up community forest conservation, promote agriculture and strengthen environmental resilience. To serve this purpose, reputable academic database Scopus has been used 59 relevant studies were selected by employing PRISMA method. Further, VOS viewer and R studio was used to systemically map the annual scientific production, source dynamics, word cloud, treemap, thematic map were graphed for better understanding. The findings of the study revealed that 2023 was the peak stage of this research domain and Ecological Indicators was the highly published journal. Further, Remote sensing of Environment was found to be first journal to publish article on remote sensing based on the inclusion and exclusion criteria of the study. Employing geospatial approaches helps to address socio-economic disparities in forest access, biodiversity conservation, natural resource management, forest fire susceptibility and prevention, long-term monitoring vegetation changes, mapping tree species diversity, land use and land cover classification, forest degradation and restoration, environment assessment, territory identification and land phenology. Apart from forest management, geospatial approaches plays an indispensable role in improving agriculture by analysing desertification and drought variability, assessing soil moisture, mapping soil fertility, predicting yield, pest and disease identification and management, estimating groundwater potential and much more. Ultimately, blending multi-spectral remote sensing with participatory frameworks provides the scalable, data-driven architecture required to enhance crop monitoring, support decision making in agricultural planning for sustainable agriculture and ensure food security.

KEYWORDS: Systematic literature, Bibliometric analysis, Geospatial approach, Community forest, Environmental resilience

INTRODUCTION
Forests serve as the Earth's foundational life-supporting systems by acting as a 'carbon sink', which is essential to mitigate climate change, regulate global temperatures and freshwater cycle, preserve global biodiversity and sustain human livelihoods by ensuring complex ecological resilience (1). It covers about 31% of world's land surface and over 1.6 billion people around the world depend directly on its resources for their livelihood (2). Intensified human activities and inadequate management practices drive severe forest disturbances, resulting in extensive deforestation and degradation (3,4). This resulting ecological decline weakens forest resilience, threatening indigenous biodiversity alongside the vulnerable human populations that depend directly on these ecosystems for survival (5).

Mitigating these threats requires precise and scalable data, which can be obtained through geospatial approach (6). This method connects specific geographic locations on earth to find patterns, relationships and trends and explain where it is happening, why it is happening there and what necessary actions should be taken (7). Employing geospatial approaches helps to assess land use and land cover changes, that intends to safeguard the stability and sustainability of natural resources and ecosystems (8). In this regard, geospatial approaches plays a critical role in monitoring, evaluating, and scaling community forest management based on the co-ordinates, characteristics of that location by using tools like remote sensing, Geographical Information Systems (GIS), and participatory frameworks (9,10,11). These technologies provide region-specific insights (12) which helps in building environmental resilience by bridging localized social governance with macro-level governance (13).

Thus, by integrating these spatial technologies, researchers can assess climate vulnerability (14), identify the socio-economic factors affecting surrounding communities (15), map the ecological health of the forest, and formulate targeted, data-driven conservation strategies (16), to identify forest degradation, wetland conversion, weak policy enforcement,

limited livelihood diversification (17). However, traditional community forest management (CFM) struggles to defend ancestral land rights and combat illegal resource extraction because communities lack the formalized spatial evidence required by legal and regulatory systems (18). Without operationalizing decentralized, participatory GIS (PGIS) frameworks, localized ecological knowledge remains unquantified, rendering communities vulnerable to land grabbing and top-down policy failure (19).
Further, geospatial modelling can be used to facilitate prioritized landscape strategy (17), enhance ecological integrity (20) promote conservation and climate resilient agriculture (21), enhance effectiveness and benefits of restoration (22) that provides support for decision making and restoration of degraded area (23) based on both support evidence based coastal management and long term climate adaptation planning (24). Therefore, it is necessary to understand the role of geospatial approaches in monitoring community forest and ensuring environmental resilience. In this connection, the present study adopts a bibliometric analysis (25) and systematic literature review to serve the purpose.

METHODOLOGY

Inorder to examine the role of geospatial approaches in managing community forest and ensuring environmental resilience, this study adopts a systematic literature review method combined with bibliometric analysis. To ensure a holistic examination of the literature, this research design combines quantitative data with qualitative synthesis. The bibliometric analysis serves as a quantitative diagnostic of the publication environment, identifying citation-heavy studies, key thought leaders, and central thematic shifts (26). This methodological framework effectively delineates the intellectual architecture and research frontiers, exposing the long-term evolution of scientific knowledge production (27).

Database selection and search strategy

Primary data for the bibliometric mapping was sourced from prominent scholarly engine namely Scopus to ensure a robust inventory of rigorous, peer-reviewed literature. The search strategy employed involves a combination of Boolean characters with appropriate keywords to capture a comprehensive set of relevant studies on geospatial approaches on community forest management and environmental resilience such as forest health assessment, biodiversity conservation and forest fire impact. Keywords such as, “remote sensing”, “satellite imaging”, “geospatial approach”, “community forest”, “participatory forest”, “environmental resilience”, “forest health” and “biodiversity conservation”.

