International Journal of Education, Vocational and Social Science
https://e-journal.citakonsulindo.or.id/index.php/IJEVSS
E-ISSN : 2963 4954
IJEVSS

The Role of Remote Sensing in Environmental Damage Assessment and Accelerated Post-Disaster Recovery

Rosi Fitria[1]
[1]Indonesia Defense University, Indonesia
Asep Adang Supriyadi[2]
[2]Indonesia Defense University, Indonesia
Syachrul Arief[3]
[3]Geospatial Information Agency, Indonesia
Dangan Waluyo[4]
[4]Indonesia Defense University, Indonesia

Corresponding Author: rosi.fitria@tp.idu.ac.id

Abstract

Remote sensing technology in post-disaster environmental damage assessment has become an essential focus for more efficient recovery planning. This research aims to identify the role of remote sensing technology in assessing environmental damage and supporting the recovery process in a faster and more precise way. This research was conducted through a literature study approach by exploring the basic concepts of remote sensing sourced from various scientific journals. The results show that remote sensing has a vital role in assessing damage, with its ability to collect data in real-time and cover large areas. This makes it easier to identify damage in various locations affected by the disaster. Although this technology faces several challenges, such as limited image resolution, limited data frequency, and interference due to erratic weather conditions, remote sensing has proven effective in accelerating post-disaster recovery. With the support of good coordination between relevant agencies, this technology can make a significant contribution to accelerating and facilitating the post-disaster recovery process.

Keywords: Remote Sensing, Environmental Damage, Post-Disaster Management.

INTRODUCTION

Disasters occur due to natural factors or human actions that cause property losses, loss of

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

life, and environmental damage, which can be a severe disruption and a special concern for humans. Examples of disasters caused by natural factors include hurricanes, typhoons, tornadoes, heavy rain, snowstorms, and forest fires (McKnight & Linnenluecke, 2019). In addition, disasters that are not caused by nature, for example, environmental damage, occur due to human activities, either intentionally or unintentionally. Natural disasters can hurt infrastructure, the business sector, and communities in the affected areas (Ghaffarian et al., 2020). More than 11,000 natural disasters have been recorded since 1960 (Kharb et al., 2022). This indicates that natural disasters result in significant material and human losses worldwide, necessitating the consideration of risk reduction and management strategies at various scales, given the increasing severity and intensity of disasters and the resulting damage (Ghaffarian et al., 2021). One way to reduce disaster risk is to manage disasters before they occur, during disasters, and in post-disaster recovery to mitigate negative impacts and economic, social, and environmental losses. The success of disaster risk management depends on a comprehensive emergency response and early recovery phase (Tonti et al., 2023). The biggest challenge that needs to be considered is post-disaster recovery. According to Chang, SE, 2010, in Sheykhmousa et al. (2019), post-disaster recovery is the process of recovering to normal after experiencing challenging conditions. At this point, remote sensing technology plays a vital role by providing accurate, precise, and easily accessible information to assess the level of damage and support planning in post-disaster recovery. Ghaffarian et al. (2018) conveyed that remote sensing data and techniques have been widely utilized in all aspects of risk management.

Sensing technology can monitor large areas in a short time, so that it can provide an effective solution to carry out post-disaster damage assessments quickly and accurately. The data produced can detect various damages both on the land surface and in the marine and air environments by utilizing sensors in remote sensing. According to Lorenzo-Alonso et al. (2019), significant developments in remote sensing, including advancements in satellite sensors, data accessibility, applications, and services, as well as support from space agencies in regulating data sharing policies, have facilitated access to remote sensing data for easier and more efficient use in disaster management. In addition, remote sensing and geoinformation systems have become effective and rapidly developing tools in their use for disaster risk management, especially in vulnerability mapping and risk impact assessment (Sambah & Miura, 2016). Post-disaster environmental damage assessment is a critical initial stage for later planning for sustainable environmental improvement and development.

With this sensing technology, the data produced can monitor environmental changes over

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

time, track the development of the recovery process, and quickly identify the following steps to accelerate environmental recovery. However, despite the advantages of remote sensing, it remains a challenge, particularly in terms of quickly accessing high-resolution data after a disaster, especially in areas that are difficult to reach. In addition, the interpretation of remote sensing data requires special expertise and needs to be matched with data in the field to ensure the accuracy of the analysis results. Thus, cooperation between institutions at the national and international levels is essential to optimize the use of remote sensing technology in environmental recovery efforts.

LITERATURE REVIEW

This research adopts a literature study approach that begins by examining the general concept of remote sensing through a descriptive qualitative method. The descriptive qualitative approach is employed to provide an in-depth understanding of theoretical foundations and to synthesize knowledge from diverse sources. The literature reviewed consists of scientific journals indexed in SCOPUS, academic articles, and authoritative reference books, which serve as the primary basis for constructing the initial conceptual framework. By critically analyzing and comparing these sources, the study seeks to identify key principles, emerging trends, and theoretical perspectives that are relevant to the development and application of remote sensing in environmental studies and disaster management.

RESEARCH METHODS

The research process begins with an understanding of the concept of remote sensing, encompassing its definition, basic principles, various types, and applications. Furthermore, this study presents a case study that applies remote sensing technology. It also outlines the benefits of remote sensing in the context of environmental restoration and damage assessment. Finally, the study discusses the challenges encountered, such as data accuracy and resolution, data availability, weather conditions, and collaboration. The collected data are presented descriptively and concluded with general findings. The results of this process are then visualized in the form of a brainstorming diagram (Figure 1), which serves as an initial map for designing the structure of the discussion.

