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Mapping the Evolution of Remote Sensing Technologies in Post-Disaster Ecological Assessment: A Bibliometric Analysis

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A B S T R A C T

This study maps the thematic evolution of remote sensing in post-disaster ecological recovery, providing a novel quantitative synthesis of this technological transformation. Applying a PRISMA-compliant bibliometric analysis, 329 Scopus journal articles (2016–2025) were evaluated using Biblioshiny and VOSviewer to assess publication metrics and keyword co-occurrence. Results reveal an exponential publication surge led by China, USA, and India. Thematically, the field relies on three pillars: optical satellites for macro-risk evaluation, AI/UAVs for automated damage detection, and active sensors overcoming extreme weather. These findings highlight a paradigm shift from manual observation toward autonomous predictive analytics. Consequently, this paper recommends integrating multi-sensor data with hybrid algorithms to reduce field validation biases and strengthen future ecosystem restoration strategies.

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INTRODUCTION

Post-disaster environmental damage assessment is an essential step in the recovery, mitigation, and prevention of future crisis impacts. Remote sensing is a rapidly developing technology for this purpose. This technology enables rapid and efficient monitoring of environmental anomalies through the use of satellite imagery, radar, and various other earth observation tools. Through the utilization of these spatial instruments, the recovery process can be accelerated and data-driven decisions can be executed effectively. Remote sensing is crucial in detecting physical damage caused by disasters while simultaneously evaluating ecosystem changes that require emergency intervention.

The main advantage of remote sensing lies in its broad geographical coverage and temporal analysis capabilities to monitor environmental changes continuously. This characteristic is highly relevant for managing natural disasters that frequently occur on a regional scale. In the case of earthquakes, remote sensing radar data is proven valid for detecting ground surface deformation and determining the most affected areas (Jia & Ye, 2023). Other instruments such as infrared satellite imagery is relied upon during forest fire events to measure the extent of burned areas and calculate the damage level of ecosystem vegetation (Chuvieco & Kasischke, 2007). The extracted data serves as the primary foundation for planning reforestation and identifying the zones most vulnerable to subsequent disasters.

The utilization of remote sensing still faces several operational challenges. The most dominant obstacles include the limited spatial and temporal resolutions of the available data. Low image resolution hinders the identification process of detailed infrastructure and small-scale environmental degradation. Poor atmospheric conditions due to thick clouds or heavy rain also disrupt the image data recording process in tropical regions experiencing extreme weather (Ghaffarian et al., 2018). Technical aspects related to the integration of remote sensing and geographic information systems require high computational expertise and adequate software infrastructure. Poorly structured cross-institutional coordination frequently slows down the data distribution flow to field teams during the emergency response phase (Lozano & Tien, 2023).

The increased frequency of global hydrometeorological and geological disasters has triggered a surge in the production of academic literature examining this mitigation technology extensively. Previous studies have generally focused on qualitative reviews regarding the utilization of specific sensor instruments for single disaster types. To date, quantitative scientific mapping that comprehensively evaluates the entire remote sensing research ecosystem for post-disaster ecological assessment remains limited. The absence of this bibliometric synthesis creates a significant research gap, making the direction of technological evolution, international collaboration dynamics, and new knowledge niches difficult to identify systematically.

To fill this literature gap, this study adopts a bibliometric analysis and science mapping approach to dissect the global publication anatomy comprehensively. This study is specifically designed to explore three main research questions. First, this study examines the growth trend of remote sensing publications for post-disaster environmental damage assessment over the last decade. Second, the analysis focuses on identifying the most influential authors, institutions, and countries driving the research ecosystem in this field. Third, this study maps the research topics that become the main trends while tracing the thematic evolution from conventional optical observation methods to artificial intelligence-based technological automation.

The main scientific contribution of this study lies in the formulation of a new taxonomy synthesizing the paradigm shift of active sensors and artificial intelligence within the ecosystem recovery framework. By providing this quantitative synthesis, this study successfully generates a new methodological roadmap capable of bridging the gap between earth observation technology capabilities and tactical mitigation needs in the field. All findings from this research ultimately present a comprehensive navigation framework for the academic community and policymakers in formulating disaster management agendas in the future.

LITERATURE REVIEW

Ecological Resilience Theory and Disaster Management

Post-disaster environmental damage assessment is based on the Ecological Resilience Theory. This theory defines resilience as the capacity of an ecosystem to absorb large-scale disturbances and reorganize its structure so that its ecological functions continue to operate during a crisis. In the disaster management cycle, the post-incident phase requires a precise understanding of the land vulnerability level so that recovery interventions do not damage the remaining natural balance. Previous research by Chuvieco & Kasischke (2007) supports this concept by proving that the instant measurement of vegetation severity is highly crucial to prevent further ecosystem degradation caused by forest fires. Without rapid data-driven evaluation, reforestation and habitat recovery strategies will lose direction and potentially trigger secondary disasters (Kurbanov et al., 2022).

Earth Observation Theory and Electromagnetic Radiation

The utilization of space technology for disaster mitigation relies on the Electromagnetic Radiation and Spectral Interaction Theory. This theory explains that every material on the earth surface emits or reflects electromagnetic waves with a unique spectral signature pattern. Physical changes caused by disasters will modify these reflection patterns drastically. Passive optical instrument satellites capture sunlight reflections to identify plant stress levels or burned areas extensively (Zang et al., 2020). Even though optical instruments are highly efficient, their operations are severely limited by weather anomalies.

To overcome the weaknesses of optical sensors, scientists developed active sensors based on the Microwave Backscatter Theory. Instruments such as Synthetic Aperture Radar emit their own microwaves toward the earth and measure the luminescence of the reflections returning to the sensor. These microwaves possess the absolute capability to penetrate thick storm clouds and record the physical condition of the earth without depending on sunlight. Empirical research by Ramirez et al. (2020) confirms that radar technology is capable of detecting post-earthquake ground movement deformation continuously on a millimeter scale. The integration between these observation sensor platforms and artificial intelligence algorithms has now become a new foundation for solving spatial data complexities automatically and instantly (Furuya et al., 2020).