Inclusion and Exclusion criteria

The criteria for selecting articles were 2015-2025 (timespan), research and review articles (document type), English (language), Agriculture and Social sciences (subject), Open access and published article were selected for the study. Whereas, the articles before and after the timespan, other than research and review article (document type), Non-English, other than agriculture and social science articles were excluded. The structured framework for evaluating studies is presented in Table.1.

Table.1. Inclusion and Exclusion criteria

Criteria	Inclusion	Exclusion
Identification		
Time span	2015-2025	<2015 & >2025
Document type	Research article, Review	Conference paper, Book chapters
Language	English	Non-English
Access	Open access	Gold, Hybrid Hold, Green, Bronze
Source	Journal	Conference proceedings, Book and Book chapters
Subject	Agriculture and Social science	Environmental science, Earth and Planetary science, Engineering and other
Screening		
Title and Abstract	Relevant and pre-defined keywords in the titles and abstract	
Full text	Relevant studies that focus on pre-defined keywords and purpose of the study	

Screening and selection process

An extensive corpus of literature was initially retrieved during the baseline search phase. This dataset was systematically refined through an initial screening of titles and abstracts to filter out irrelevant studies. Shortlisted records then underwent a rigorous full-text examination to guarantee they met the established inclusion criteria. This systematic extraction workflow was executed under the guidance of the PRISMA framework, with the precise step-by-step breakdown detailed in Figure 1.

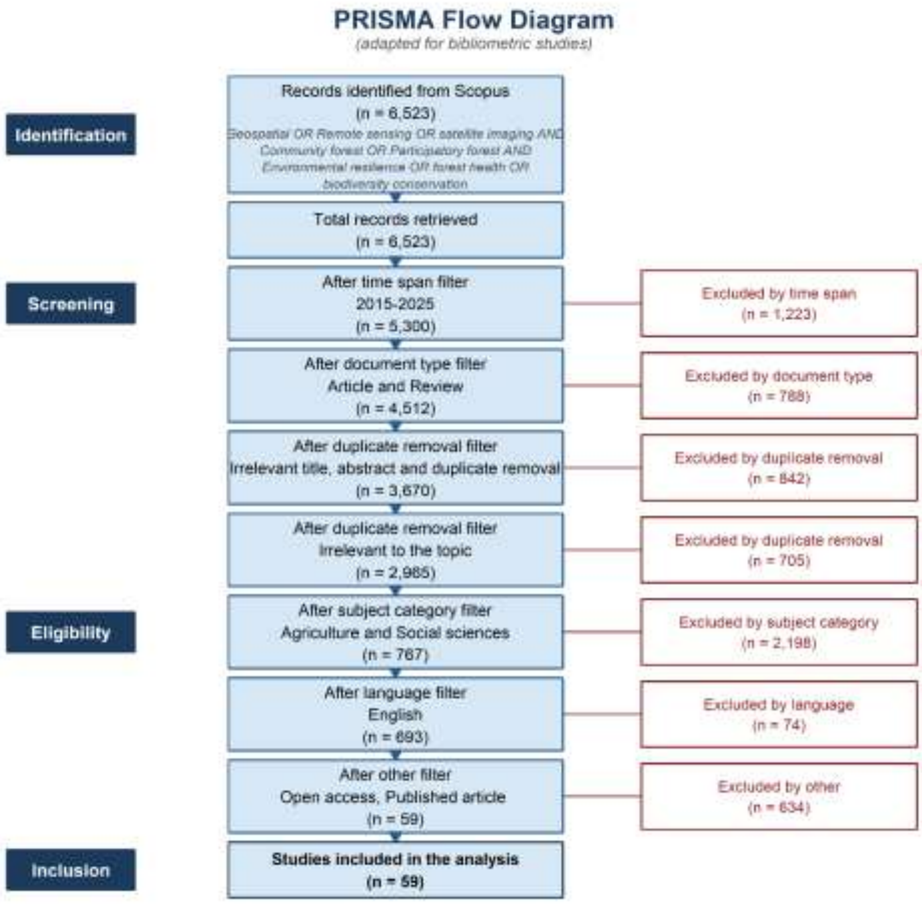

Fig.1. PRISMA Flow Chart

Data Analysis

Bibliometric analysis was done through VOS viewer version 1.6.20 to identify thematic clusters and R studio (Bibliometrix) version of 4.6.0 to examine identify annual scientific production, most relevant sources, most relevant authors, countries scientific production over time, trending topics, concurrence network. By using the aforementioned tools, a comprehensive quantitative overview of the previous literatures was gathered. Further, qualitative insights about the role of geospatial approach towards community forest management and environmental resilience was gathered through systematic literature review for better understanding.

