APPLICATION OF REMOTE SENSING FOR ENVIRONMENTAL DAMAGE ASSESSMENT IN POST-DISASTER RECOVERY

(*Penerapan Penginderaan Jauh untuk Penilaian Kerusakan Lingkungan dalam Pemulihan Pasca Bencana*)

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ABSTRACT

This study discusses using sensing technology in post-disaster handling to detect environmental damage in Indonesia. Remote sensing can collect large amounts of data and be utilized in environmental monitoring after disasters and mitigation preparations. With technology that can take a wide range of surface and temporal data, sensing technology is important in comparing conditions before and after a disaster. Using satellites, radar and lidar sensors, remote sensing provides accurate information on land cover classification, weather analysis and natural disaster monitoring. This paper discusess of current trends and advancements in Indonesia's use of remote sensing technologies for managing natural disasters. It emphasizes how crucial quick damage assessment is becoming to enabling prompt and efficient disasters response. Remote sensing technology using satellite imagery and synthetic aperture radar (SAR) is important for mapping disaster-affected areas, improving disaster management and faster recovery efforts. The combination of remote sensing technology with advanced algorithms and artificial intelligence (AI) improves the accuracy of environmental damage detection and supports the preparation of effective disaster mitigation strategies. This discovery emphasizes the importance of continuous development and cooperation in using remote sensing technology to manage and reduce environmental damage risks and ensure sustainable resource management and disaster preparedness.

Keywords : Disaster, Environment, Remote sensing

ABSTRAK

Studi ini membahas pemanfaatan teknologi penginderaan dalam penanganan pascabencana untuk mendeteksi kerusakan lingkungan di Indonesia. Penginderaan jauh mampu mengumpulkan data dalam jumlah besar dan berperan penting dalam pemantauan kondisi lingkungan pascabencana sekaligus mendukung persiapan mitigasi. Dengan kemampuan menangkap data permukaan dan temporal, teknologi ini memungkinkan perbandingan kondisi sebelum dan sesudah bencana. Melalui pemanfaatan satelit, radar, dan sensor LiDAR, penginderaan jauh dapat memberikan informasi akurat terkait klasifikasi tutupan lahan, analisis cuaca, serta pemantauan bencana alam. Teknologi ini sangat relevan untuk menangani bencana yang sering terjadi di Indonesia, seperti kebakaran hutan, banjir, dan gempa bumi, dengan penekanan pada pentingnya penilaian dampak kerusakan secara cepat. Selain itu, tren terkini menunjukkan bahwa integrasi penginderaan jauh dengan algoritma canggih dan kecerdasan buatan (AI) mampu meningkatkan akurasi deteksi kerusakan lingkungan. Pendekatan ini mendukung perumusan strategi mitigasi bencana yang lebih efektif, memperkuat manajemen bencana, dan mempercepat proses pemulihan. Hasil kajian ini menekankan pentingnya pengembangan serta kerja sama berkelanjutan dalam pemanfaatan teknologi penginderaan jauh untuk mengurangi risiko kerusakan lingkungan, memastikan pengelolaan sumber daya yang lebih baik, serta meningkatkan kesiapsiagaan dalam menghadapi bencana di Indonesia.

***Kata Kunci** : Bencana alam, Lingkungan, Remote sensing*

INTRODUCTION

The use of remote sensing for environmental observation plays an important role in Indonesia. Remote sensing systems can take data on a large scale and then manage and analyze it using software (Amani et al., 2020). Remote sensing systems make it possible to make indirect observations over a large area and for a long period in each area. So, the benefits are great for comparing the area or surface topography in events before and after an event. Technologies used in remote sensing in Indonesia include satellites, radar, and other devices that utilize sensors with different characteristics – different from spectrum and spatial and temporal resolutions. Satellites like

Landsat and Sentinel are examples of remote sensing technology that are frequently utilized in Indonesia. These platforms serve several disaster-related applications, like mapping floods, detecting forest fires, and assessing the effects of earthquakes, by using sensors with diverse spectral, geographical, and temporal resolutions. Sensing systems make it possible to obtain accurate information processed with unique algorithms and used for various applications such as land cover classification processes, hydrological land use, urban planning, weather and climate analysis, and natural disasters.

Indonesia is a region that has a high potential for natural disasters. Natural disasters that threaten Indonesian territory include volcanic eruptions, earthquakes, tsunamis, and forest fires. Natural disasters such as earthquakes, tsunamis, forest fires, and volcanic eruptions pose a serious threat to Indonesia. El Niño caused 1.16 million hectares of woodland to burn in 2023, and BMKG recorded 10,789 earthquakes, 219 of which were stronger than magnitude 5. Furthermore, escape windows in tsunami-prone regions like Aceh are as short as eight minutes, highlighting the importance of having a strong emergency plan. This natural disaster resulted in significant losses both in the economic and social context. To face and assess the impact of natural disasters that occur in Indonesia, a remote sensing system can be used. Rapid identification of natural disasters plays an important role in emergency rescue efforts and post-disaster analysis to assess the resulting impact (Liang et al., 2024). The disaster mitigation steps that must be developed are the development of a disaster warning system that supports community preparedness and recovery after a disaster. The remote sensing system method used in post-disaster management is satellite image mapping at locations affected by natural disasters. The disadvantage of satellite imagery is weather conditions. Continuous cloud cover will have an impact on the image results obtained. Satellites can produce high-resolution data for post-disaster identification compared to manual observations, which require a lot of time and effort (Casagli et al., 2017). In addition to the use of satellites, radar can make it possible to carry out an inventory in mapping. Radar can make observations on the earth's surface without being obstructed by weather conditions by receiving microwaves for coverage of a specific area (Gupta et al., 2022). Compared to satellites, the radar coverage area is narrower (Wakayama et al., 1998) .