METHODOLOGY

This study integrates quantitative bibliometric mapping and qualitative thematic synthesis. This hybrid framework is applied to track the historical record of scientific evolution and extract a comprehensive understanding regarding the role of earth observation technology during the emergency ecosystem recovery phase. The PRISMA protocol was strictly adopted throughout the data curation process. This step was taken to guarantee the transparency of the research flow so that similar stages can be replicated by other researchers in the future

Table 1. Inclusion and Exclusion Criteria for Literature Selection.

Parameter	Inclusion Criteria	Exclusion Criteria
Timeframe	2016 – 2025	Documents published outside 2016 – 2025
Document Type	Journal Articles	Proceedings, Books, Book Chapters, and Editorials
Language	English	Languages other than English
Data Source	Scopus Database	Databases other than Scopus
Topic Relevance	Evaluation of environmental or ecosystem damage post-disaster	Articles not focusing on ecology or environmental damage

The literature mining process exclusively focused on the Scopus database. The search tactic was designed specifically to filter publications that purely discuss remote sensing instruments in the context of environmental damage evaluation. A combination of Boolean logic operators was used to execute the advanced search query. The search query included ("remote sensing" OR "satellite image*" OR "UAV" OR "unmanned aerial vehicle*" OR "LiDAR" OR "multispectral" OR "hyperspectral" OR "synthetic aperture radar" OR "SAR") AND ("post-disaster" OR "damage assessment" OR "disaster recovery" OR "post disaster") AND ("environmental damage" OR "ecosystem*" OR "vegetation" OR "forest*" OR "agriculture" OR "ecological" OR "land deformation").

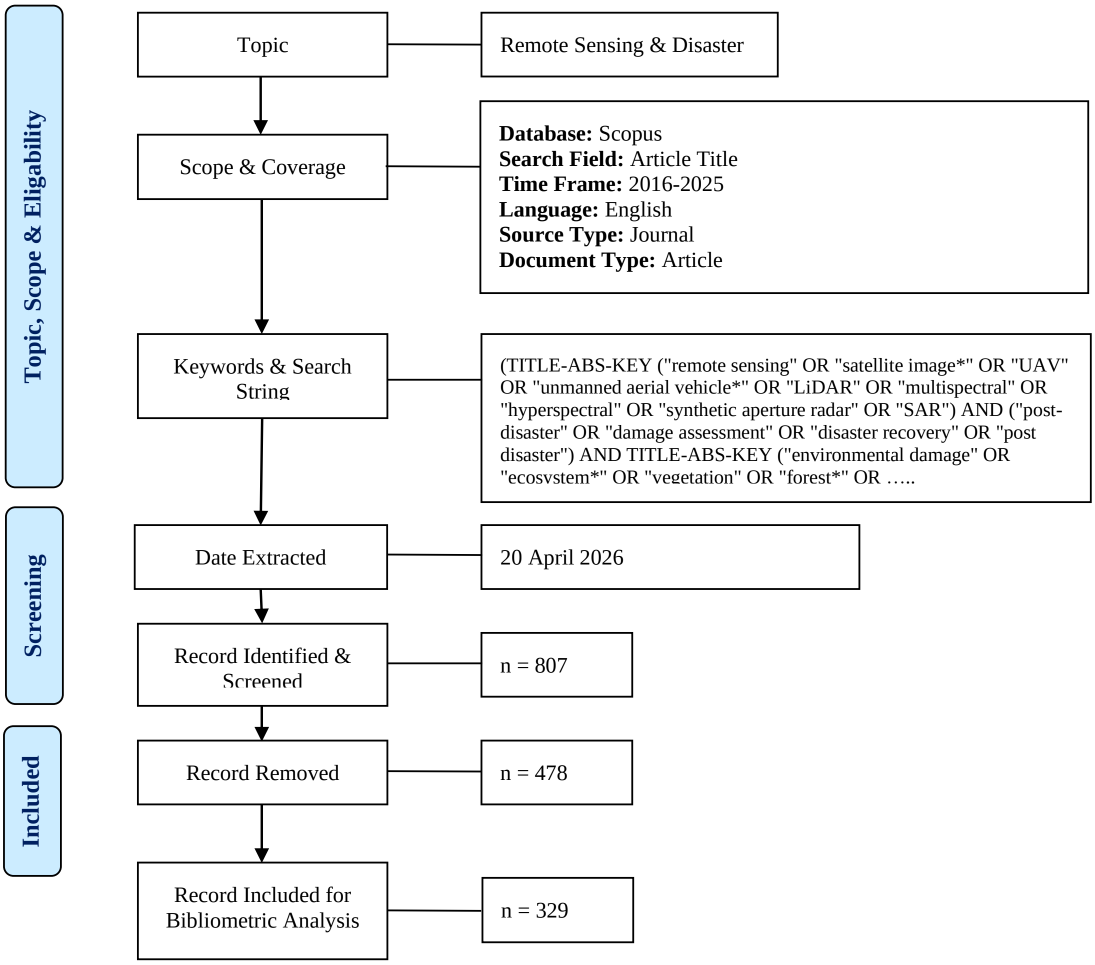

Figure 1. PRISMA flow diagram for the literature selection process

Referring to the PRISMA flowchart presented in Figure 1, the initial selection stage applied a publication calendar filter from 2016 to the first quarter of 2025. This boundary aims to completely capture the observation technology transition from the conventional passive sensor era to the artificial intelligence automation phase. The inclusion criteria were formulated strictly and only included original research articles along with review articles in English. The selection of the journal article format is based on the fact that these documents have passed high-standard peer review tests. The English language requirement was applied to standardize the technical nomenclature circulating in the global academic ecosystem. This layered filtering system eliminates conference proceedings materials and grey documents whose scientific validity has not been tested. This systematic curation stage produced a final dataset containing 329 core publications.