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

International Journal of Education, Vocational and Social Science
https://e-journal.citakonsulindo.or.id/index.php/IJEVSS
E-ISSN : 2963 4954
IJEVSS

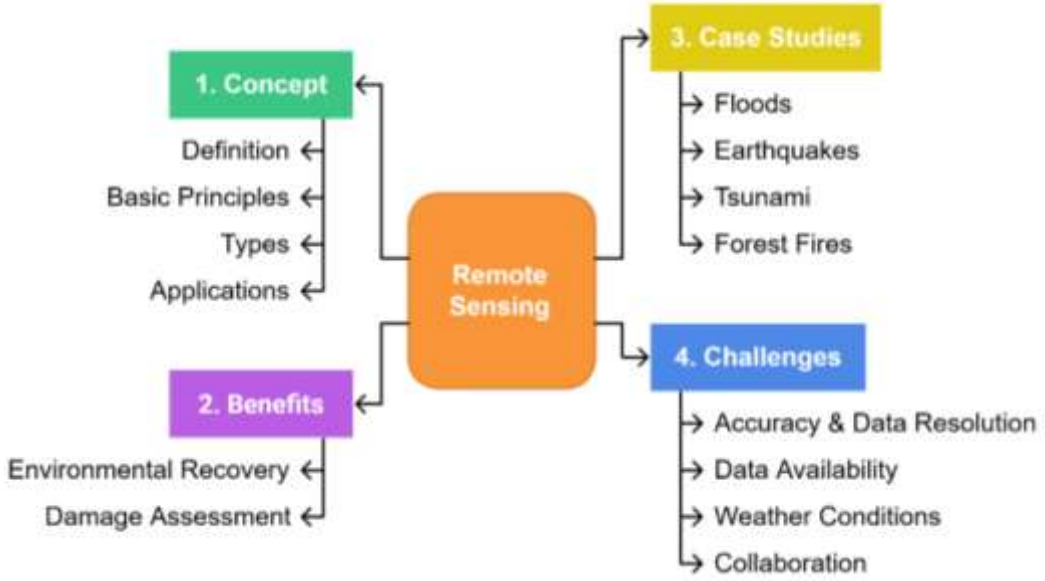


Figure 1. Brainstorming Diagram

DISCUSSION

Remote Sensing Concept

The technique for obtaining information about objects or phenomena on the Earth's surface without making direct contact is known as remote sensing techniques, or what is commonly called remote sensing. According to Moore GK (1979) in Roy et al. (2017), remote sensing is the process of measuring the physical characteristics of an object from a distance by utilizing reflected or emitted energy. Remote sensing technology can measure radiation emitted and reflected by objects, for example, satellites, radars, airplanes, or drones. The basic concept of remote sensing is divided into two, namely active sensing and passive sensing. The difference between the two lies in the use of light sources, where active sensing utilizes artificial light sources while passive sensing relies on natural light sources. Passive sensing that uses natural light, such as sunlight, is used to detect objects. An example is the Landsat satellite, which relies on sunlight reflected by the Earth's surface. In contrast, active sensing uses artificial light sources such as radar and lidar, which reflect or emit waves on objects and are captured by sensors. In general, remote sensing sensors operate at various wavelengths in the electromagnetic spectrum, including visible light, infrared, and microwaves. The working principle of remote sensing technology is to determine the differences in electromagnetic waves emitted, reflected, and absorbed, where this

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

technology operates in the visible wave band (0.4–0.7 mm), infrared (0.7–15 mm), and microwave (0.75–100 cm) in the electromagnetic spectrum (Huang et al., 2018). According to Gumma (2011), the wavelength used in remote sensing has a significant influence on the quality and type of information obtained. For example, the infrared spectrum is usually beneficial for detecting vegetation and soil moisture, while microwaves are often used in weather sensing because of their ability to penetrate clouds.

Remote sensing systems that we currently know include radar, lidar, satellites, and drones. Each of these remote sensing systems has its own characteristics and advantages, which allow its use in various types of applications. Radar (Radio Detection and Ranging) is a remote sensing technology that utilizes radio waves to detect and measure the distance and speed of objects by emitting electromagnetic waves and then receiving their reflections. Radar is helpful in various fields, including aviation and navigation. On aircraft, radar helps detect bad weather, such as cumulonimbus clouds (thick and dark clouds), which pilots can immediately avoid if they detect them. In addition, the weather radar owned by BMKG is also used to determine the type of cloud, wind speed, and direction, and to detect dangerous weather phenomena such as strong winds, tornadoes, storms, and other phenomena. Lidar (Light Detection and Ranging) is one of the remote sensing systems that is capable of producing very detailed digital terrain models and can show photographic features in low relief (Schindling & Gibbes, 2014). Lidar uses laser light to measure the distance between a sensor and an object on the earth's surface by sending a laser pulse to the surface and measuring the time it takes for the pulse to return to the sensor. The data produced by lidar is very accurate and detailed, so it is often used in topographic mapping, vegetation analysis, and natural resource management. One example of the application or use of lidar is forest mapping, which allows for the identification of tree structures and biomass measurements with a high degree of precision, which is very important for ecological research and forest management (Lim et al., 2003). In addition, Bhardwaj et al. (2016) applied lidar to research on the cryosphere, snow cover, polar ice and its atmosphere, alpine glaciers, and permafrost, demonstrating an increase in the number of cryosphere studies using lidar in recent years. This is due to the advantages of lidar compared to conventional passive remote sensors.

Satellites also play an important role in remote sensing. Satellites are devices launched into orbit around the Earth and equipped with various sensors to collect data from the surface. Satellites can detect multiple parameters such as surface temperature, humidity, sea level, and even air pollution levels. One example is the Himawari 8/9 satellite, which is used to monitor meteorological information with a broader coverage area and is commonly used by BMKG in

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

making weather predictions in the Indonesian region. The Himawari 8/9 satellite is a Japanese geostationary meteorological satellite equipped with optical sensors that have much higher radiometric, spectral, and spatial resolutions than previous satellites in geostationary orbit. This satellite can be used for numerical weather prediction, volcanic ash products, Aeolian dust products, disaster observation, and environmental monitoring (Bessho et al., 2016). Meanwhile, other sensing technologies, namely drones or what are known as uncrewed aircraft, are currently a popular choice in remote sensing due to technological developments that make them more flexible and easier to operate. Remote sensing using drones has many advantages, including low material and operational costs, flexible spatial and temporal resolution, and the ability to collect large amounts of data without risk to the aircraft crew (Tang & Shao, 2015). In addition, Zhang et al. (2021) stated that remote sensing products using drones can provide practical information over a reasonably large area and can be used to detect the impact of wind erosion on landforms and vegetation communities because of their low and efficient use costs.