Remote sensing technology allows easy and fast access to data that can improve the ability to detect, monitor, and map disaster areas to minimize the risk to researchers and optimize work in the field in assessing the consequences of natural disasters (Casagli et al., 2017). Natural disasters that often occur in Indonesia include disasters on the ground surface, such as earthquakes, tsunamis, forest fires, and volcanic eruptions. High-resolution data obtained from satellite sensing analyzes soil movement on the surface, which is helpful for post-disaster management. Sensing allows the study of the earth's surface structure by analyzing curves seen from the surface that can identify shifts or faults (Nekuie Mouafo et al., 2024). Soil typology and geomorphology can show the characteristics and predictions of soil movement obtained from data processing techniques from satellite or radar sensing results. Using remote sensing technology is essential for detecting and tracking environmental damage in addition to easing public anxiety about the effects of natural disasters. In Indonesia, where regular disasters can hasten ecosystem deterioration, this is especially critical. Timely information is crucial for policymakers to lower disaster risk and long-term environmental damage.

Recent research on remote sensing in post-disaster recovery shows a trend in using advanced computing techniques. Many studies (e.g. narrative or bibliometric) report on the integration of cloud computing platforms such as Google Earth Engine (GEE), machine learning/deep learning methods, as well as the incorporation of multisensory data (optics, SAR, drones) to improve the accuracy of damage detection. However, there is a significant global gap. For example, most research focuses on assessing the physical damage of infrastructure (buildings, roads) after an earthquake or tsunami, while monitoring environmental damage (vegetation, water quality) is still relatively limited. Research is generally based on one type of disaster or emergency response stage alone, so a multi-disaster approach and long-term recovery are inadequate.

Some key findings are that the study highlights the need for more field validation and large-scale models that can be applied to different regions/disasters. Future research recommendations include developing adaptive algorithms responsive to local conditions, integrating multiple data sources (e.g. satellites, UAVs, socio-economic data), and implementing remote sensing-based early warning systems. In addition, it stated the urgency of long-term environmental impact monitoring, inclusivity of climate change data, and local community participation in the analysis and validation process. This approach is expected to improve the resilience and sustainability of the post-disaster environment in the future.

Remote sensing in Indonesia faces challenges typical of the tropics, especially thick cloud cover that interferes with optical imagery. Majorly used satellites include Sentinel-2, Landsat-8/9, MODIS (Terra/Aqua), and Himawari-8/9. Sentinel-2 produces multispectral images with a spatial resolution of 10 meters (visible-band–NIR) and 20 meters (SWIR) with a revisit frequency of about five days, while Landsat-8/9 provides 30-meter (spectral and 15-meter (panchromatic) imagery every 16 days. MODIS can cover the global surface every 1–2 days with a spatial resolution of 250 m to 1 km, which is suitable for large-scale monitoring, such as regional forest fires, but less accurate for detecting minor damage. Meanwhile, Himawari-8/9 monitors the horizon every 10 minutes with a resolution of 0.5–2 km per channel, which is ideal for extreme weather prediction but unsuitable for detailed mapping. These spatial and temporal resolution characteristics significantly affect operational performance, where high-resolution imagery, such as Sentinel and Landsat, is more thorough but susceptible to weather disturbances. In contrast, radars, such as Sentinel-1, can penetrate clouds and operate day and night, making them ideal for monitoring floods and vegetation during the rainy season. Data access is relatively open through Copernicus, USGS, and NASA and supported by platforms such as Google Earth Engine. However, processing large amounts of data still requires adequate information technology infrastructure. Field disturbances and processing algorithms greatly influence the detection accuracy; for example, cloud-covered imagery needs correction before classification, and land cover classification requires field validation.

METHODS

This research reviews scientific research literature that provides an overview of the use of remote sensing technology for post-disaster recovery. The findings of recent and varied studies on the application of remote sensing for environmental monitoring and disaster management in Indonesia are summarized in this article using a narrative literature review methodology. The review is predicated on a thorough selection of peer-reviewed journal publications that were released in the 2019–2024 timeframe. The inclusion of only papers ranked as Q1 or Q2 in Scopus rankings and indexed in reliable databases ensured quality and relevance. These studies were chosen due to their direct importance to the use of remote sensing technology, such as radar and satellite imaging, in evaluating or responding to natural disasters, including earthquakes, floods, and wilderness fires. To ascertain eligibility, the review approach entailed a methodical screening of complete texts, abstracts, and titles. Key findings were then extracted and thematically synthesized. The findings of several studies are combined in this synthesis to show the most recent developments in the subject, including research trends, and technology. The strategy seeks to give a thorough and current summary of the subject while remaining adaptable enough to take into account various research designs and techniques (**Figure 1**).