RESULTS AND DISCUSSION

Annual Scientific Production

Through Biblioshiny of R studio, the annual scientific production of relevant articles on geospatial approaches for community forest management and environmental resilience between 2015 to 2025 was analyzed and mapped in Fig.2.

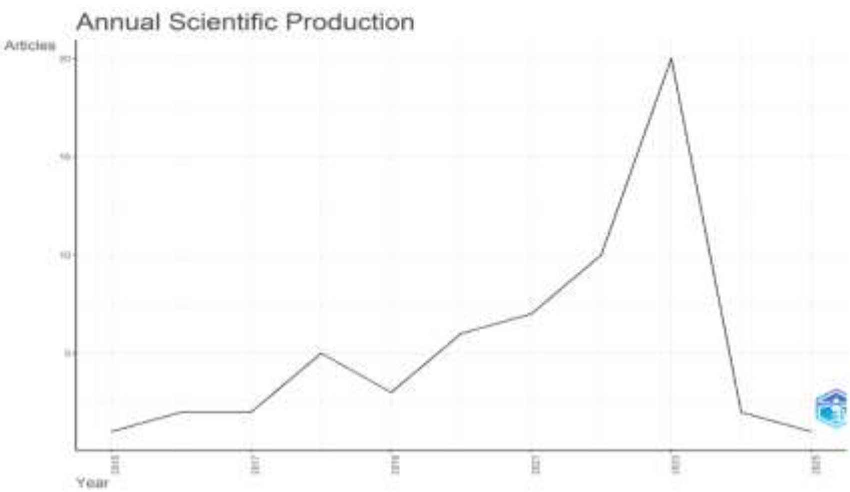

Fig.2. Annual scientific production of articles between 2015-2025

It could be interpreted from the Fig.2, that only few articles were published during 2015-2025 indicating very low baseline activity and maintaining a steady output of only one to two articles per year. While, researchers after experiencing in this domain published five articles in 2018, but later it dropped to three articles in 2019. This erratic early pattern is characteristic of an emerging research niche, likely constrained by limited data availability, unstandardized foundational methodologies, and restricted computational processing power.

Conversely, a phase of steady growth commenced in 2020 (6 articles) and carried through 2021 (7 articles), before accelerating rapidly in 2022 (10 articles). The domain achieved its historical peak in 2023 (20 articles), implying that nearly half of the entire analyzed dataset was published within that single calendar year. This aggressive expansion can be attributed to enhanced public access to high-resolution satellite constellations and the widespread adoption of open-access, cloud-based geospatial computing platforms.

Finally, following the 2023 surge, recorded publications dropped sharply to two articles in 2024 and one article in 2025. This sudden contemporary decline should be interpreted as a database indexing lag and collection delay rather than a true loss of scholarly interest in the topic.

Most relevant sources

Most relevant sources publishing articles on geospatial approaches for community forest and environmental resilience was systemically mapped in Fig.3 using Biblioshiny of R studio.

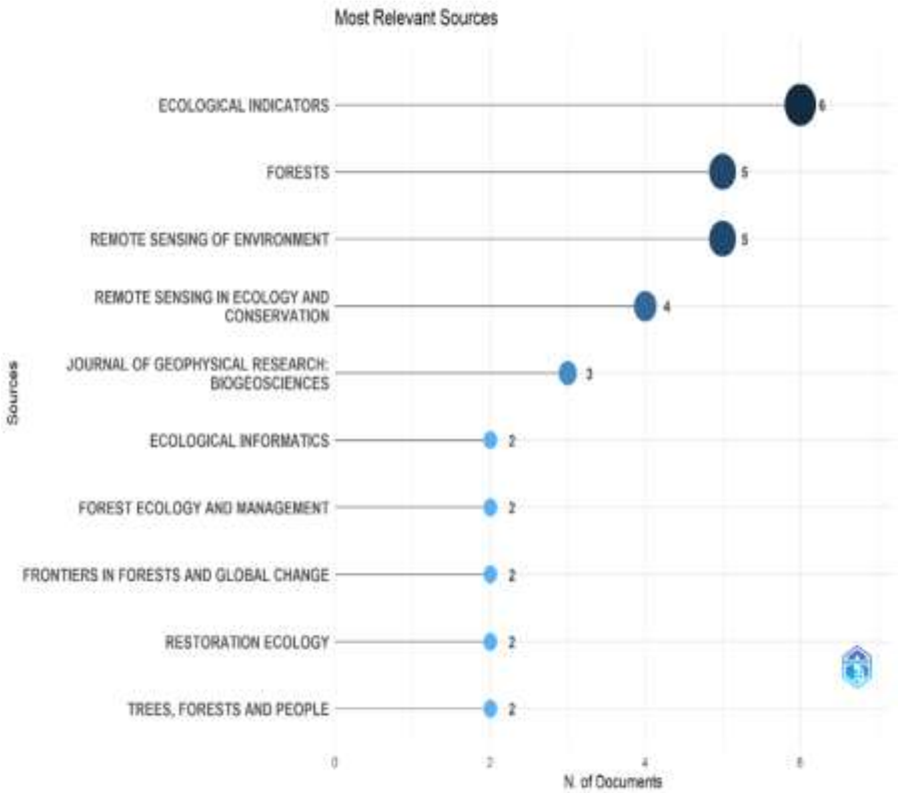

Fig.3. Most relevant sources of articles on geospatial approaches for community forest and environmental resilience