All metadata elements from this publication set were then downloaded for advanced computational needs. The extracted information contains the track records of authors, institutional affiliations, keyword arrays, and citation footprints. The quantitative dissection phase was executed with the help of the Bibliometrix R-tool package accessed through the Biblioshiny platform. This instrument is tasked with calculating four essential indicators. The initial metric focuses on the calculation of annual scientific production volume. The subsequent analysis maps the global research strength by highlighting the countries contributing the most documents while measuring their international collaboration ratios. The mapping of the most influential literature sources was completed through the formulation of Bradford's Law to identify priority journals. This system is also tasked with tracking the movement of specific trends from year to year to detect leaps in remote sensing innovation.

The scientific visualization construction phase was entrusted to the VOSviewer application with a priority on mapping the relationships between author keywords. This network analysis began with a meticulous data sterilization procedure. A special thesaurus list was compiled to unify keyword variations having identical definitions. This normalization action converted compound phrases like 'damage assessments' into the singular form 'damage assessment' and combined the abbreviation 'UAV' with its extension. This node unification procedure is required so that the relationship intensity between variables within the cluster truly reflects its original conceptual weight without being distorted by word duplication. The minimum keyword occurrence threshold was set in the VOSviewer system to filter out statistically irrelevant terms. The calculation results of the number of nodes, relationship links, and accumulated network strength were used to verify the cluster validity mathematically. The visual blueprint created from this application was then used as the foundational framework to dissect the findings qualitatively in the next section.

RESEARCH RESULT AND DISCUSSION

Annual Scientific Production and Source Impact

The analysis of annual scientific production shows significant development over the last decade. Based on the Scopus database extraction data, the total publications recording the utilization of remote sensing for post-disaster environmental damage assessment reached 329 articles. This growth dynamic began with a relatively stable volume between 2016 and 2019, averaging approximately twelve articles annually. Research acceleration became clearly visible in 2020 when the number of publications jumped to 31 articles. The peak of global academic attention occurred in 2025 with the highest record reaching 75 publication articles. This substantial increase reflects a global urgency triggered by the rising frequency of climate change-induced disasters, thereby encouraging the scientific community to generate faster and more efficient environmental evaluation methods.

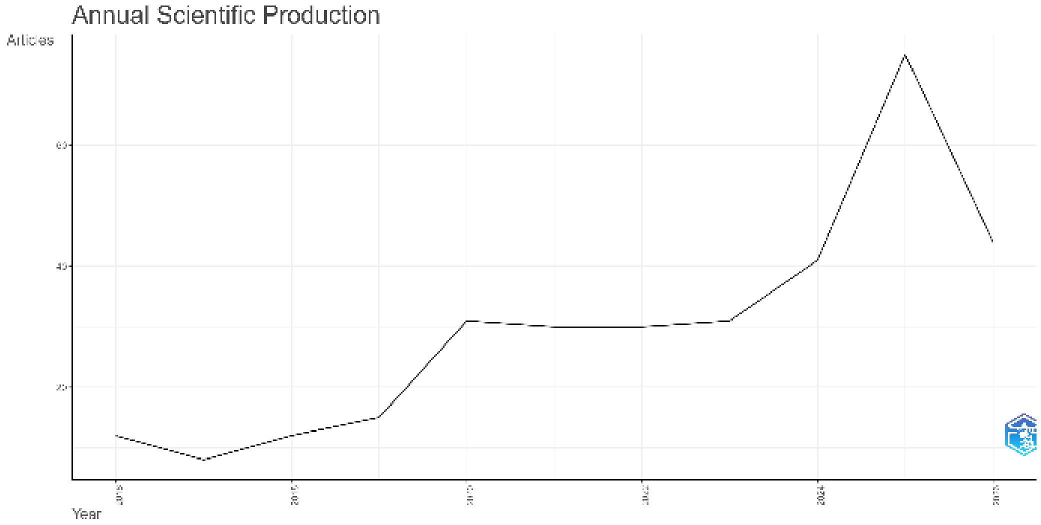

Figure 2. Annual Scientific Production.

The distribution map of publication sources analyzed using Bradford's Law identifies the existence of core journals acting as the main driving force in this research domain. This analysis groups literature sources into several zones based on their productivity. The journal Remote Sensing dominates Zone 1 with a contribution of 62 articles. The next position is followed by the journal Natural Hazards with 10 articles, along with Computers and Electronics in Agriculture, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, and International Journal of Disaster Risk Reduction, each contributing 8 articles. This distribution confirms that post-disaster environmental recovery studies possess a highly multidisciplinary nature. The research characteristics in this field successfully marry space engineering science with forestry management, agriculture, and natural disaster risk mitigation.