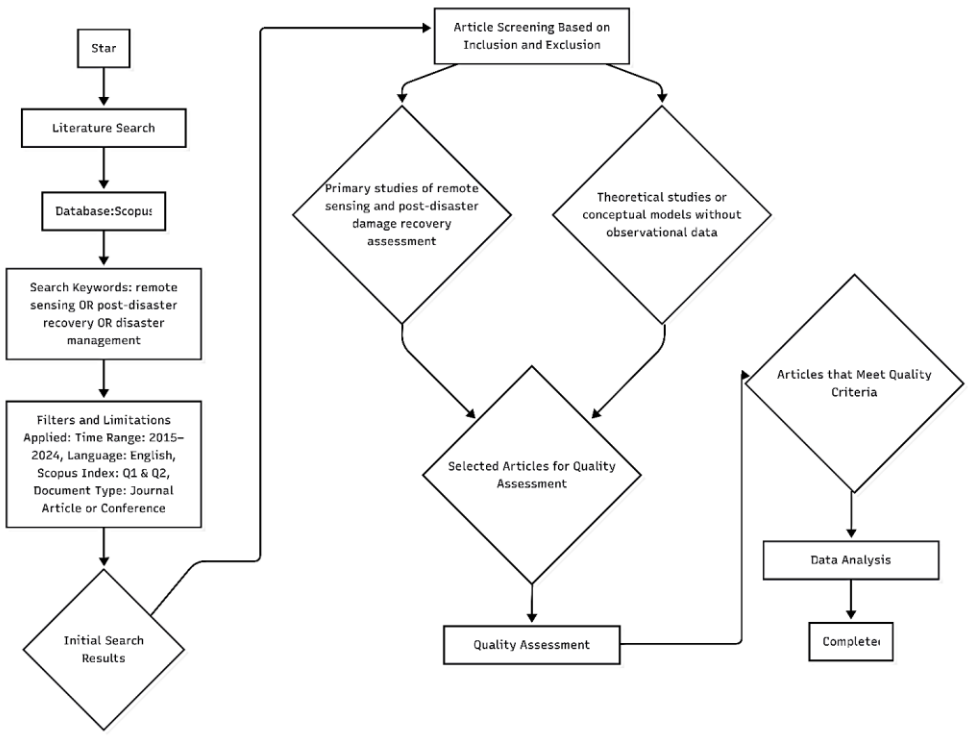

Figure 1. Research flowchart.

The first part explains the essential aspects of remote sensing in the form of a basic definition that refers to the concept and resolution that describes the details of remote sensing images. In addition, the integration of remote sensing data with other data was also explained. The resulting data will be processed using geometric correction and spectral analysis, and the required information will be extracted using classification and object recognition methods. Because the data produced is extensive, the images obtained require ample storage space before being analyzed. Remote sensing applications can be used for vegetation, seabed, water level monitoring, and other commercial uses.

In the context of implementation for post-disaster handling, remote sensing technology helps with early detection and recovery after forest fires, floods, landslides, and earthquakes, which assist in mapping damage and providing data for reconstruction planning. This technology is essential for environmental management and aids in strategically responding to disaster situations (**Figure 2**).

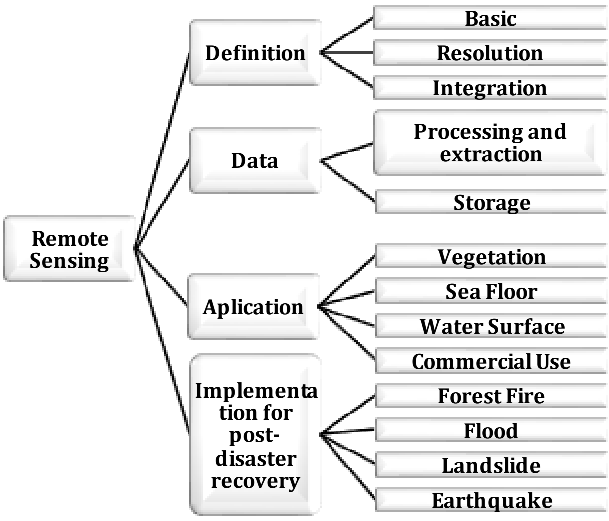

Figure 2. Research framework.

RESULTS AND DISCUSSION

Remote sensing in environmental observation

Remote sensing is a field of data analysis that can detect, map, and monitor areas for certain purposes related to the observation of environmental conditions. Advances in remote sensing technology significantly improve the temporal resolution of data (Cheng et al., 2023). Observations with remote sensing technology are carried out based on physical signals from instruments outside the earth's surface. Currently, there are several types of sensor characteristics, namely sensors from multi-spectral images with medium and high resolution to hyperspectral images that have a spectrum of electromagnetic waves with a high level of resolution (Romero et al., 2016). These various sensors allow for different purposes with a specific focus. From these multiple sensors, it is possible to classify results that can be mapped with particular objectives. In observation using sensing technology for the surface, Synthetic Aperture Radar (SAR) equipment attached to the satellite is used with the ability to make continuous observations without being affected by weather constraints (Romero et al., 2016). This system is an active system that directs electromagnetic waves at a target surface that will re-emit those waves in various directions and to the sensor.