Figure 3 depicts the distribution of the most relevant publishing sources within the compiled dataset (36 total sources), showcasing a distinct interdisciplinary concentration across remote sensing, forestry, and ecological monitoring. The journal Ecological Indicators published the highest volume of literature within the study corpus (6 articles). Meanwhile, two journals, Forests (5 articles) and Remote Sensing of Environment (5 articles) contributed an equal number of relevant papers, followed closely by Remote Sensing in Ecology and Conservation (4 articles). These top four journals account for over a third of the compiled dataset, reflecting a highly consolidated core literature base.

Additionally, Journal of Geophysical Research: Biogeosciences contributed 3 articles, while the remaining sources; Ecological Informatics, Forest Ecology and Management, Frontiers in Forests and Global Change, Restoration Ecology, and Trees, Forests and People, each contributed 2 articles. The prominent representation of these specific outlets indicates that the literature is heavily focused on specialized forest phenology and canopy dynamics rather than generic vegetation monitoring, which explains the highly targeted nature of the dataset under study.

Sources production over time

For better understanding of cumulative publication growth over time (2015-2025), sources production over time was examined through Biblioshiny of R studio and the observed map is presented in Fig.4, detailing the temporal evolution and historical shifts within the research domain.

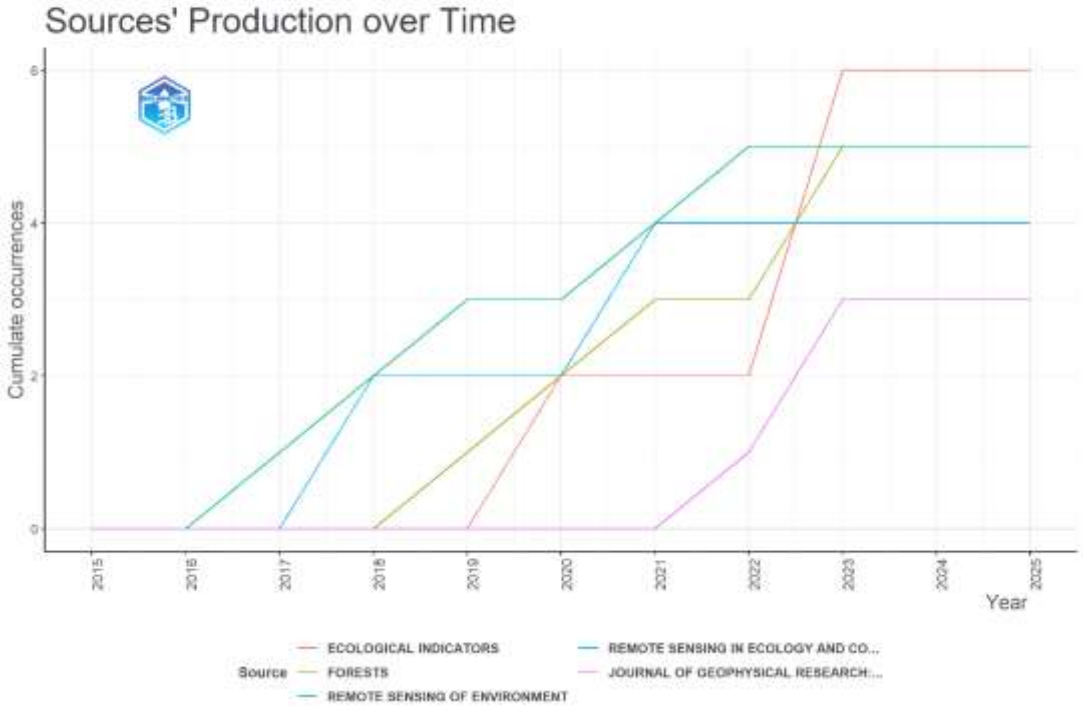

Fig.4. Source dynamics of articles over 2015-2025

By observing the map (Fig.4), it could be understood that Remote sensing of Environment paved early foundations for the domain by publishing an article in 2016. Consequently, they maintained a steady growth and published three articles in 2018 and reached stagnant in 2021. This emphasize that foundational years were highly technical, focused on algorithm development and processing methodologies and later drove the rapid expansion observed in years.