Applications of remote sensing technology can be used in various fields, including environmental and urban planning. Currently, the use of satellites for remote sensing is increasingly used in disaster management to overcome the limitations of surveillance in a place (Giardina et al., 2024). In addition, environmental monitoring utilizes satellites and air sensors to track environmental changes, including areas affected by forest fires and illegal logging. Remote sensing is also helpful in agriculture by utilizing drone technology and its sensors. Farmers can monitor plant health and soil moisture, and even predict crop yields. In the field of mapping and urban planning, remote sensing is used to create topographic maps and land use analysis. Remote sensing also has essential applications in disaster mitigation, for example, by using satellites that allow monitoring of natural disasters such as floods, earthquakes, and forest fires. In the field of public health, remote sensing, such as satellites, can be used to monitor environmental conditions related to health, such as air pollution and the spread of disease, and map areas at high risk for certain diseases, so that appropriate intervention or prevention can be carried out. Thus, remote sensing can be utilized in various aspects or areas of life, not only useful for scientific research but also to improve the quality of life, health, and safety of the community environment.

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

The use of remote sensing is not only limited to scientific research but also has broad benefits in various sectors, especially in the analysis of environmental damage assessment and

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

post-disaster recovery. Post-disaster damage assessment is a very crucial initial step to ensure a sustainable recovery process (Singh, D.K., & Hoskere, V., 2023). Post-disaster damage assessment helps examine the extent to which the hazard and risk assessments that occur for planners are appropriate in supporting decision-making before a disaster occurs. These assessments are truly used as a basis for selecting locations and zoning (Mejri et al., 2017). In addition, sustainable post-disaster recovery must involve decision-making based on experience from previous events to prevent the re-emergence of various forms of vulnerability (Monteil et al., 2020). The post-disaster recovery process varies between communities depending on their respective levels of vulnerability (Contreras et al., 2016). The use of remote sensing data is essential in post-disaster damage assessment in certain situations, using geomatics techniques in disaster management operations (Calantropio et al., 2021). Geomatics techniques focus on validating new strategies that aim to quickly map and document diverse and complex environments in damaged areas (Calantropio et al., 2018).

Natural disasters often cause significant damage to local ecosystems, such as forests, agricultural land, and coastal areas. This can be seen by mapping the extent of the impact using remote sensing. Damage caused by forest and land fires has a significant impact on the quantity and quality of natural resources and ecosystems, which can reduce the diversity of flora and fauna that function as sources of germplasm, reduce soil quality, change hydrological functions, and contribute to climate change (Wasis et al., 2019). With remote sensing, damage caused by floods that can damage agricultural land and change river flow patterns can be detected by mapping water areas in the form of temporary puddles that occur during floods (Priyatna et al., 2023). Thus, this damage can be mapped accurately, making it easier for scientists to evaluate its impact on biodiversity and ecosystem function. Therefore, damage assessment must utilize change detection techniques that can observe an object at different times and identify changes (Romaniello et al., 2017). Furthermore, continuous monitoring using satellite imagery can help identify areas requiring restoration efforts and monitor the recovery process over time.

The application of remote sensing is handy for obtaining post-disaster area information, especially when other data is not available (Derakhshan et al., 2020). By using remote sensing technology, data obtained from satellites, drones, or airplanes can be used for visual observation from a specified height and broad area coverage in a short time. Another advantage of remote sensing is its ability to detect changes on the earth's surface due to disasters by observing differences in the condition of an object or area at various times, thereby helping to identify the impact of the disaster more quickly and efficiently than conventional methods. After a disaster,

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

such as an earthquake, flood, or tsunami, the damage mapping process becomes a crucial step to help determine the priority of aid and reconstruction efforts. Data obtained from remote sensing can provide a clear picture of the extent of damage, starting from infrastructure such as buildings, roads, and bridges, to the impact on agricultural land and the natural environment. Remote sensing imagery is needed in the detection and assessment of road damage using high resolution to find the causes of natural disasters and the necessary disaster relief efforts (J. Wang et al., 2015). The availability of high-resolution satellite data and aerial data creates new opportunities to monitor land cover and land use at a smaller scale (Chen et al., 2022). For example, the use of high-resolution satellite imagery, namely Synthetic Aperture Radar (SAR), can be used by researchers and emergency response teams to quickly identify collapsed or damaged buildings and assess the possibility of road access used to deliver rescue assistance. In addition to providing visual data on damage, remote sensing plays a role in mapping the most affected areas, making it easier to determine which locations are most likely to deliver aid and plan evacuations. Another example, post-flood event mapping utilizes remote sensing using a cloud platform to analyze areas that are still submerged in water and identify areas most vulnerable to subsequent flooding (Priyatna et al., 2023). In addition to damage to infrastructure, natural disasters can also cause significant damage to the environment, including ecosystems and natural resources. Thus, remote sensing can help scientists and policymakers in assessing environmental impacts in more detail. This remote sensing technology has been successfully applied in various fields, including classification and change detection. However, the process of processing remote sensing images involves several procedures before carrying out classification and change detection by looking at the methods to be applied (L. Ma et al., 2019).