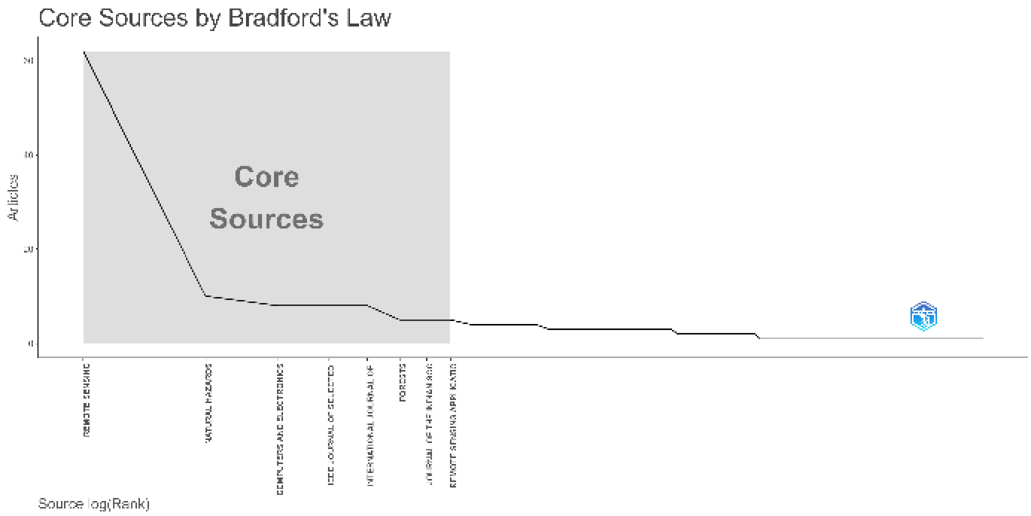

Figure 3. Core sources identified through Bradford's Law

Geographical Distribution of Publications and Collaboration Networks

Observations of author affiliations indicate that research contributions in this domain are still concentrated in several countries with established space technology capabilities. China holds the top position with a total of 93 publication articles, followed by the United States with 45 articles, and India with 37 articles.

Table 2. Top Ten Countries and Collaboration Ratios (MCP/SCP)

Country	Total Articles	SCP	MCP	MCP Ratio
China	93	76	17	18,27%
Usa	45	32	13	28,88%
India	37	33	4	10,81%
Japan	15	8	7	46,66%
Turkey	9	8	1	11,11%
Canada	8	5	3	37,5%
Italy	8	6	2	25%
Korea	8	5	3	37,5%
Germany	6	5	1	16,66%
Australia	5	3	2	40%

The dominance of these three countries strongly correlates with their independent ownership of earth observation satellite constellations and the high vulnerability index of their territories to large-scale natural disasters. This phenomenon illustrates that the capacity for developing remote sensing technologies requires massive research funding support and the availability of adequate computational infrastructure.

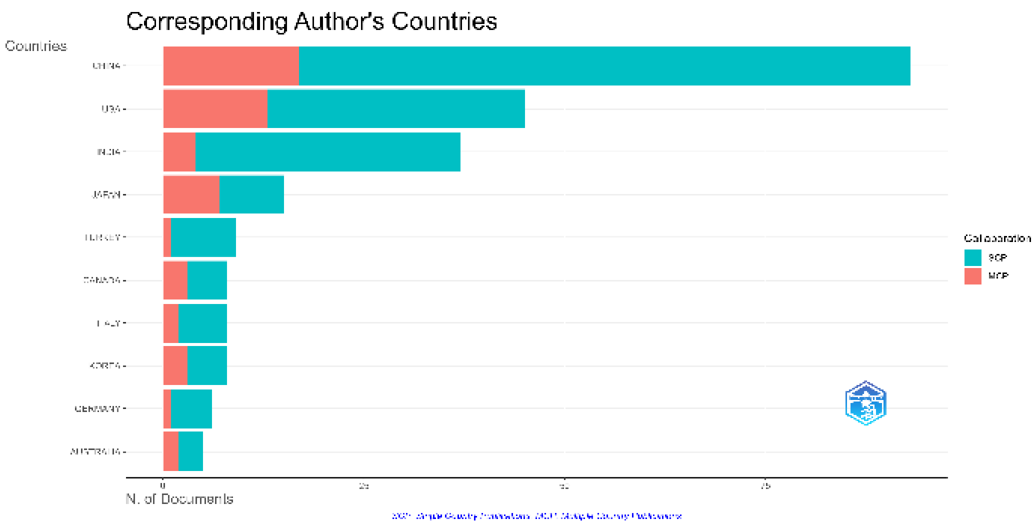

Figure 4. Top ten corresponding authors' countries and international collaboration ratios

The Single Country Publications (SCP) and Multiple Country Publications (MCP) metrics reveal the characteristics of international cooperative relationships built by researchers. China shows highly robust domestic productivity with an SCP value reaching 76 articles and 17 international collaborations. Conversely, Japan displays a highly intensive global interaction pattern with an MCP ratio reaching 46.66% of their total 15 articles. This cross-country collaboration pattern is an important indicator for the technology transfer process. Equal international partnerships open significant opportunities for developing nations located in disaster-prone regions to adopt the latest mapping algorithms without having to build satellite infrastructure from scratch.

Thematic Evolution and Trend Topics

The visualization of topic development from year to year records a clear technological paradigm transition in post-disaster monitoring. At the beginning of the observation period, namely from 2017 to 2018, researchers' attention was still limited to conventional subjects such as mapping tsunami impacts and developing general hazard assessment methods. Entering the middle period from 2019 to 2021, the research focus expanded toward land cover classification, agricultural crop monitoring, and the utilization of traditional optical satellite data like Landsat to analyze earthquake-affected areas.

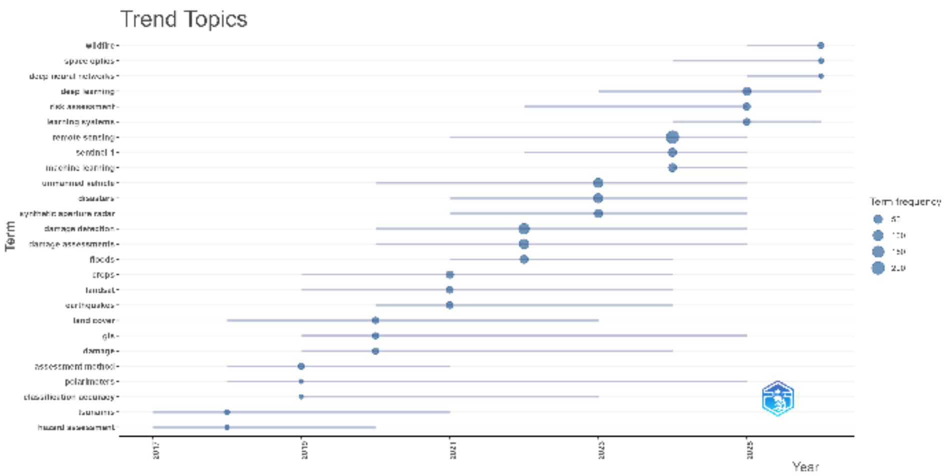

Figure 5. Thematic evolution and trend topics across the analysis period

A fundamental shift has occurred significantly within the last three years. Research topics moved dynamically toward high-level automation with the emergence of keywords such as unmanned vehicle, damage detection, and synthetic aperture radar, which reached their peak popularity between 2023 and 2025. This evolution signifies a departure from time-consuming manual visual evaluation methods. Current trends concentrate entirely on providing tactical information instantly through the integration of aerial drones and active radar sensors capable of penetrating atmospheric barriers in emergency field situations.