Similarly, Remote Sensing in Ecology and Conservation had matching steady trajectory in 2018 (2 articles) after 2017. Forests entered the domain in 2018, followed by Ecological Indicators in 2019. Both journals initially showed modest baseline participation, contributing 1 to 2 articles through 2021. Journal of Geophysical Research: Biogeosciences is the most contemporary core venue, seeing its first publication appear in 2021. The fact that nearly all core journals show their steepest slopes or plateaus right around 2023 confirms that 2023 was the definitive breakout year for this field, heavily driven by macro-level factors like cloud computing democratization.

The most striking feature of the chart is the steep vertical spike between 2022 and 2023. Ecological Indicators surged dramatically from 2 cumulative articles to 6, surpassing all other journals to become the top source. Similarly, Forests jumped from 3 to 5 articles, and JGR: Biogeosciences spiked from 1 to 3 articles in 2023. The flatlines across all five journals from 2023 onward do not indicate a sudden complete halt in interest; rather, they reflect the data-indexing lag discussed previously, as papers published in late 2024 and 2025 take time to fully populate cumulative database metrics.

Keyword analysis

To map the intellectual core of the dataset, a keyword frequency analysis was conducted using RStudio to generate a word cloud visualization (Figure 5). This approach effectively identifies the dominant research pillars, foundational technical methodologies, and emerging sub-themes that characterize the conceptual boundaries of the literature.

Figure 5 presents a keyword word cloud that visually conceptualizes the thematic core and intellectual boundaries of the compiled literature. The clear visual dominance of "remote sensing" establishes it as the primary methodological framework linking the entire dataset, tightly integrated with the central pillars of "forestry", "biodiversity", "ecosystems", and "satellite imagery". Beyond these foundational categories, the structural prominence of terms such as "deforestation", "restoration ecology", "conservation", and "climate change" highlights that contemporary research is heavily driven by pressing environmental challenges and resource management priorities. Methodologically, the frequent occurrence of "landsat", "ndvi", "lidar", and "sentinel-2" points to a strong reliance on multi-sensor earth observation data, while terms like "machine learning" and "time series analysis" signify an increasing adoption of advanced computational workflows to model complex vegetation dynamics. Furthermore, the explicit inclusion of localized keywords such as "India" and "tropics" reveals a distinct geographic interest in tropical forest ecosystems, demonstrating that the overarching objective of this research domain is to leverage advanced satellite tracking systems for applied ecological conservation and forest canopy monitoring.

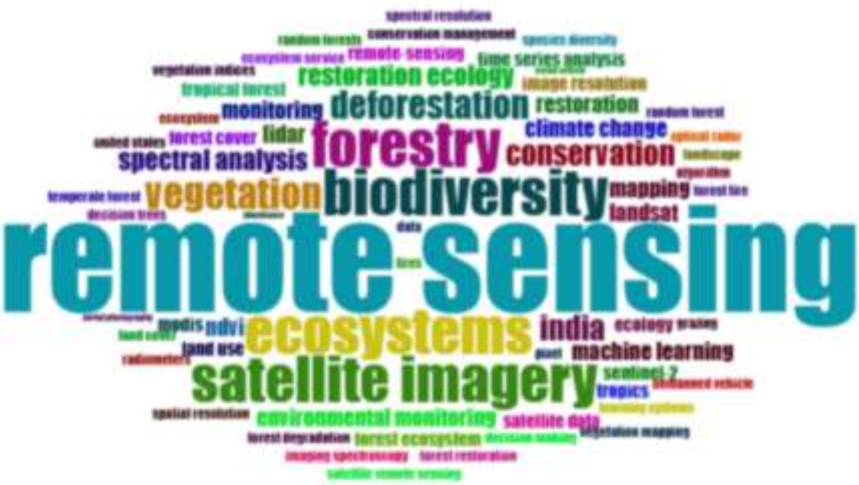

Fig.5. Keyword cloud representing dominant research areas and emerging sub-themes

Further, Keyword Co-occurrence Network maps the actual intellectual architecture of a field by linking words that frequently appear together in the same papers. This network analysis identifies distinct thematic subdivisions (clusters) and highlights structural nodes that act as conceptual bridges across the literature. Figure 6 displays the co-occurrence network generated from the dataset, mapping the primary research domains through color-coded community clusters.

Figure 6 illustrates the keyword co-occurrence network, providing a structural map of the intellectual framework and thematic subdivisions within the literature. The network displays a highly interconnected topology partitioned into four distinct color-coded thematic clusters, with the node "remote sensing" serving as the central, high-centrality hub that anchors the entire dataset. The red cluster outlines the primary operational workflows, linking baseline sensors (Landsat, MODIS) and indices (NDVI) directly with regional landscape features and conservation challenges specific to tropical regions like India. This technical cluster shares strong conceptual links with the blue cluster, which represents applied ecosystem management; here, "ecosystems", "biodiversity", and "forestry" form a dense nucleus tightly tied to "restoration ecology", "conservation", and structural LiDAR measurements. The green cluster highlights data acquisition and preprocessing dimensions, focusing on "satellite imagery", "spectral analysis", and high-resolution assets like Sentinel-2. Finally, the purple cluster represents an emerging data-driven frontier, where macro-scale stressors such as "climate change" and "forest fires" are modelled using advanced automated computational methods like "machine learning" and automated "algorithms". Collectively, this co-occurrence topology demonstrates that the field has successfully evolved beyond isolated sensor evaluations into a fully integrated, multi-platform computational paradigm for monitoring forest ecosystem health and biodiversity.