Remote sensing imaging technology has made significant progress in recent decades (Aleissaee et al., 2023). Remote sensing is one of the most valuable technologies in assessing environmental damage, especially after natural disasters or destructive human activities. This technology provides accurate data on a large scale and provides continuous assessment of large areas, even to locations that are difficult to reach directly. Another benefit of remote sensing is the ability to quickly identify and map environmental changes, providing images, visuals, and quantitative data that help in decision-making, such as mitigation, rehabilitation, and conservation. Another benefit is that remote sensing can also be used to assess water and air quality after a disaster. By using satellite imagery, changes in water quality can be identified and monitored by analyzing changes in water surface color, water turbidity, pollution, and the presence or absence of heavy metal contamination. In addition, remote sensing can also be used

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

in monitoring ecosystems and animal habitats affected by disasters or human activities. Habitat damage can be detected by remote sensing, which makes it easier for researchers to assess the extent of biodiversity loss and ecosystem disturbance so that efforts to restore the ecosystem more effectively can be planned and carried out. In addition to disaster recovery, remote sensing also plays a crucial role in preventing further environmental damage by providing usable data and facilitating the anticipation of environmental threats. Remote sensing provides repeated serial data that is used in continuous monitoring over time, which is very important in assessing environmental recovery. Scientists and policymakers can use this repeated data to monitor the process of ecosystem repair and ensure that remedial measures are taken according to the plan. Thus, remote sensing not only helps in ensuring the success of long-term recovery efforts. Overall, remote sensing has made a significant contribution to the assessment of environmental damage. The ability to provide accurate, real-time, and continuous data makes it an essential tool in dealing with complex and dynamic environmental challenges. Remote sensing technology helps speed up the emergency response and recovery process and ensures that mitigation and remediation efforts can be carried out effectively.

Case Study of the Use of Remote Sensing in Post-Disaster Recovery for Environmental Damage Assessment

Remote sensing plays a vital role in the context of post-disaster recovery throughout the world. Indonesia, the largest archipelagic country in the world and located in the Ring of Fire, is particularly vulnerable to natural disasters due to the various natural disasters that occur there (Efendi et al., 2022). Natural disasters occur suddenly, causing extensive and unpredictable damage, so they become a serious threat to human safety and property security (Shafian, S.A., & Hu, D., 2024). According to Y. Ji et al. (2018), earthquakes and tsunamis are among the most dangerous disasters, capable of destroying human life and property. Natural disasters have a significant impact and pose a serious threat to large urban areas, necessitating an understanding and prediction of the changes that occur. This is important for evaluating vulnerability and resilience, as well as developing plans for evacuation, response, and preparation of disaster relief (Q. Wang & Taylor, 2016). With the ability to provide fast and accurate data, remote sensing provides an efficient solution for monitoring environmental conditions affected by disasters. Through several case studies, it is shown that sensing technology can be an important tool in assessing the impact of damage and supporting the recovery process. One example of the application of remote sensing technology in dealing with flood cases is a study conducted by

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

Rahman & Di (2020), which discusses the use of remote sensing to evaluate crop damage caused by floods. In their study, they stated that the most frequently used parameters in assessing damage are flood area, followed by rainfall intensity, depth, duration, and flow velocity. In addition, Rahman & Di (2020) also emphasized that there is a need to develop remote sensing options from satellites such as Sentinel-1 and Sentinel-2 and the Visible Infrared Imaging Radiometer Suite (VIIRS), which are very useful in accurate flood mapping and assessment of crop condition profiles and the availability of remote sensing data on a longer scale and period can be the basis for accurate assessment of crop damage at a local scale. Another study conducted by Lin et al. (2016) examined flood conditions in the United States by comparing the use of optical sensors from satellites and radar in assessing flood damage. The results of the study showed that radar sensors provide more detailed spatial information than sensors from satellites, and both optical sensors have an important role in assessing flood damage. Another study that discusses flooding in the Thai River Region using Synthetic Aperture Radar (SAR) imagery by Rakwatin et al. (2013) mapped flooded areas and estimated water volume in real time to support decision-making in flood control operations. In addition, the use of remote sensing is also seen in case studies of earthquakes related to post-disaster recovery, such as that conducted by M. Ji et al. (2018), who stated that earthquakes are the most destructive natural disasters, so that post-earthquake rescue and reconstruction planning is needed. In his research, he also stated that the use of satellite imagery gave good results in classifying collapsed and non-collapsed buildings in the case of the 2010 Haiti earthquake. On the other hand, Xu (2015) has conducted research on landslide inventory maps caused by earthquakes by utilizing remote sensing technology, namely satellite imagery and GIS. His research emphasizes the importance of developing objective and consistent methods for creating landslide inventory maps. According to Qing et al. (2022), the steps that need to be taken after an earthquake are to assess building damage immediately and accurately.

Other natural disasters, such as tsunamis, are also very crucial disasters and cause widespread damage, not only in one location but can also spread to other points. For example, the tsunami that occurred in the Indian Ocean in December 2004, which was the most devastating natural disaster ever recorded, caused widespread damage in several Asian and African countries. This disaster also caused enormous environmental damage, including the loss of mangrove forests, coastal erosion, and water pollution in coastal areas. With the latest advances in remote sensing technology and aerial image analysis in assessing environmental damage caused by tsunamis, information on tsunami-affected areas can be obtained more quickly and efficiently (Koshimura et al., 2020). In addition, the use of tsunami satellite imagery can map the most

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

affected areas, especially along the coastline. This can help identify areas eroded by water and those exposed to sediment and contamination due to the movement of tsunami water. Another example of a disaster is forest fires, which also have a significant impact on ecosystems, human health, and even climate change. As explained by Hua & Shao (2017), forest fires are a significant and increasing threat to human safety, wildlife habitats, regional economies, and global climate change. Forest fires, according to Neger et al. (2022), are a phenomenon that hurts the environment and society but also contributes to the natural dynamics of the ecosystem. For example, the forest fires in the Amazon in 2019 attracted much attention from the world, where the fires hit millions of hectares of tropical rainforest, known as the lungs of the world, causing enormous ecological and economic losses. By utilizing satellite imagery processing technology and its data, this problem can be overcome by assessing the impact of forest fires for post-fire selection. Another study on forest fires conducted by Rokhmatuloh et al. (2022) stated that the phenomenon of forest fires has become more frequent in recent years due to human activities, which ultimately affects the form of the forest and land cover in the Kalimantan region. His research used a rapid mapping method using Synthetic Aperture Radar (SAR) imagery. Thus, remote sensing technology plays a crucial role in accurately assessing forest damage through satellite data that can map burned areas widely and in detail. According to Arnett et al. (2015), remote sensing technology is a very suitable platform for assessing the level and impact of fires on various scales. In other words, remote sensing is a crucial tool for assessing environmental damage and a rapid technology for monitoring changes in real-time. This enables researchers and decision-makers to respond more effectively to post-disaster events and design strategies that accelerate the recovery of affected ecosystems and environments.