Co-occurrence Network Clustering

The keyword co-occurrence network analysis divides the conceptual research into several interconnected main groups. This grouping facilitates the identification of the scientific pillars building the post-disaster remote sensing research architecture.

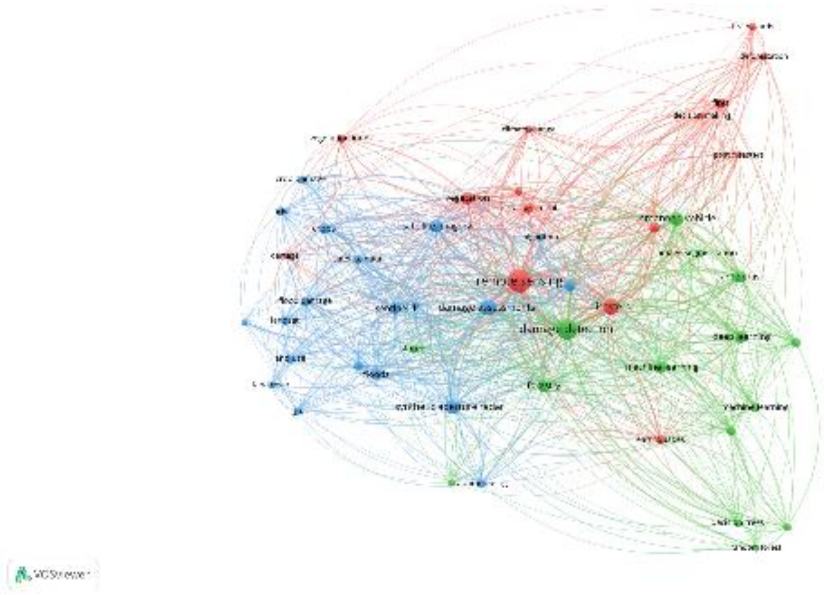

Figure 6. Keyword co-occurrence network visualizing three core clusters

Based on the division of these three main clusters, a synthesis is required to summarize the connections between dominant keywords, thematic meanings, and the representations of the underlying technical literature. This synthesis is specifically arranged to bridge the quantitative statistical mapping results with a more comprehensive conceptual interpretation.

Table 3. Synthesis Matrix of Post-Disaster Remote Sensing Network Clustering

Cluster	Dominant Keywords	Thematic Meaning	Technical Literature Representation
Red	Remote-sensing, disasters, vegetation, fires, risk assessment, earthquakes	General Disaster Management and Macro Ecological Risk Evaluation	Zang et al. (2020), Shimabukuro et al. (2020), Szpakowski & Jensen (2019), Kurbanov et al. (2022), Pham & Brabyn (2017), Xie et al. (2022)
Green	Deep learning, machine learning, change detection, random forest, UAV	Automated Damage Detection Based on Artificial Intelligence	Barbedo (2019) Qiao et al. (2013), Yu et al. (2018), Furuya et al. (2020), Zheng et al., (2021), Tilon et al. (2020), C. Wu et al. (2021)
Blue	Damage assessments, Sentinel-1, synthetic aperture radar, satellite imagery, floods	Active Sensor Operations for High-Resolution Anomaly Monitoring	Gong et al. (2016), Ramirez et al. (2020), Su et al. (2024), Shafapourtehrany et al. (2023), Q. Wu et al. (2024), Stuart et al. (2019), Yan et al. (2023)

This synthesis matrix clearly illustrates that each cluster is not merely a statistically grouped set of keywords standing apart without meaning. The integration of scientific references emphasizes the close connection between the type of remote sensing instrumentation utilized and the environmental damage phenomena occurring in the field. Each group represents a measurable operational contribution starting from the macro-scale landscape monitoring phase, automatic data processing, to sensor penetration through extreme weather anomalies during emergencies.

This knowledge structure also reflects a logical methodological roadmap for researchers to identify research novelty objectively. Through this well-documented visual relationship network with strong citations, readers can trace the conceptual roots of earth observation technology transitions sequentially and systematically. The arrangement of this matrix, rich with empirical references, simultaneously validates the accuracy of the quantitative analysis before being explored critically in the subsequent sub-chapter discussions.

Red Cluster: General Disaster Management and Ecological Risk Evaluation

The network map positions the red cluster as the foundation of macro-scale evaluation in post-disaster monitoring. This group encompasses essential keywords such as disaster, land cover, vegetation, and risk assessment. The primary research focus in this cluster points to monitoring affected areas across vast geographical coverages using conventional optical instruments. Observation satellites like MODIS dominate this realm due to their capability to provide dense temporal data. The reliability of this instrument was confirmed by Zang et al. (2020), asserting the effectiveness of satellite data in generating spectral indices for mapping large-scale environmental degradation.

In the context of fire ecology, monitoring burned areas in forest regions is one of the most crucial implementations of this spectral approach. Szpakowski & Jensen (2019) proved that utilizing satellite imagery accelerates the monitoring of affected areas so that mitigation responses can be formulated precisely. This approach was further refined by Shimabukuro et al. (2020), who applied multi-sensor satellite datasets to measure the severity of burned areas in the Amazon region. Optimizing this satellite data is proven capable of drastically reducing operational costs compared to ground survey methods.