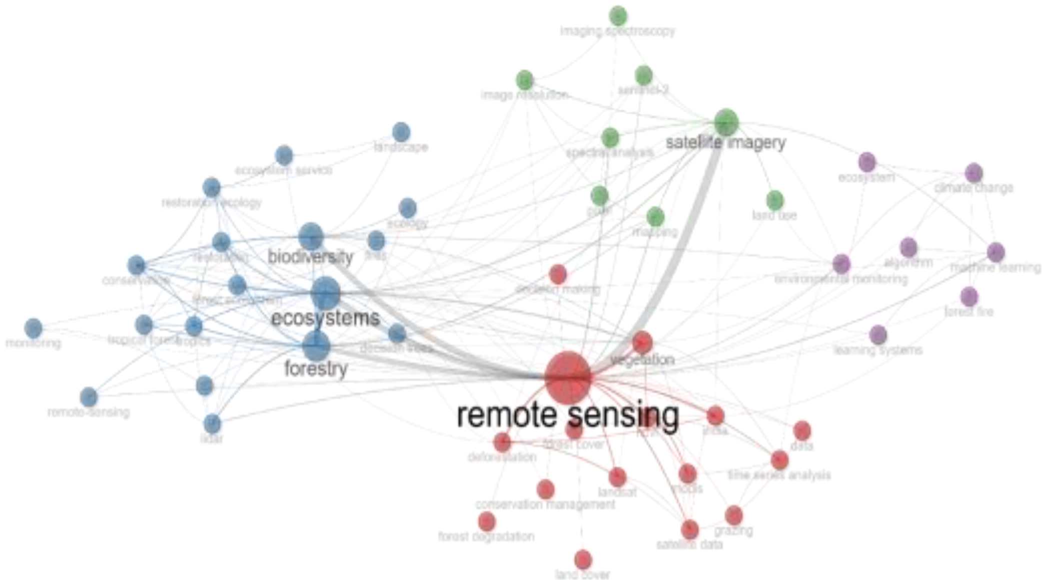

Fig.6. Keyword Concurrence network map indicating intellectual framework and thematic subdivisions of the selected articles

Thematic Treemap

Thematic Treemap offers a precise hierarchical and fractional breakdown of the conceptual space by grouping keywords into proportional tiles based on their exact occurrence counts and percentage share within the corpus. As it helps to quickly map out the dominant thematic pillars versus the minor sub-themes shaping the field. Figure 7 presents the thematic treemap of author keywords generated from the dataset.

Fig.7. Thematic treemap of author keywords

Figure 7 illustrates a thematic treemap of author keywords, providing a nested hierarchical view of the conceptual landscape based on exact occurrence frequencies and percentage shares. The structural layout is dominated by the keyword "remote sensing," which accounts for 11% of the total keyword weight with 30 occurrences, establishing it as the definitive methodological anchor of the literature corpus. Beneath this central hub sits a balanced tier of secondary core pillars, consisting of "forestry" (13 occurrences, 5%), "satellite imagery" (13 occurrences, 5%), "biodiversity" (13 occurrences, 5%), and "ecosystems" (13 occurrences, 5%). This even distribution demonstrates a strong thematic alignment, where traditional forestry metrics are consistently integrated with multi-spectral space observation and broader ecosystem health indicators.

The mid-tier rectangles delineate operational contexts and geographic focus areas, highlighting "deforestation" (3%), "conservation" (3%), and "India" (3%), which indicates a substantial emphasis on applied forest protection within tropical environments. Finally, the lower-order blocks map out a diverse technological and computational ecosystem, tracking traditional sensors like Landsat (2%) and MODIS (1%) alongside advanced structural metrics like LiDAR (2%) and modern classification workflows such as "machine learning" (2%). Collectively, this hierarchical distribution indicates that contemporary research in this domain leverages multi-sensor data and advanced algorithmic modeling to address critical, localized forest conservation and ecosystem biodiversity challenges.

Thematic map

Thematic map assess the maturity and structural importance of a research domain by plotting keyword clusters based on Callon's bibliometric indicators, viz., Centrality (external relevance) and Density (internal development). Figure 8 illustrates the thematic strategic mapping of the literature under study.