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

Remote sensing is a key technology that can be used in post-disaster recovery and post-disaster environmental damage assessment. Remote sensing data has increased rapidly along with technological advances (Y. Ma et al., 2015). Remote sensing devices are widely used to observe the planet inhabited by humans from various perspectives, making human life easier (Chi et al., 2016). In addition, remote sensing also has the potential to provide a very valuable complementary data source, both at local and global scales, as well as the development of sensors, methodologies, and data availability that can be used further by researchers and stakeholders to utilize this information in various fields (Palmer et al., 2015). However, the large amount of big

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

data also poses new scientific challenges, including in assessing uncertainty, managing large amounts of data, combining or collecting from various data sources, and the need to ensure consistency between various observations and existing data sets (AghaKouchak et al., 2015). Although sensing technology has great potential in supporting post-disaster recovery, its implementation in the field does not always run smoothly and faces various challenges. The challenges in using remote sensing for disaster recovery are very complex and have many obstacles. One of the challenges that arises is technical limitations. Technical limitations are related to data resolution, both spatially and temporally, which can later hinder the accuracy of the data produced. Spatial resolution is related to the extent to which the satellite can distinguish objects on the Earth's surface. Most satellites used for environmental monitoring have lower resolution. However, there are still satellites that have high resolution, such as WorldView-3, which is capable of achieving a resolution of 30 cm per pixel. For example, the Landsat satellite, which is often used for vegetation and land change observations, has a resolution of around 30 meters per pixel. This suggests that satellites may struggle to assess minor damage in detail, such as collapsed buildings or more specific damage to plants. In addition, temporal resolution refers to the satellite's ability to reach the same area at a specific time. Many satellites only pass over certain areas every few days or weeks, meaning they do not cover the entire area at any given time. In a post-disaster situation, the initial phase required is a rapid response that relies on data available only at specific time intervals, leading to delays in damage assessment and recovery. For example, the Sentinel-2 satellite from the Copernicus program has a repetition frequency of 5-10 days, so in some emergencies, the use of this satellite data does not cover the need to provide the required data quickly. However, currently, remote sensing technology has developed with the presence of new sensors that have high performance with better spatial, spectral, and temporal resolution (Huang et al., 2018). In addition to data resolution and availability, weather and atmospheric conditions pose challenges to the availability of this data, as they can impact the reception of data from remote sensing sensors. For example, optical satellites that use visual and infrared sensors to monitor the Earth's surface, such as Landsat and Sentinel, sometimes provide poor data when weather conditions, such as thick clouds, fog, or smoke, are present. In addition, disaster conditions that exacerbate these limitations, such as forest fires or storms, which frequently occur, hinder the use of satellite imagery in damage assessments. Consequently, the collected data is inconsistent and cannot provide timely insights for post-disaster recovery efforts. However, currently, some satellites that can operate in all types of weather conditions, namely the Synthetic Aperture Radar (SAR) satellite, detect the Earth's surface. This satellite is one of the

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

options used to map changes in surface shape with good spatial resolution over a large area to mark aspects of terrain movement and potentially dangerous processes (Strozzi et al., 2018). However, the resulting SAR data requires special interpretation using specific software, so not only software is needed, but also deeper technical skills to be able to process and interpret the results precisely and accurately. Thus, this limitation poses a challenge because the lengthy data processing process in the field necessitates immediate data production, which makes it challenging to utilize in supporting disaster damage recovery.

Another challenge that needs to be faced in the use of remote sensing is related to operational and logistical aspects. Access and use of satellite data require special skills, but in many post-disaster situations, human resources who have the competence to process and analyze remote sensing data are limited. This limitation of human resources is a problem because in many countries, especially developing countries or in remote areas, the facilities needed to receive, store, and process satellite data may not be available or inadequate. On the other hand, limited internet access is also a challenge, considering the importance of downloading and processing large amounts of satellite data. In disaster situations, when time is minimal and the available experts do not have adequate competence, delays in processing this data can have a significant impact on the effectiveness of the use of remote sensing. An equally important challenge is the issue of accessibility and ownership because most of the satellite data currently available is produced by government agencies such as NASA (for example, the Landsat program) or the European Space Agency (ESA) (for example, the Copernicus program), which are only available in limited quantities, even though they can be accessed for free. Meanwhile, high-resolution satellites operated by private companies, such as those from Maxar Technologies or Planet, are not easily accessible due to their high costs. This poses an obstacle for developing countries and non-governmental organizations seeking to obtain better data at a high price, given their limited budgets, and, consequently, it impacts post-disaster recovery. In addition to the high-cost issue, another obstacle is the regulatory and policy framework for accessing data. Specific data access policies apply to several countries that implement this because the data produced covers sensitive areas such as borders and military applications. Thus, international organizations or humanitarian aid agencies do not get permission to access data from specific areas, which is an obstacle to collecting data to support post-disaster recovery. This requires strong coordination and cooperation between various institutions, such as meteorological agencies, research institutions, and local and national governments in the provision, collection, and utilization of remote sensing data. On the other hand, the lack of communication and coordination between these institutions

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

can slow down the process of collecting and utilizing satellite data. For example, in the earthquake disaster that occurred in Haiti in 2010, the lack of coordination in the implementation of post-disaster recovery between institutions caused delays in response and damage evaluation, even though many international institutions helped in the disaster. Thus, the many challenges in the use of remote sensing to assist post-disaster recovery and damage assessment require improvements in various aspects of technology, infrastructure, technical skills, and cooperation both nationally and internationally, as well as innovations so that remote sensing can function optimally and make a significant contribution to disaster prevention and recovery.