Continuous monitoring in this red cluster relies heavily on image extraction techniques such as the Normalized Difference Vegetation Index (NDVI) and change detection algorithms. These techniques are deemed highly precise in reading land cover changes caused by both earthquakes and forest fires (Pham & Brabyn, 2017). Kurbanov et al. (2022) strengthened this argument with findings that multispectral remote sensing presents crucial data for monitoring the recovery rate of post-fire forest ecosystems. In the hydrological analysis landscape, macro observations using satellite instruments such as GRACE and GRACE-FO provide valuable information to identify water resource degradation caused by extreme floods (Xie et al., 2022). Critically, the entire literature within this cluster indicates that although passive satellite technology has resolution limitations, its role as a provider of foundational data for regional ecosystem restoration remains irreplaceable (Hong et al., 2023).

Green Cluster: Artificial Intelligence and Automated Damage Detection

The green cluster represents the most revolutionary methodological leap in contemporary remote sensing disciplines. The keyword network in this group is centered on unmanned aerial vehicles (UAV), machine learning, random forest algorithms, and automated change detection. The demand for extremely high-resolution data triggered a surge in drone usage in disaster areas. Barbedo (2019) noted that UAVs equipped with multispectral cameras are capable of presenting detailed visualizations of plant stress levels in real-time. This drone maneuverability becomes increasingly crucial when integrated with ground sensor networks to map landslide vulnerability on a small scale (Qiao et al., 2013). Object-based analysis paired with decision tree-based classifiers from UAV data has proven highly effective in identifying physical environmental damage (Zawadzka et al., 2021).

However, the transition toward utilizing ultra-high-resolution data generated a new obstacle in the form of a data volume explosion. Yu et al. (2018) dissected this technical barrier by stating that massive data management requires advanced processing techniques to conquer the heterogeneity of information formats. Artificial intelligence algorithms emerge as a robust solution to overcome this computational bottleneck. The application of artificial neural network architectures is capable of resolving spatial data complexity to identify damage patterns with incredible speed. Furuya et al. (2020) confirmed a significant accuracy improvement in mapping riparian vegetation through the application of machine learning on Sentinel-2 imagery. A deep object-based semantic change detection framework has also been proven to drastically reduce damage assessment analysis time (Zheng et al., 2021).

Although AI automation appears promising, studies within this cluster highlight critical limitations. Tilon et al. (2020) reminded that algorithmic detection errors often originate from the use of low-spatial imagery. Sheykhmousa et al. (2019) also highlighted the image acquisition time lag that damages data relevance in long-duration disasters. To address these algorithmic weaknesses, rigorous field validation is necessary to calibrate scale interpretation biases between satellite pixels and the actual ground conditions (C. Wu et al., 2021). The collaboration of optimization algorithms with open map data such as OpenStreetMap becomes one of the most rational hybrid strategies to offset these weaknesses (Goldblatt et al., 2020).

Blue Cluster: Active Sensor Technologies and High-Resolution Anomaly Monitoring

The blue cluster consolidates literature exclusively exploring active sensors and physical anomaly tracking instruments. The specific dominant keywords include synthetic aperture radar (SAR), Sentinel-1 satellite imagery, structured damage assessment, and flood disasters. Passive sensors from optical satellites frequently lose functionality due to storm cloud cover during the initial post-disaster hours. Radar instruments resolve this visibility limitation because microwave signals are unaffected by atmospheric disturbances.

This radar penetration advantage positions Sentinel-1 as the main backbone in geological anomaly monitoring. Ramirez et al. (2020) highlighted the operation of the Sentinel-1 platform to detect ground movement deformation long-term after an earthquake. The detection of this invisible ground shift produces important information regarding the structural destruction level of the land (Rao et al., 2023). The use of ultra-high-resolution radar satellite data like TerraSAR-X also proves its reliability in reading physical damage without having to rely on visual observations from the field (Gong et al., 2016). In the case of hydrometeorological disasters, specialized spectral index approaches like the Sentinel Multi-Band Water Index successfully extracted inundation boundaries with an extraordinary accuracy level reaching 96.5 percent (Su et al., 2024).

Besides radar, this blue cluster is supported by in-depth studies concerning hyperspectral sensors and LiDAR (Light Detection and Ranging). The high spectral resolution of hyperspectral sensors dissects the chemical composition of materials, making them highly accurate in identifying complex geological changes (Giordan et al., 2022). Portable hyperspectral devices are utilized precisely to track chemical pollution exposure in post-disaster aquatic ecosystems (Stuart et al., 2019). Water quality parameters post-disaster can also be estimated efficiently using multispectral sensors hovering with UAVs (Yan et al., 2023). The mapping of damaged landscapes becomes even more precise with the integration of LiDAR technology. LiDAR laser beam emissions are proven crucial in recording topographic changes and post-earthquake ground deformation with extreme spatial resolution (Shafapourtehrany et al., 2023). When LiDAR point cloud data is combined with convolutional neural networks, experts are capable of mapping active deformation zones with the potential for subsequent landslides precisely (Q. Wu et al., 2024). The cross-integration of these various advanced sensors produces a highly comprehensive and solid disaster risk assessment architecture (Harb & Dell'acqua, 2017).

CONCLUSIONS AND RECOMMENDATIONS

This bibliometric analysis has mapped the global literature evolution regarding the utilization of remote sensing technology for post-disaster environmental damage assessment over the past decade. The evaluation of publication metrics confirms an exponential surge in academic interest corresponding to the increasing frequency of global ecological crises. The scientific map in this domain is driven by three main, mutually complementary research pillars. The first pillar focuses on macro risk management using conventional optical instruments to measure the severity of land on a regional scale. The second pillar marks the era of computational disruption through the integration of unmanned aerial vehicles and artificial intelligence tasked with automating damage detection precisely. The third pillar highlights the operational urgency of active sensors such as synthetic aperture radar and LiDAR, which possess the absolute capability to penetrate extreme weather obstacles and uncover structural earth deformation anomalies.