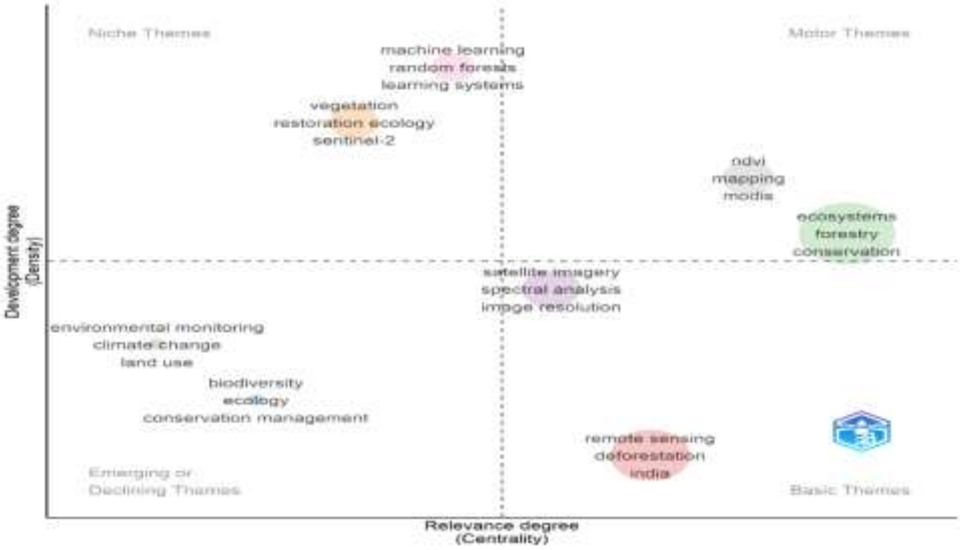

Fig.8. Thematic map (strategic diagram) of articles under study

Figure 8 displays a thematic map strategic diagram that categorizes keyword clusters based on their density (development degree) and centrality (relevance degree), offering structural insight into the maturity of the research domain. The top-right quadrant identifies the primary "Motor Themes" of the field, led by a well-established cluster linking "ecosystems", "forestry", and "conservation", alongside an operational sensor cluster consisting of "ndvi", "mapping", and "modis". The high centrality and density of these nodes demonstrate that traditional spaceborne canopy mapping forms the well-developed core driving the current literature. Conversely, the bottom-right quadrant highlights "Basic Themes", anchored by a prominent cluster of "remote sensing", "deforestation", and "India".

This positioning confirms that regional deforestation tracking in tropical environments serves as a foundational, cross-cutting framework that supports the entire corpus despite possessing lower internal methodological density. The top-left quadrant showcases highly specialized "Niche Themes", where advanced computational approaches like "machine learning", "random forests", and "learning systems" sit alongside high-resolution sensor metrics (Sentinel-2). The strong vertical development of this computational cluster indicates a rapid transition toward algorithmic automation. Finally, the bottom-left quadrant maps "Emerging or Declining Themes," capturing broad macro-environmental concerns such as "climate change", "environmental monitoring", and "biodiversity". The low density and centrality of these concepts suggest that while they represent critical global contexts, they function as overarching conceptual umbrellas rather than isolated, technically dense research sub-networks within this specific dataset.

Role of geospatial approach towards community forest management and environmental resilience

A geospatial approach shifts forest management from slow, subjective ground tracking to a precise, objective digital mapping framework. By providing access of these tools to local communities, they can protect, manage, and adapt their resources with unprecedented efficiency.

As securing legal custody of the land is a constraint in community forest management, using Global Navigation Satellite Systems (GNSS) and Participatory GIS (PGIS) can map traditional territories with high precision (28). This would help the communities and Government to identify corporate encroachment and illegal mining. Tools like remote sensing bridge the gap between high-level scientific data and grassroots forest protection. Mapping allows for exact tracking of deforestation, canopy health, biodiversity loss, and carbon sequestration capacity. Further, Traditional forest patrols can only cover a fraction of a forest. Satellite constellations like Sentinel-2 and Landsat capture imagery over the same forest every few days (29). It would help to identify canopy degradation and stop illegal logging (30, 31, 32, 33). Spatial analysis helps communities predict, mitigate, and adapt to climate threats like wildfires, landslides, and droughts. Combining local indigenous knowledge with participatory GIS (PGIS) ensures equitable resource distribution and secures community land rights.

By combining 3D structural data from airborne or spaceborne LiDAR with optical imagery, researchers can calculate Above-Ground Biomass (AGB) without cutting down trees (34, 35). This data allows local community forests to qualify for international carbon trading programs (like REDD+). It turns standing forests into a steady, long-term source of local income. Land Surface Phenology (LSP) tracks the seasonal timing of canopy greening, flowering, and leaf-drop using time-series indices like NDVI (Normalized Difference Vegetation Index) (36). Monitoring these cycles gives communities an early warning system for ecological stress (37, 38). If satellite data shows a delayed start to the growing season or unexpected canopy browning, it flags drought stress or pest infestation early, allowing community managers to adapt their water and soil conservation strategies (39, 40, 41).