Natural disasters cause both social and economic losses in the affected areas. The use of sensing technology helps save disaster victims by combining the results of surface observations for various needs to detect damage to buildings or areas and determine areas for evacuation (Ashifa et al., 2024). To improve the level of urban natural disaster risk assessment and provide a scientific basis for disaster prevention and reduction decision making, it is therefore necessary to gather data and create databases about the value and vulnerability (e.g., depth-damage curves) of buildings, infrastructure, human society, economy, and other prone areas in each city (X. Zhang et al., 2023).The approach to disaster management based on geographical data analysis requires the input of geospatial images on the surface area, which are then reprocessed by eliminating disturbances or noise. High spatial and temporal resolution is required in observation to produce good data. These two parameters significantly impact the processing of digital image data. Spatial resolution is the level of accuracy of the image based on the area or area size. The observed area will be grouped into pixels so that the smaller the pixel size, the higher the spatial accuracy. Temporal resolution is the level of accuracy based on the period of capture. The more often a satellite or sensing device takes images, the higher the temporal resolution. Satellites commonly used in Indonesian territory for observation are MODIS, Sentinel, Landsat, and Himawari (Kadam et al., 2024). The satellite has different temporal resolution and spatial resolution. For example, the Himawari satellite, with a resolution every 10 minutes, is suitable for weather observation. Meanwhile, a Sentinel with lower temporal resolution is ideal for land surface observation (Gibson et al., 2020). Meanwhile, Landsat with a short wavelength of about 2.15 µm is essential for forest fire detection, producing data with medium to high resolution (Jin et al., 2024). Drones can be used to produce higher data resolution and sharper images, but these sensing devices have a narrower range than radar or satellites.

The rapidly increasing use of remote sensing technology in natural disaster management has made detecting, mapping, and monitoring surfaces easier. The tool used for sensing techniques is a combination of very high-resolution imagery (VHR) and synthetic aperture radar (SAR) is a very effective tool because it has a very high spatial resolution (Casagli et al., 2017). Active optical sensors generated from the sensing process are used for disaster detection through visual analysis with analysis methods. For example, optical degradation (sharpening, grouping) can provide input to visual image interpretation. This procedure results in a rougher resolution compared to analytical processing. The use of hyperspectral data for identifying and grouping surface types based on their characteristics is still being developed (Scaioni et al., 2014).

Remote sensing technology uses four main types of data with different characteristics: optical, thermal, microwave, and laser scanning (Scaioni et al., 2014). Optical sensors use light and infrared rays to capture observed surface details and produce high-quality images. In its use for post-disaster observations, optical imagery can observe changes in soil surface and vegetation. Thermal sensors can detect changes in surface temperature, soil activity, and surface moisture that can identify strong or landslide-prone soil structures. Microwave sensors have the advantage of being able to penetrate clouds so that monitoring the condition of the earth's surface is not affected by weather conditions. The development of technology and the improvement of data quality, observation time, processing time, and cost-effectiveness can match the capabilities of direct observation devices on the surface, such as unmanned aerial vehicles (drones). The effectiveness of the use of this integration continues to be explored in researching various cases of natural disasters that facilitate risk management and as a better effort to improve community safety.

Data processing on remote sensing technology in environmental observation

Data processing from remote sensing technology requires excellent technical expertise and has major obstacles in information management, data storage, networking, and geospatial data processing (Gorelick et al., 2017). The Google machine applications have cloud-based storage that can help access data and process data at scale (Dong et al., 2016). The first step in utilizing the results of sensing technology is data collection. Data collection can be obtained from the results of satellite imagery producing large data because of the ability of satellites to collect data over a wide area consistently (Ma et al., 2015). The type of data collected can come from optical sensors, thermal sensors, and microwaves. After the data collection process, it is necessary to correct the image results to eliminate cloud-like disturbances due to weather conditions. The next stage is geometric correction which occurs due to distortion during image acquisition due to angle, tool movement, and topographic conditions. This correction should be integrated with other data, such as region topographic maps. The processing of the acquired images must be corrected again to improve the observation results. Image processing with unique algorithms can enhance the sharpness of images to facilitate analysis and interpretation. This correction is rough because it still relies on visual techniques. Understanding sensors and devices is essential for the correction process. Expertise helps to maximize data and adjust to the limitations of each tool. Image processing expertise can use software that allows image analysis and interpretation. Constraints that often arise in geospatial data processes require high computing systems as well as significant time analysis. With the development of technology, it is hoped that the obstacles that have arisen before can be overcome so that the use of data from sensing technology will be more effective and valuable for policymaking for disaster management.

The second stage after the data processing process is the extraction and classification of the mind based on needs. The segmentation process is an important issue in the field of classification of image results such as land cover (Wang et al., 2024). Land cover is related to the earth's surface cover, identifying vegetation, water, and other types of surfaces (Gómez et al., 2016). Extraction aims to identify surface types such as vegetation, rocks, water surfaces, and urban areas from the images obtained. After extraction, the image data will be classified according to the needs. The classification includes the analysis of images at high pixel dimensions with a level of noise that must be eliminated. Classification analysis allows in-depth observation of surface conditions from period to period. In the classification process, segmentation is required, namely, the results of the image data will be converted into a smaller and uniform area so that noise will be easier to remove. Segmentation can be in pixel division or division based on larger objects according to shape. The challenges of the classification process are different lighting levels, surface textures, and noise, so an algorithm that matches the parameters is needed for the accuracy of the results.

The high data dimensions of remote sensing results have led to many technologies developed to reduce data dimensions (Romero et al., 2016). The problem caused by the large data dimension is that processing the image data will take longer and slower time and require significant resources. Along with the oversized dimensions, the process of producing new data will also be hampered. Data also tends to carry inappropriate information or noise, so data analysis will be disrupted. The technique developed is a statistical engineering method with a linear combination of the main component as a source. The information will be summarized well so that the reduction in dimensions will not reduce the information (K & K, 2024). Extraction techniques can provide faster data analysis and accurate results. Changes in land surface cover can be identified for environmental monitoring. The results obtained will improve natural resource management and risk analysis against disaster impacts. The feature extraction technique will reduce the data dimension so that researchers utilizing remote sensing imagery can adequately analyze and interpret the data. Reducing the dimensions can speed up the analysis and increase the accuracy of the results so that a good result is produced.