Even though observation instruments develop rapidly, the literature synthesis reveals that remote sensing implementation still faces various fundamental hurdles. Spatial resolution limitations in conventional optical imagery and visibility disruptions caused by atmospheric anomalies frequently reduce emergency data accuracy levels. The automation of machine learning and artificial intelligence algorithms offers the accelerated analysis solutions highly needed during the critical post-disaster phase. However, these advanced analytical methods still demand rigorous calibration and field validation to avoid producing scale interpretation biases between satellite pixels and actual conditions in the field.

The geopolitical collaboration map also uncovers the dominance of countries with established space infrastructure in producing mainstream literature. This fact urges the need for strengthening transcontinental research cooperation to distribute mitigation technology capabilities evenly to developing countries with high disaster vulnerability levels. Future research is recommended to focus on designing hybrid algorithms capable of integrating open data with satellite multi-sensor captures. Technical studies regarding the automation of determining radar imagery backscatter threshold values in detecting both land and water anomalies also present highly prospective research niches. Ultimately, the utilization of remote sensing is no longer limited to a passive monitoring tool but has transformed into a highly resilient predictive decision support instrument in mitigating future disaster impacts.

To maximize the potential of these predictive capabilities, a strategic synergy involving technological practitioners and policymakers is highly recommended. Practitioners and remote sensing engineers should prioritize standardizing spatial big data processing protocols and developing open-source libraries capable of instantly harmonizing disparate optical and radar image formats during early emergency phases. Furthermore, policymakers and national disaster management agencies must construct a fully integrated spatial data infrastructure supported by regulations that guarantee the rapid sharing of high-resolution satellite data across institutions. These technical and regulatory advancements must be coupled with strong multilateral science diplomacy to facilitate equitable technology transfer, ensuring that highly vulnerable developing nations possess adequate mitigation capacities to face future ecological crises.

ADVANCED RESEARCH

This study possesses several methodological limitations that need to be acknowledged. The literature extraction process was exclusively confined to the Scopus database. This single-database approach might exclude highly relevant publications indexed in other major databases such as Web of Science or Google Scholar. Furthermore, the inclusion criteria strictly limited the dataset to English language journal articles. This language restriction potentially ignores significant local mitigation case studies published in regional languages. Future research should expand the literature search across multiple academic databases to capture a more comprehensive global perspective. Researchers are also encouraged to conduct systematic literature reviews focusing on specific disaster types to evaluate the detailed technical performance of hybrid remote sensing algorithms during field implementations.

REFERENCES

Barbedo, J. G. A. (2019). A review on the use of unmanned aerial vehicles and imaging sensors for monitoring and assessing plant stresses. In Drones (Vol. 3, Number 2). https://doi.org/10.3390/drones3020040

Chuvieco, E., & Kasischke, E. S. (2007). Remote sensing information for fire management and fire effects assessment. Journal of Geophysical Research: Biogeosciences, 112(1). https://doi.org/10.1029/2006JG000230

Furuya, D. E. G., Aguiar, J. A. F., Estrabis, N. V., Pinheiro, M. M. F., Furuya, M. T. G., Pereira, D. R., Gonçalves, W. N., Liesenberg, V., Li, J., Junior, J. M., Osco, L. P., & Ramos, A. P. M. (2020). A machine learning approach for mapping forest vegetation in riparian zones in an atlantic biome environment using sentinel-2 imagery. Remote Sensing, 12(24). https://doi.org/10.3390/rs12244086

Ghaffarian, S., Kerle, N., & Filatova, T. (2018). Remote sensing-based proxies for urban disaster risk management and resilience: A review. In Remote Sensing (Vol. 10, Number 11). https://doi.org/10.3390/rs10111760

Giordan, D., Luzi, G., Monserrat, O., & Dematteis, N. (2022). Remote Sensing Analysis of Geologic Hazards. In Remote Sensing (Vol. 14, Number 19). https://doi.org/10.3390/rs14194818

Goldblatt, R., Jones, N., & Mannix, J. (2020). assessing OpenStreetMap completeness for management of natural disaster by means of remote sensing: A case study of three small Island States (Haiti, Dominica and St. Lucia). Remote Sensing, 12(1). https://doi.org/10.3390/RS12010118

Gong, L., Wang, C., Wu, F., Zhang, J., Zhang, H., & Li, Q. (2016). Earthquake-induced building damage detection with post-event sub-meter VHR terrasar-X staring spotlight imagery. Remote Sensing, 8(11). https://doi.org/10.3390/rs8110887

Harb, M. M., & Dell'acqua, F. (2017). Remote Sensing in Multirisk Assessment: Improving disaster preparedness. IEEE Geoscience and Remote Sensing Magazine, 5(1). https://doi.org/10.1109/MGRS.2016.2625100

Hong, Y., Xu, J., Wu, C., Pang, Y., Zhang, S., Chen, D., & Yang, B. (2023). Combining Multisource Data and Machine Learning Approaches for Multiscale Estimation of Forest Biomass. Forests, 14(11). https://doi.org/10.3390/f14112248

Jia, J., & Ye, W. (2023). Deep Learning for Earthquake Disaster Assessment: Objects, Data, Models, Stages, Challenges, and Opportunities. In Remote Sensing (Vol. 15, Number 16). https://doi.org/10.3390/rs15164098

Kurbanov, E., Vorobev, O., Lezhnin, S., Sha, J., Wang, J., Li, X., Cole, J., Dergunov, D., & Wang, Y. (2022). Remote Sensing of Forest Burnt Area, Burn Severity, and Post-Fire Recovery: A Review. In Remote Sensing (Vol. 14, Number 19). https://doi.org/10.3390/rs14194714