CONCLUSIONS AND RECOMMENDATIONS

Post-disaster environmental damage assessment is currently assessed using sophisticated tools, namely remote sensing technology. This technology is a method used to obtain information about an object or phenomenon on the Earth's surface without making direct contact. The working principle involves emitting and reflecting electromagnetic radiation to the earth's surface using sensors mounted on platforms, such as satellites, radars, aircraft, or drones. In addition, this technology also produces real-time data collection that is obtained quickly and covers a wide area, so it is very suitable for use to assist the post-disaster recovery process quickly and accurately. Remote sensing utilizes sensors to detect changes in ecosystems resulting from natural disasters or human-induced disasters. Detection carried out by remote sensing can provide an overview of damage on a macro and micro scale to the affected environment. It can map the affected area and see the changes that occur due to the disaster. However, although remote sensing technology has many advantages and benefits, there are still many challenges that must be faced when applying it in the environment. One of the main challenges is the limitations related to the spatial and temporal resolution of the data produced. For example, not all satellites have good resolution, so low-resolution satellites allow for the detection of damage on a small scale that is less clear, such as in earthquake case studies, which require data on the number of building collapses in areas not covered by satellite data. In addition, limitations in the frequency of data collection occur when there are satellites that only pass over an area a few times a month, so the data needed may not be available, and this can slow down the rapid response needed for rapid and timely damage assessment. On the other hand, weather conditions are also a matter of great concern in remote sensing challenges. Certain weather conditions, such as thick clouds, fog, and smoke, can interfere with the quality of optical satellite imagery so that the resulting data is inaccurate and unavailable. However, radar satellites are currently available that can operate in

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

all weather conditions but require higher technical expertise and software in data collection and processing. Another significant challenge is the availability and accessibility of data, as not all remote sensing data can be accessed for free, particularly for data with higher resolutions that require substantial financial investment. In addition to costs, regulations related to ownership pose a challenge, as not all countries provide their data freely, particularly those with more detailed information. In addition, the availability of experts who are trained in processing and analyzing remote sensing data is minimal. Thus, strong coordination and cooperation are needed between various institutions, such as meteorological agencies, research institutions, and local and national governments in the provision, collection, and utilization of remote sensing data. Nevertheless, remote sensing remains a very valuable tool in post-disaster recovery because it helps speed up the emergency response process and ensures that mitigation and recovery efforts can be carried out more effectively.

To improve post-disaster recovery, it is recommended to use higher-resolution satellites and increase the frequency of data collection, as well as utilize drones for more accurate data details. The development of human resource capacity and analytical software should also be strengthened. Prioritize the use of radar satellites that can operate in all weather conditions and enhance coordination between relevant agencies. Policies that expand the accessibility of satellite data at affordable costs are needed, along with the integration of technologies such as GIS and AI to accelerate analysis and improve accuracy.

FURTHER STUDY

Future research should focus on integrating remote sensing with GIS, AI, and machine learning to improve the accuracy and efficiency of post-disaster assessments. The combined use of optical, radar, and UAV data also requires further exploration to enhance coverage and resolution. In addition, studies on data accessibility policies and capacity building are essential to strengthen technical expertise and institutional collaboration in disaster management.

REFERENCES

AghaKouchak, A., Farahmand, A., Melton, F. S., Teixeira, J., Anderson, M. C., Wardlow, B. D., & Hain, C. R. (2015). Remote sensing of drought: Progress, challenges and opportunities. In Reviews of Geophysics (Vol. 53, Issue 2). https://doi.org/10.1002/2014RG000456

Aleissaee, A. A., Kumar, A., Anwer, R. M., Khan, S., Cholakkal, H., Xia, G. S., & Khan, F. S. (2023). Transformers in Remote Sensing: A Survey. In Remote Sensing (Vol. 15, Issue 7).

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

https://doi.org/10.3390/rs15071860

Arnett, J. T. T. R., Coops, N. C., Daniels, L. D., & Falls, R. W. (2015). Detecting forest damage after a low-severity fire using remote sensing at multiple scales. International Journal of Applied Earth Observation and Geoinformation, 35(PB). https://doi.org/10.1016/j.jag.2014.09.013

Bessho, K., Date, K., Hayashi, M., Ikeda, A., Imai, T., Inoue, H., Kumagai, Y., Miyakawa, T., Murata, H., Ohno, T., Okuyama, A., Oyama, R., Sasaki, Y., Shimazu, Y., Shimoji, K., Sumida, Y., Suzuki, M., Taniguchi, H., Tsuchiyama, H., … Yoshida, R. (2016). An introduction to Himawari-8/9 — Japan's new-generation geostationary meteorological satellites. Journal of the Meteorological Society of Japan, 94(2). https://doi.org/10.2151/jmsj.2016-009

Bhardwaj, A., Sam, L., Bhardwaj, A., & Martín-Torres, F. J. (2016). LiDAR remote sensing of the cryosphere: Present applications and prospects. In Remote Sensing of Environment (Vol. 177). https://doi.org/10.1016/j.rse.2016.02.031

Calantropio, A., Chiabrando, F., Codastefano, M., & Bourke, E. (2021). DEEP LEARNING for AUTOMATIC BUILDING DAMAGE ASSESSMENT: APPLICATION in POST-DISASTER SCENARIOS USING UAV DATA. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 5(1). https://doi.org/10.5194/isprs-annals-V-1-2021-113-2021

Calantropio, A., Chiabrando, F., Sammartano, G., Spanò, A., & Losè, L. T. (2018). UAV strategies validation and remote sensing data for damage assessment in post-disaster scenarios. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42(3W4). https://doi.org/10.5194/isprs-archives-XLII-3-W4-121-2018

Chen, H., Qi, Z., & Shi, Z. (2022). Remote Sensing Image Change Detection with Transformers. IEEE Transactions on Geoscience and Remote Sensing, 60. https://doi.org/10.1109/TGRS.2021.3095166