Remote sensing can collect large amounts of data by managing and analyzing it using specific software and computing (Amani et al., 2020). Large quantities of data contain information from various aspects observed from the earth's surface. Large volumes of data from remote sensing results include multiple data with different formats and specific characteristics that require integration for processing. The challenges of extensive data processing and data analysis are divided into general and individual. General aspects related to data processing include computing, collaboration, and big data working methodologies. Meanwhile, challenges in individual elements relate to various applications' data cycles. The data cycle concerns aspects of accurate data identification, data dissemination, data visualization, and interpretation. Solutions that can be drawn from this problem in remote sensing need to be further developed.

Cloud computing platforms make it possible to store data in an efficient way that is accessible and visualize it for users. The infrastructure of this platform has open access with further processing. Users do not need to download the available data and process it directly. In this way, users can collaborate between researchers without regional restrictions. Data updates are also possible in real-time so that the latest data can be analyzed. Developing processing algorithms and applying analysis techniques will improve the quality of data from remote-sensing images more efficiently. The sophisticated classification process will speed up the interpretation and analysis process, making it easier to formulate results.

Application of remote sensing technology in environmental observation

Remote sensing applications can be used to observe vegetation in the area to be studied. Remote sensing using satellites is an important technology to monitor the earth's surface, such as in cases of vegetation damage, deforestation, and forest fires (Zhao et al., 2024). Remote sensing technology enables continuous observation with accurate and fast data results related to environmental conditions. With satellite imagery, users can detect surface cover changes more practically. An example is the observation of vegetation damage carried out with satellite imagery. Vegetation is one of the ecosystem indicators that plays a role in maintaining environmental balance, water cycle, and energy and material flow (Leppä et al., 2020).

Vegetation damage events such as forest fires, deforestation, and landslides often occur due to natural factors and Anthropogenic force. Changes in vegetation have a long-term impact on environmental stability. Conventional methods of observing vegetation changes such as repeat photography and canopy survey require expensive costs and a long time, with the presence of remote sensing by satellite, these conventional activities can be replaced. The following **Table 1** provides a brief overview of remote sensing (RS) applications in disaster management, highlighting the benefits and drawbacks of various imagery and resolution types.

Table 1. Remote sensing (RS) applications in disaster management.

Application	Image Type Resolution	Advantages	Disadvantages
Vegetation Mapping	Landsat TM (30 m)	Effective for monitoring land cover changes and vegetation post-disaster.	Low resolution may reduce detail of information.
Flood Monitoring	Sentinel-1 (10 m)	Accurately detects water inundation quickly in near real-time.	Limited by weather conditions; not effective when cloud cover exists.
Earthquake Hazard Analysis	Landsat 8 and SRTM	Enables comprehensive geological analysis and risk mapping.	Requires additional field survey data for validation.
Tropical Disaster Management	MODIS (250 m)	Provides rapid temporal data for continuous disaster monitoring.	Lower resolution for in-depth analysis.

Remote sensing for observation of agricultural land is also rampant in Europe. Heterogeneous planting systems with small to medium agricultural land ownership and diversity of plant species require intensive monitoring (Bazzi et al., 2024). Vegetation regulates the exchange of carbon, water, and energy on regional and global ecosystems' surface and atmosphere. Remote sensing can also be used to observe drought propagation (Palagiri et al., 2024). Weather and climatic factors such as temperature and rainfall are significantly related to reforestation. The current research examines temporal and spatial variations in vegetation that affect global warming. One example of research that examines vegetation change is the discussion of correlations between dynamic changes in vegetation cover.

Remote sensing technology can also be used for seabed observation. High-accuracy seafloor mapping, such as coral reef ecosystems, is essential for coral reef habitats (Liu et al., 2024). Remote sensing data with optical sensors is an important tool for basic mapping because it can provide detailed visual information about sea surface conditions up to the seabed and its elements. Sensors from satellites can detect light reflections coming from the surface of the water and the ocean floor that produce images with spectral information. Image data analysis techniques can identify coral reef types and water conditions such as pollution. Remote sensing technology allows continuous observation on a large area scale compared to conventional direct observation. Remote sensing can increase knowledge about marine ecosystems that can support conservation efforts and more effective management of natural resources in the ocean so that it can be used to support the sustainability of marine ecosystem habitats for the future. Evaluation of the impact of combining topographic data with coral reef classification provides spectral and topographic information derived from satellite imagery. Researchers can obtain information about marine ecosystems and assess marine habitats more accurately. The incorporation of topography can improve the accuracy of the classification process, especially for some categories of clear slope slopes, such as in the study of coral reefs in deep ocean areas. This merger provides limitations in remote sensing-based seafloor mapping with optical sensors.

Global climate change can affect the water level in the lake area (Bai et al., 2024). In the global era, climate change will experience a tendency to continue to increase, resulting in extreme climate events occurring frequently. The cause of climate change is global warming, which has resulted in prolonged droughts and high rainfall in several regions. Remote sensing technology is useful for detecting global water level changes in lake areas. Studies on the occurrence of lake water level subsidence quantitatively using satellite data have been conducted. The lakes studied are categorized as reservoir lakes, endorheic lakes, and lakes with frozen soil layers. The research focuses on spatial and temporal differences in the occurrence of water level differences in lakes. The analysis correlates the relationship between extreme events in water level subsidence associated with meteorological variables and the global climate cycle to determine the event's cause. The temporal-spatial distribution of different types of lakes experiences differences that are closely related to evaporation and air temperature. The implications include ecological forecasts of the area, understanding the effects of climate change, and facilitating water management as a sustainable resource.