Lozano, J. M., & Tien, I. (2023). Data collection tools for post-disaster damage assessment of building and lifeline infrastructure systems. In International Journal of Disaster Risk Reduction (Vol. 94). https://doi.org/10.1016/j.ijdrr.2023.103819

Pham, L. T. H., & Brabyn, L. (2017). Monitoring mangrove biomass change in Vietnam using SPOT images and an object-based approach combined with machine learning algorithms. ISPRS Journal of Photogrammetry and Remote Sensing, 128. https://doi.org/10.1016/j.isprsjprs.2017.03.013

Qiao, G., Lu, P., Scaioni, M., Xu, S., Tong, X., Feng, T., Wu, H., Chen, W., Tian, Y., Wang, W., & Li, R. (2013). Landslide investigation with remote sensing and sensor network: From susceptibility mapping and scaled-down simulation towards in situ sensor network design. Remote Sensing, 5(9). https://doi.org/10.3390/rs5094319

Ramirez, R., Lee, S. R., & Kwon, T. H. (2020). Long-term remote monitoring of ground deformation using sentinel-1 interferometric synthetic aperture radar (INSAR): Applications and insights into geotechnical engineering practices. Applied Sciences (Switzerland), 10(21). https://doi.org/10.3390/app10217447

Rao, A., Jung, J., Silva, V., Molinario, G., & Yun, S. H. (2023). Earthquake building damage detection based on synthetic-aperture-radar imagery and machine learning. Natural Hazards and Earth System Sciences, 23(2). https://doi.org/10.5194/nhess-23-789-2023

Shafapourtehrany, M., Batur, M., Shabani, F., Pradhan, B., Kalantar, B., & Özener, H. (2023). A Comprehensive Review of Geospatial Technology Applications in Earthquake Preparedness, Emergency Management, and Damage Assessment. In Remote Sensing (Vol. 15, Number 7). https://doi.org/10.3390/rs15071939

Sheykhmousa, M., Kerle, N., Kuffer, M., & Ghaffarian, S. (2019). Post-disaster recovery assessment with machine learning-derived land cover and land use information. Remote Sensing, 11(10). https://doi.org/10.3390/rs11101174

Shimabukuro, Y. E., Dutra, A. C., Arai, E., Duarte, V., Cassol, H. L. G., Pereira, G., & Cardozo, F. da S. (2020). Mapping burned areas of mato grosso state brazilian amazon using multisensor datasets. Remote Sensing, 12(22). https://doi.org/10.3390/rs12223827

Stuart, M. B., McGonigle, A. J. S., & Willmott, J. R. (2019). Hyperspectral imaging in environmental monitoring: A review of recent developments and technological advances in compact field deployable systems. In Sensors (Switzerland) (Vol. 19, Number 14). https://doi.org/10.3390/s19143071

Su, Z., Xiang, L., Steffen, H., Jia, L., Deng, F., Wang, W., Hu, K., Guo, J., Nong, A., Cui, H., & Gao, P. (2024). A New and Robust Index for Water Body Extraction from Sentinel-2 Imagery. Remote Sensing, 16(15). https://doi.org/10.3390/rs16152749

Szpakowski, D. M., & Jensen, J. L. R. (2019). A review of the applications of remote sensing in fire ecology. In Remote Sensing (Vol. 11, Number 22). https://doi.org/10.3390/rs11222638

Tilon, S., Nex, F., Kerle, N., & Vosselman, G. (2020). Post-disaster building damage detection from earth observation imagery using unsupervised and transferable anomaly detecting generative adversarial networks. Remote Sensing, 12(24). https://doi.org/10.3390/rs12244193

Wu, C., Zhang, F., Xia, J., Xu, Y., Li, G., Xie, J., Du, Z., & Liu, R. (2021). Building damage detection using u-net with attention mechanism from pre-and post-disaster remote sensing datasets. Remote Sensing, 13(5). https://doi.org/10.3390/rs13050905

Wu, Q., Ge, D., Yu, J., Zhang, L., Ma, Y., Chen, Y., Wan, X., Wang, Y., & Zhang, L. (2024). Active Deformation Areas of Potential Landslide Mapping with a Generalized Convolutional Neural Network. Remote Sensing, 16(6). https://doi.org/10.3390/rs16061090

Xie, J., Xu, Y. P., Yu, H., Huang, Y., & Guo, Y. (2022). Monitoring the extreme flood events in the Yangtze River basin based on GRACE and GRACE-FO satellite data. Hydrology and Earth System Sciences, 26(22). https://doi.org/10.5194/hess-26-5933-2022

Yan, Y., Wang, Y., Yu, C., & Zhang, Z. (2023). Multispectral Remote Sensing for Estimating Water Quality Parameters: A Comparative Study of Inversion Methods Using Unmanned Aerial Vehicles (UAVs). Sustainability (Switzerland), 15(13). https://doi.org/10.3390/su151310298

Yu, M., Yang, C., & Li, Y. (2018). Big data in natural disaster management: A review. In Geosciences (Switzerland) (Vol. 8, Number 5). https://doi.org/10.3390/geosciences8050165

Zang, Y., Chen, X., Chen, J., Tian, Y., Shi, Y., Cao, X., & Cui, X. (2020). Remote sensing index for mapping canola flowers using modis data. Remote Sensing, 12(23). https://doi.org/10.3390/rs12233912

Zawadzka, J., Truckell, I., Khouakhi, A., & Rivas Casado, M. (2021). Detection of flood damage in urban residential areas using object-oriented uav image analysis coupled with tree-based classifiers. Remote Sensing, 13(19).

https://doi.org/10.3390/rs13193913

Zheng, Z., Zhong, Y., Wang, J., Ma, A., & Zhang, L. (2021). Building damage assessment for rapid disaster response with a deep object-based semantic change detection framework: From natural disasters to man-made disasters. Remote Sensing of Environment, 265. https://doi.org/10.1016/j.rse.2021.112636