Chi, M., Plaza, A., Benediktsson, J. A., Sun, Z., Shen, J., & Zhu, Y. (2016). Big Data for Remote Sensing: Challenges and Opportunities. Proceedings of the IEEE, 104(11). https://doi.org/10.1109/JPROC.2016.2598228

Contreras, D., Blaschke, T., Tiede, D., & Jilge, M. (2016). Monitoring recovery after earthquakes through the integration of remote sensing, GIS, and ground observations: The case of L'Aquila (Italy). Cartography and Geographic Information Science, 43(2). https://doi.org/10.1080/15230406.2015.1029520

Derakhshan, S., Cutter, S. L., & Wang, C. (2020). Remote sensing derived indices for tracking urban

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

land surface change in case of earthquake recovery. Remote Sensing, 12(5). https://doi.org/10.3390/rs12050895

Efendi, F., Indarwati, R., Aurizki, G. E., Susanti, I. A., & Maulana, A. E. F. (2022). Policymakers' perspectives on responding to the elderly's mental health needs in post-disaster situations. Journal of Public Health Research, 11(1). https://doi.org/10.4081/jphr.2021.2386

Ghaffarian, S., Farhadabad, A. R., & Kerle, N. (2020). Post-disaster recovery monitoring with google earth engine. Applied Sciences (Switzerland), 10(13). https://doi.org/10.3390/app10134574

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, Issue 11). https://doi.org/10.3390/rs10111760

Ghaffarian, S., Roy, D., Filatova, T., & Kerle, N. (2021). Agent-based modelling of post-disaster recovery with remote sensing data. International Journal of Disaster Risk Reduction, 60. https://doi.org/10.1016/j.ijdrr.2021.102285

Giardina, G., Macchiarulo, V., Foroughnia, F., Jones, J. N., Whitworth, M. R. Z., Voelker, B., Milillo, P., Penney, C., Adams, K., & Kijewski-Correa, T. (2024). Combining remote sensing techniques and field surveys for post-earthquake reconnaissance missions. Bulletin of Earthquake Engineering, 22(7). https://doi.org/10.1007/s10518-023-01716-9

Gumma, M. K. (2011). Mapping rice areas of South Asia using MODIS multitemporal data. Journal of Applied Remote Sensing, 5(1). https://doi.org/10.1117/1.3619838

Hua, L., & Shao, G. (2017). The progress of operational forest fire monitoring with infrared remote sensing. Journal of Forestry Research, 28(2). https://doi.org/10.1007/s11676-016-0361-8

Huang, Y., CHEN, Z. xin, YU, T., HUANG, X. zhi, & GU, X. fa. (2018). Agricultural remote sensing big data: Management and applications. In Journal of Integrative Agriculture (Vol. 17, Issue 9). https://doi.org/10.1016/S2095-3119(17)61859-8

Ji, M., Liu, L., & Buchroithner, M. (2018). Identifying collapsed buildings using post-earthquake satellite imagery and convolutional neural networks: A case study of the 2010 Haiti Earthquake. Remote Sensing, 10(11). https://doi.org/10.3390/rs10111689

Ji, Y., Sumantyo, J. T. S., Chua, M. Y., & Waqar, M. M. (2018). Earthquake/Tsunami damage assessment for urban areas using post-event PolSAR data. Remote Sensing, 10(7). https://doi.org/10.3390/rs10071088

Kharb, A., Bhandari, S., Moitinho de Almeida, M., Castro Delgado, R., Arcos González, P., & Tubeuf, S. (2022). Valuing Human Impact of Natural Disasters: A Review of Methods. In

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

International Journal of Environmental Research and Public Health (Vol. 19, Issue 18). https://doi.org/10.3390/ijerph191811486

Koshimura, S., Moya, L., Mas, E., & Bai, Y. (2020). Tsunami damage detection with remote sensing: A review. In Geosciences (Switzerland) (Vol. 10, Issue 5). https://doi.org/10.3390/geosciences10050177

Lim, K., Treitz, P., Wulder, M., St-Ongé, B., & Flood, M. (2003). LiDAR remote sensing of forest structure. Progress in Physical Geography, 27(1). https://doi.org/10.1191/0309133303pp360ra

Lin, L., Di, L., Yu, E. G., Kang, L., Shrestha, R., Rahman, M. S., Tang, J., Deng, M., Sun, Z., Zhang, C., & Hu, L. (2016). A review of remote sensing in flood assessment. 2016 5th International Conference on Agro-Geoinformatics, Agro-Geoinformatics 2016. https://doi.org/10.1109/Agro-Geoinformatics.2016.7577655

Lorenzo-Alonso, A., Utanda, Á., Aulló-Maestro, M. E., & Palacios, M. (2019). Earth observation actionable information supporting disaster risk reduction efforts in a sustainable development framework. Remote Sensing, 11(1). https://doi.org/10.3390/rs11010049

Ma, L., Liu, Y., Zhang, X., Ye, Y., Yin, G., & Johnson, B. A. (2019). Deep learning in remote sensing applications: A meta-analysis and review. In ISPRS Journal of Photogrammetry and Remote Sensing (Vol. 152). https://doi.org/10.1016/j.isprsjprs.2019.04.015

Ma, Y., Wu, H., Wang, L., Huang, B., Ranjan, R., Zomaya, A., & Jie, W. (2015). Remote sensing big data computing: Challenges and opportunities. Future Generation Computer Systems, 51. https://doi.org/10.1016/j.future.2014.10.029

McKnight, B., & Linnenluecke, M. K. (2019). Patterns of Firm Responses to Different Types of Natural Disasters. Business and Society, 58(4). https://doi.org/10.1177/0007650317698946

Mejri, O., Menoni, S., Matias, K., & Aminoltaheri, N. (2017). Crisis information to support spatial planning in post disaster recovery. International Journal of Disaster Risk Reduction, 22. https://doi.org/10.1016/j.ijdrr.2017.02.007