Remote sensing by satellite of the water level height allows for wide spatial coverage (Bjerklie et al., 2023). As a follow-up to the lake water level study, further integration is needed to create policies in water resource management. By studying changes in water level patterns, policymakers can develop effective strategic plans to deal with the risks of climate change impacts such as drought. Periodic monitoring with remote sensing technology helps to better plan the use of water resources and can be an early warning in anticipation of disaster impacts. Supported by collaboration between scientists, policy makers, and the community will create a good approach to water resource management. This is useful in maintaining the environment and the sustainability of water sources for the future. Therefore, continuous research and policy formulation with remote sensing results play a major role in dealing with natural disasters due to global climate change.

The expansion of coastal land-based aquaculture has substantially reduced wetlands (Jiang et al., 2024). The increase in population encourages increasing public demand for aquatic products. Coastal aquaculture activities are an important means of supporting the availability of marine resources that ensure world food security. The Asian region plays an important role in the production of aquaculture in the world. The construction of aquaculture ponds on land is an important route for carbon sequestration greater than aquaculture in the ocean or lakes. The large-scale use of coastal land vegetation has significantly changed the pattern of temporal spacing of land planning in coastal areas. Remote sensing technology is used to effectively monitor the dynamics of coastal aquaculture based on periods. The data used is Landsat images with a long-time duration with a classification method. Data extraction identifies water bodies with a specific algorithm by combining them with the inundation frequency index to eliminate disturbance data. Mapping of the results of satellite imagery allows researchers to identify the distribution area of the aquaculture area.

Sensing technology used to identify area changes in coastal areas for aquaculture uses Landsat data (Jiang et al., 2024). Data processing is currently supported by the Google Earth Engine, allowing researchers to work more effectively and efficiently and supports a wide range of remote sensing analyses across various fields. Further analysis is required for accuracy with actual conditions on the surface. In the process of taking images, satellite images often have cloud covers due to weather conditions. This results in the loss of imagery of the observed area. The process of eliminating cloud interference is an important factor before analysis because the distortion caused will result in less accurate data. The method used in reducing cloud distortion is the use of a special algorithm (image fusion,wavelet transform) that can erase the cloud image due to weather conditions. In addition to this method, a technique is also used to combine several images obtained to fill in gaps or missing surface images so that a perfect surface image is produced. The above approach allows researchers to obtain a complete description of the dynamics of changes in the area of aquaculture land and its impacts. Sensing technology also improves the efficiency of data collection and decision-making capabilities for managing coastal aquatic resources.

Utilization of Remote Sensing in Post-Disaster Recovery for Environmental Damage Assessment

Climate change and worsening weather conditions due to forest fires encourage the need for disaster mitigation and recovery plans for environmental damage. Remote sensing can provide information about the condition of vegetation in an area on a spatial and temporal scale to overcome the impact of disasters. The approach is carried out using remote sensing data to explore the level of forest land damage in situ (Chatzopoulos-Vouzoglanis et al., 2024). Geostationary satellite data provides fire information on an ongoing basis and is used to detect and monitor the impact of forest fires, create variable maps for forest damage observation, and generally use combined satellite imagery to obtain comprehensive coverage (Pitkänen et al., 2024). A model is built to predict variables based on the reflectivity values used to create thematic maps. The main challenge in mapping forest land in the tropics is weather conditions, so clouds will easily cover the image, so further correction is needed before analysis.

In disaster and environmental management, remote sensing can be used for a variety of things, such as monitoring floods, landslides, wildfires, and land cover change. This type of remote sensing application is indicated in the literature reviewed. To improve the accuracy and efficiency of data processing, technologies such as Google Earth Engine (GEE), machine learning, and deep learning are widely used. The use of cloud computing platforms and the integration of data from various sources is the current trend. Nonetheless, there are still some problems. These include a lack of field validation, limited model scalability, and lack of integration of shared risk analysis between disaster types and socio-economic data. In addition, there is still little effort to monitor environmental impacts in the long term.The development of more responsive algorithms, the integration of data from multiple sources, remote sensing-based early warning systems, and easy-to-use cloud applications are upcoming research topics. Weaknesses in feature selection, data validation, and lack of consideration for uncertainty are criticisms of previous research. The impact of climate change, local community participation, and ethical issues of data use are areas that are still underexplored. Future research is expected to answer these issues with the aim of improving environmental resilience and sustainability (**Table 2**).

Table 2. Literature mapping table.