Deploying systematic geospatial approaches yields critical benefits for long-term resilience:

- Democratic Governance: Bridges local community actions with macro-level policy
- Legal Empowerment: Provides high-precision boundaries using GNSS and PGIS
- Asset Security: Prevents corporate encroachment and illegal mineral mining
- Near Real-Time Alerts: Tracks under-canopy degradation via Landsat and Sentinel-2
- Economic Diversification: Quantifies above-ground biomass for carbon trading platforms
- Predictive Adaptation: Deploys vegetation indices for early drought warnings

Ultimately, blending multi-spectral remote sensing with participatory frameworks provides the scalable, data-driven architecture required to secure both indigenous biodiversity and human livelihoods against accelerating global climate changes.

Importance of Geospatial Approaches in Agriculture

Agriculture is increasingly vulnerable to climate variability and land degradation, threatening rural livelihoods and food security (42). Geospatial approaches when integrated with Artificial Intelligence can be used to analyse slope gradients to identify stagnation of flooded water (43), climate vulnerabilities (44), drought variability (45, 46), flood susceptibility (47), desertification (48) and land degradation (49).

It also provides ways to improve agriculture by identifying accurate soil property predictions (50) and nutrient deficient zones, as it promote site specific nutrient management practices (51, 52) and inform climate smart soil management practices (35); estimate soil volumetric water content to improve irrigation management (53); risk assessment of Cadmium and Nickel contamination in agricultural soil (54); create site specific soil fertility maps (51, 52, 55).

In addition, it estimates water productivity (52), identifies areas with high groundwater potential (56) and optimize rainwater potential to meet the increasing demands of domestic and agriculture (57); disease prediction (58); groundwater restoration (59); crop yield prediction (60, 61, 62) accurately for sugarcane (63); and potato (64); enhance crop monitoring (60), identify soil type for predicting P storage in lake sediments (65) thereby reduce crop loss, minimize chemical dependency and improve resource efficiency (66). Eventually, mapping the land use pattern, cropping pattern, cropping

intensity and grain yield (67) support decision making and promote sustainable agriculture (62, 68) in agricultural planning and food security (61, 62, 69).
Further, it helps to estimate peanut maturity to enhance harvest precision and economic returns ultimately improving the efficiency and quality of life for peanut producers (70) and provides economic assessment in precision spraying (33). It also facilitates field specific parametrization for local conditions which helps in informing area-wide pest management strategies (71), increase protection of biodiversity without compromising yield production (72), improved environmental planning (33) and strengthen adaptive conservation governance to reduce human wildlife conflict (73). With respect to policy making, it helps to develop policies that align with agricultural productivity with environmental sustainability (74) as it facilitates land suitability based strategic crop management (68) and Community centered agricultural strategies (75) it helps in resource conservation, long term soil productivity (76), and prevent encroachment on agricultural lands (77) and enable targeted restoration strategies (48).
Thus, it could be understood that, integrating geospatial approaches with AI provide both strategic land use planning and evidence-based policy making (42) that enables adaptive crop management (78) supporting effective disaster management and sustainability planning in flood prone regions (47). By overcoming the limitations in existing featurization methods in agriculture (79), it helps to improve and maintain water quality during conservation planning (80), implement diverse agroforestry practices, enhance ecosystem, mitigate environmental degradation (81) which is important to maintain productivity, sustainability and environmental health of watersheds (82); promote climate resilient farming practices (83) and improve agricultural decision making suited to diverse agro-ecological settings (84) that promotes sustainable agriculture and food security (85).

Future Research Frontiers
To bridge the remaining knowledge gap between localized social governance and macro-level ecological shifts, future research must prioritize three primary frontiers;
● Algorithmic Maturity: Accelerating the transition of specialized machine learning models (such as Random Forests and Deep Learning) from technical niche spaces into standardized, user-friendly mobile community interfaces.
● Multi-Sensor Fusion: Standardizing the synergetic fusion of structural LiDAR, active Radar (SAR), and high-resolution passive optical data to accurately map highly complex, multi-tiered tropical and forest canopies.
● Socio-Ecological Harmonization: Constructing standardized global repositories that systematically pair qualitative community governance variables with empirical, spaceborne vegetation indices to capture real-time feedback loops.

CONCLUSION
Geospatial approaches to community forest and environmental resilience refers to use of digital mapping, satellite data and location based technologies to help local communities protect, manage, and adapt their forests to withstand climate change and natural disasters. Geospatial technologies are revolutionary tools for advancing community forest management and building environmental resilience. By integrating satellite imagery, Geographic Information Systems (GIS), and global positioning data, local communities and policymakers can transition from reactive conservation to proactive environmental stewardship. Ultimately, combining spatial data with community-led action creates a scalable, transparent framework for protecting ecosystems. Investing in these digital tools ensures that local forests remain sustainable, biodiverse, and resilient against global climate changes.

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