Monteil, C., Barclay, J., & Hicks, A. (2020). Remembering, Forgetting, and Absencing Disasters in the Post-disaster Recovery Process. International Journal of Disaster Risk Science, 11(3). https://doi.org/10.1007/s13753-020-00277-8

Neger, C., de Manzo Delgado, L. L., & Galicia Sarmiento, L. (2022). Geographical research on forest fires in Mexico: a bibliometric and territorial perspective. Investigaciones Geograficas, 108. https://doi.org/10.14350/rig.60488

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

Palmer, S. C. J., Kutser, T., & Hunter, P. D. (2015). Remote sensing of inland waters: Challenges, progress and future directions. In Remote Sensing of Environment (Vol. 157). https://doi.org/10.1016/j.rse.2014.09.021

Priyatna, M., Khomarudin, M. R., Wijaya, S. K., Yulianto, F., Nugroho, G., Afgatiani, P. M., Rarasati, A., & Hussein, M. A. (2023). Rapid Flood Mapping Using Statistical Sampling Threshold Based on Sentinel-1 Imagery in the Barito Watershed, South Kalimantan Province, Indonesia. Journal of Engineering and Technological Sciences, 55(1). https://doi.org/10.5614/j.eng.technol.sci.2023.55.1.10

Qing, Y., Ming, D., Wen, Q., Weng, Q., Xu, L., Chen, Y., Zhang, Y., & Zeng, B. (2022). Operational earthquake-induced building damage assessment using CNN-based direct remote sensing change detection on superpixel level. International Journal of Applied Earth Observation and Geoinformation, 112. https://doi.org/10.1016/j.jag.2022.102899

Rahman, M. S., & Di, L. (2020). A systematic review on case studies of remote-sensing-based flood crop loss assessment. In Agriculture (Switzerland) (Vol. 10, Issue 4). https://doi.org/10.3390/agriculture10040131

Rakwatin, P., Sansena, T., Marjang, N., & Rungsipanich, A. (2013). Using multi-temporal remote-sensing data to estimate 2011 flood area and volume over Chao Phraya River basin, Thailand. Remote Sensing Letters, 4(3). https://doi.org/10.1080/2150704X.2012.723833

Rokhmatuloh, Ardiansyah, Indratmoko, S., Riyanto, I., Margatama, L., & Arief, R. (2022). Burnt-Area Quick Mapping Method with Synthetic Aperture Radar Data. Applied Sciences, 12(23). https://doi.org/10.3390/app122311922

Romaniello, V., Piscini, A., Bignami, C., Anniballe, R., & Stramondo, S. (2017). Earthquake damage mapping by using remotely sensed data: the Haiti case study. Journal of Applied Remote Sensing, 11(1). https://doi.org/10.1117/1.jrs.11.016042

Roy, P. S., Behera, M. D., & Srivastav, S. K. (2017). Satellite Remote Sensing: Sensors, Applications and Techniques. In Proceedings of the National Academy of Sciences India Section A - Physical Sciences (Vol. 87, Issue 4). https://doi.org/10.1007/s40010-017-0428-8

Sambah, A. B., & Miura, F. (2016). Spatial data analysis and remote sensing for observing tsunami-inundated areas. International Journal of Remote Sensing, 37(9). https://doi.org/10.1080/01431161.2015.1136450

Schindling, J., & Gibbes, C. (2014). LiDAR as a tool for archaeological research: a case study. Archaeological and Anthropological Sciences, 6(4). https://doi.org/10.1007/s12520-014-0178-3

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

Shafian S.A., & Hu, D. (2024). Integrating Machine Learning and Remote Sensing in Disaster Management: A Decadal Review of Post-Disaster Building Damage Asessment. Buidings, 14, 2344. https://doi.org/10.3390/buildings14082344

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

Singh, D.K., & Hoskere, V. (2023). Posy Disaster Damage Assessment Using Ultra-High-Resolution Aerial Imagery with Semi-Supervised Transformers. Sensors. 23, 8235. https://doi.org/10.3390/s23198235

Strozzi, T., Klimeš, J., Frey, H., Caduff, R., Huggel, C., Wegmüller, U., & Rapre, A. C. (2018). Satellite SAR interferometry for the improved assessment of the state of activity of landslides: A case study from the Cordilleras of Peru. Remote Sensing of Environment, 217. https://doi.org/10.1016/j.rse.2018.08.014

Tang, L., & Shao, G. (2015). Drone remote sensing for forestry research and practices. In Journal of Forestry Research (Vol. 26, Issue 4). https://doi.org/10.1007/s11676-015-0088-y

Tonti, I., Lingua, A. M., Piccinini, F., Pierdicca, R., & Malinverni, E. S. (2023). Digitalization and Spatial Documentation of Post-Earthquake Temporary Housing in Central Italy: An Integrated Geomatic Approach Involving UAV and a GIS-Based System. Drones, 7(7). https://doi.org/10.3390/drones7070438

Wang, J., Qin, Q., Zhao, J., Ye, X., Feng, X., Qin, X., & Yang, X. (2015). Knowledge-based detection and assessment of damaged roads using post-disaster high-resolution remote sensing images. Remote Sensing, 7(4). https://doi.org/10.3390/rs70404948

Wang, Q., & Taylor, J. E. (2016). Patterns and limitations of urban human mobility resilience under the influence of multiple types of natural disasters. PLoS ONE, 11(1).

Wasis, B., Saharjo, B. H., & Putra, E. I. (2019). Impacts of peat fire on soil flora and fauna, soil properties and environmental damage in Riau province, Indonesia. Biodiversitas, 20(6). https://doi.org/10.13057/biodiv/d200639

Xu, C. (2015). Preparation of earthquake-triggered landslide inventory maps using remote sensing and GIS technologies: Principles and case studies. Geoscience Frontiers, 6(6). https://doi.org/10.1016/j.gsf.2014.03.004

Zhang, J., Guo, W., Zhou, B., & Okin, G. S. (2021). Drone-based remote sensing for research on wind erosion in drylands: Possible applications. Remote Sensing, 13(2). https://doi.org/10.3390/rs13020283

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License