Topic	Journal
Disaster Mapping	Ashifa et al. (2024), Bjerklie et al. (2023), Casagli et al. (2017), Chatzopoulos-V. et al. (2024), Giardina et al. (2023), Gibson et al. (2020), Jamali et al. (2024), Jin et al. (2024), Kadam et al. (2024), Kumar & Anbalagan (2019), Liang et al. (2024), Mi et al. (2023), Marano et al. (2009), Mason et al. (2021), Nauman et al. (2021), Scaioni et al. (2014), Sharma et al. (2017), Tang et al. (2024), Tamkuan & Nagai (2019), Uehara et al. (2022), Vanama et al. (2020), Wang et al. (2024), Welikanna & Jin (2023), Yao & Qiang (2015), Zhang et al. (2023), Zhao et al. (2016)
Environmental Monitoring	Bai et al. (2024), Gao et al. (2021), Nekuie Mouafo et al. (2024), Palagiri et al. (2024), Zhao et al. (2024)
Agriculture & Forestry	Bazzi et al. (2024), Dong et al. (2016), Leppä et al. (2020), Li et al. (2014)
Disaster Risk Reduction	Dube (2019), He (2019), Hinzpeter & Sandholz (2018), Shi et al. (2021)
Land Use & Land Cover	Gómez et al. (2016), Jiang et al. (2024), Li et al. (2024), Liu et al. (2024), Pitkänen et al. (2024)
Technology & Methods	Amani et al. (2020), Cheng et al. (2023), Gorelick et al. (2017), Gupta et al. (2022), Ma et al. (2015)

Forest mapping relies on the area on the surface, with satellite imagery allowing observation over a wider area (Pitkänen et al., 2024). Further spectral analysis is needed to estimate the severity of forest fires. Adaptive algorithms developed with the advantage of distinguishing vegetation with effectiveness, generality, and stability even in areas that experience extreme damage (Jin et al., 2024). The use of Sentinel-2A, WorldView-3, and SPOT-4 satellites provides good spatial resolution for forest fire detection. In addition, detecting image changes in remote sensing for forest fires requires manual steps prone to errors. Currently, more modern methods use AI as a framework for forest estimation and analysis of changes (Zulfiqar et al., 2021). The approach carried out is semantic segmentation in processing satellite images. Automatic feature extraction on forest land cover patterns makes it easier to identify land damage.

With the use of Landsat-8, it is possible to distinguish the vegetation index by combining linear and multi-variable regression models so that the estimated age of the forest can be detected (D. Li et al., 2014). Shortwave infrared canals that can detect wetness levels correlated with leaf lifespan can identify forest damage. Observations contain important information indicating changes and potential due to forest fires. Further analysis of changes in vegetation indices from the period before and after a disaster event provides a deep understanding of forest management so that policymakers can decide on strategies for restoring forest ecosystems.

In general, integrating satellite data with analysis models will improve the accuracy of forest damage detection and provide information about changes that occur so that impact mitigation efforts can be carried out faster. The Government can respond quickly and appropriately and formulate countermeasures using accurate data sources. Identifying areas that have suffered severe damage will be easier to find so they can be tackled faster. The integration of remote sensing technology with AI also greatly improves the effectiveness of data processing. This approach encourages opportunities for the Government and communities to restore forest damage to rehabilitate the environment. The use of this technology is not only applicable in the aftermath of a disaster but can be used to mitigate fire disasters in the future.

Floods are natural disasters that occur frequently and their frequency increases from year to year. The impact of floods, including economic and social aspects, is expected to increase along with climate change and global warming. Acquiring accurate and fast data on the extent of flood-affected areas is essential for disaster preparedness and disaster mitigation efforts (Jamali et al., 2024). The remote sensing feature allows observations in flooded areas and assesses the impact without conventional observations. The increasing severity, duration, and frequency of destructive floods and affected infrastructure will be more accessible to assess using remote sensing data. Another developing research is the study of temporal spacing (H. Li et al., 2024), which combines the possibility of urban flooding with urban heat islands that help urban development in developing countries sustainably with limited resources (Jamali et al., 2024). Urban heat islands are related to the number of people in urban areas, which impacts the lack of drainage, so if there is heavy rain for a long period, it will trigger flood disasters in urban areas. Rainfall is a driving factor for runoff (Gao et al., 2021).

Remote sensing using synthetic aperture radar is a tool that can detect flood emergencies (Mason et al., 2021). This technology aims to map flooded areas in rural areas that mostly use open-access Sentinel-1 data and surface models. This data can be used in real-time in global regions. The results obtained from the use of satellite data show an accuracy of 78.5% to 82% for flood detection alone (Vanama et al., 2020). This technology can quickly respond to flood disaster management because its curation is high enough to help the Government plan post-disaster recovery actions. Evacuations can be carried out quickly, and information about the duration and spread of flood disasters can be used to prevent them in the future.

The readiness of various parties to monitor flood events and forecast floods using a forecast-based approach can shift disaster response to pre-disaster preventive measures, thereby minimizing the impact at risk (Nauman et al., 2021). This approach is very beneficial for post-flood recovery. When a disaster occurs, the impact can be minimized, and prevention can reduce physical damage to the environment and maintain the quality of water resources and living things in the affected area. At the time of the event after the disaster, the observation phase can be used to plan more effective environmental recovery to preserve natural resources in the future. By involving researchers in assessing the impact of floods with remote sensing, the Government can advance disaster preparedness and minimize the impact of flood disasters to create sustainable social and environmental resilience.

Strong earthquakes often trigger seismic landslides in various regions (Wang et al., 2024). The use of remote sensing technology can focus on detecting landslides using satellite image digital data collection techniques. Differences in vegetation index, building index, and soil can be extracted from sentinel-2 imagery and integrated with a digital elevation model to produce an information map of landslide-prone areas in an area (Uehara et al., 2022). This mapping also provides information about areas at risk of landslides so that the Government can set prohibitions for developing these areas. Synthetic aperture radar techniques can detect landslides in smaller spatial areas (Zhao et al., 2016). Synthetic aperture radar has a high resolution so it can be used to identify changes in a limited area in more detail. In addition, landslide vulnerability mapping can also be used to identify slopes that can potentially be unstable (Kumar & Anbalagan, 2019).

This technique is not only used to create a landslide disaster risk map but can also be used as information to monitor the condition of slope changes in each period. The information obtained will be more beneficial for Government decision-making in quick mitigation efforts. In addition, this information is also helpful for environmental recovery after landslide disasters. Identification of affected areas and restoration of areas can be done faster to help restore ecosystems and the environment to reduce future impacts.

Sentinel 1 imagery is used to detect areas damaged by earthquakes by utilizing interferometry coherence (Tamkuan & Nagai, 2019). Detection analysis compares the coherence between events before and after the earthquake and the damaged area. The analysis process using satellite images can describe the visual process of the sequence of earthquake events that migrate progressively (Yao & Qiang, 2015). Remote sensing technology helps to map damage and add insight into the impact of earthquakes for future mitigation. Identifying this earthquake event is difficult even through physical and geological research (Sharma et al., 2017). With the use of radar data, the level of deformation due to low-level earthquake disasters can be known (Welikanna & Jin, 2023). In addition, amplitude and decomposition analysis can identify soil categories and identify soils due to earthquakes (Liang et al., 2024). The analysis helps repair environmental damage due to earthquakes and provides Government input in determining earthquake-prone zones so that the risk of earthquake disasters can be reduced.

Texture-based environmental damage classification methods using SAR data can be used to assess building damage in a high-resolution manner (Giardina et al., 2024). These uneven surface maps are essential for environmental studies (H. Li et al., 2024). The need for rapid evaluation of a large area for areas that have been damaged by soil movement is the main impact that must be considered (Marano et al., 2010). Photogrammetry techniques can also be combined to check field conditions by utilizing unmanned vehicles (UAVs) with lower usual compared to direct field surveys (M. Zhang et al., 2024). The collection and analysis of sensing image data can improve information transfer (Schroeder et al., 2016). The rate of recovery and reconstruction after natural disasters can reflect a country's economic level and its ability to manage disasters (Shi et al., 2021). Rushed impact recovery will give less than optimal results.

The recovery and reconstruction process after an earthquake disaster will improve an accurate understanding of the changes in the affected land cover (Mi et al., 2023). Post-disaster recovery is an important social process. Post-disaster reconstruction can effectively reduce risks and maintain national resilience to achieve long-term stability (Dube, 2020). Research suggests that developing policies and reconstruction plans can increase community satisfaction and support sustainable development (Hinzpeter & Sandholz, 2018). The rebuilding of the affected areas can improve the community's living standards (He, 2019). The redevelopment concept emphasizes the role of non-physical facilities in regional spatial planning, policies, and assessment of damage due to disasters and their mitigation.

CONCLUSIONS

Remote sensing is a field of data analysis that can detect, map, and monitor areas for certain purposes related to the observation of environmental conditions. The use of this technology is rapidly increasing in the handling of natural disasters because it makes it easier to detect, map, and monitor surfaces. Data processing from remote sensing technology requires special technical expertise and has major obstacles in information management, data storage, networking, and geospatial data processing. Along with the advancement of technology, cloud computing platforms make it possible to store data in an efficient way that is re-accessible and visualize it for users. This literature review emphasizes how remote sensing technology is becoming increasingly important in managing environmental damage brought on by Indonesia's natural catastrophes. Climate change has made disasters like forest fires, floods, landslides, and earthquakes more frequent and intense, necessitating the use of efficient monitoring, mitigation, and recovery measures. Remote sensing offers an effective way to quickly and precisely identify, map, and evaluate impacted areas.

Remote sensing applications can be used for vegetation, disasters, seabed observations, water level observations, and the utilization of cultivated land. Along with the global warming process, climate change will encourage natural disasters due to environmental anomalies. Therefore, there is a need for disaster mitigation and a plan to recover from environmental damage caused by natural disasters. Summarizing current trends and advancements in remote sensing applications for disaster management, with an emphasis on how these technologies aid in environmental recovery, was the aim of this review. Through the use of cloud computing platforms, and satellite imaging, remote sensing innovations have improved data accessibility, collaboration, and actionability beyond geographical boundaries.

In Indonesia, natural disasters that often occur, such as forest fires, floods, landslides, and earthquakes, can cause social and economic losses. Remote sensing technology can be used to compile information related to impacts and efforts that must be made to improve the environment for the preservation of resources in the future. In the case of forest fires, satellite data integration with analysis models will improve the accuracy of environmental damage detection and provide information about changes that occur so that impact mitigation efforts can be carried out faster. The Government can respond properly and appropriately and formulate countermeasures using accurate data sources. Identifying areas that have suffered severe damage will be easier to determine so they can be overcome faster. The integration of remote sensing technology with AI also greatly improves the effectiveness of data processing (Cheng et al., 2023). Furthermore, the review emphasizes the role of remote sensing in shifting disaster management from reactive to proactive through forecast-based monitoring and mitigation strategies. The application of this technology not only aids in post-disaster assessment but also enhances preparedness and reduces future risks.

The readiness of various parties to monitor disaster events and forecast disaster occurrences using a forecast-based approach can shift disaster response to pre-event preventive measures, thereby minimizing risky impacts. This approach is particularly beneficial for post-disaster recovery. When the incident occurs, the impact can be minimized, and prevention can reduce physical damage to the environment and maintain the quality of resources and living things in the affected area. After a disaster, the observation phase can be used to plan environmental recovery. The Government, by involving researchers, can assess the impact of disasters and minimize the effects caused by remote sensing so as to create sustainable social, economic and environmental resilience.

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