Calamtiy
Calamity: A Journal of Disaster Technology and Engineering
Calamity 2(2): 70–86
ISSN 3025-4140

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Analysis of the impact of forest fires: Pre-wedding incident of Mount Bromo and its disaster risk

Mayabella Puspita Nugraha[1,*]
[1] *School of Environmental Science, Universitas Indonesia, Jakarta, 10430, Indonesia.*
*Correspondence: mayabella.nugrahaa@gmail.com

Received Date: December 15, 2024 Revised Date: January 31, 2025 Accepted Date: January 31, 2025

ABSTRACT

Background: Forests play a crucial role in sustaining the environment, economy, and society by acting as carbon sinks that help mitigate climate change and maintain ecosystem balance. However, forest fires remain a growing global concern, including Indonesia. One significant fire occurred in Bromo Tengger Semeru National Park (TNBTS) in 2023, sparked by human negligence during a pre-wedding photoshoot. The fire damaged 1,487 hectares of land and threatened local biodiversity and ecosystems. TNBTS is home to over 1,000 plant species and holds cultural significance for the Tengger Community, who depend on its resources for their livelihoods. The research examines the environmental, economic, and social impacts of fire, using a quantitative research approach. **Mentods:** The methodology uses quantitative analysis using Landsat 8 imagery to assess fire severity. The Delta Normalized Burn Ratio (dNBR) is used to assess fire damage, while vegetation density is analyzed using the Normalized Difference Vegetation Index (NDVI) to ensure data reliability. **Findings:** The fire caused significant environmental damage. Economically, the tourism sector was severely affected, with the park's closure for 13 days leading to an 80% drop in hotel occupancy, resulting in an estimated loss of IDR 89.76 billion. Socially, the Tengger people suffered, as the fire damaged sacred sites and disrupted their cultural practices. Also, it increases the stress and anxiety of society that depends on tourism and agriculture. Public concern about the incident underscored the importance of responsible behavior in national parks, this can be seen by Google Trend. **Conclusion:** Although signs of recovery are evident, the long-term ecological and economic impacts require continued assessment and mitigation efforts to ensure the sustainable future of TNBTS. **Novelty/Originality of this article:** This article offers a novel analysis of the Bromo Tengger Semeru National Park fire by integrating remote sensing data with environmental, economic, and social impacts, including the unique use of Google Trends to measure public concern.

KEYWORDS: biodiversity; Bromo Tengger Semeru; dNBR; forest fire; google trends; NDVI.

1. Introduction

Forests have a variety of environmental, social, and economic benefits. Forests play a vital role as carbon sinks, absorbing carbon dioxide from the atmosphere and reducing the impacts of global warming (Prăvălie et al., 2022). This carbon sequestration occurs above ground in tree biomass and below ground in root systems. Forests also play a vital role in maintaining the balance of fragile ecosystems by regulating rainfall and preventing soil erosion. The dense canopy and root systems of forests encourage high infiltration rates, allowing water to soak into the soil and contribute to a healthy hydrological cycle. In addition, forests are home to millions of species of animals and plants (Budiastuti et al., 2022). The Amazon Forest plays a vital role in maintaining the balance of the earth's ecosystem.

Cite This Article:
Nugraha, M. P. (2025). Analysis of the impact of forest fires: Pre-wedding incident of mount bromoand its disaster risk. *Calamity: A Journal of Disaster Technology and Engineering, 2*(2), 70-86. https://doi.org/10.61511/calamity.v2i2.2025.1508

The Amazon rainforest is the world's largest rainforest. Amazon is one of the most biodiverse places on earth. This rainforest harbors a diversity of life, including about 10% of the world's known mammal species and 15% of the world's known plant species. A single hectare of land in the Amazon rainforest can contain up to 300 tree species. This rich tapestry of life contributes to the Amazon's vital role in global oxygen production; scientists estimate it produces 20% of the planet's total oxygen supply (Poerwantika & Hatami, 2021). The Amazon rainforest plays a significant role in the Earth's systems by protecting global biodiversity (Prăvălie et al., 2022). Ironically, anthropocentrism is applied by communities around the Amazon Forest.

Anthropocentrism is a view that places humans at the center of everything. Humans are considered more important than other living things and the environment in this context. The anthropocentric approach often prioritizes human interests and needs in decision-making, including environmental issues. From this perspective, natural resources are considered valuable, especially if they are helpful to humans, which can result in environmental exploitation without regard to their impact on ecosystems and other species. In contrast, the ecocentric view emphasizes the importance of balance and interdependence between all living things and the environment (Bhakuni, 2021; Juráni, 2021).

Between 2001 and 2018, at least 5.5% of the remaining Amazon forest was degraded due to anthropocentric practices. This area reached 364,748 km^2, equivalent to 112% of the total forest deforested during the same period. Considering extreme drought data, the total degraded area increased to 2.5 million km^2, covering 38% of the remaining Amazon Forest. These data show how much human activity has affected the Amazon Forest and emphasize that degradation and deforestation are severe threats to this critical ecosystem (Lapola et al., 2019).

Indonesia has a long history of forest fires, with the average annual area affected by fires reaching 757,787.31 ha between 2014 and 2018. The most significant fire incident occurred in 2015, and in 2018 the area of forest burned was three times that of 2017. These fires are primarily caused by human activities, such as land clearing for plantations, but can also be influenced by natural factors such as El Nino and low rainfall. The impacts of these fires are extensive, including CO2 emissions, economic losses, health issues from haze, and decreased water quality. The government has implemented measures such as community fire care groups, monitoring technology, and legal actions, but gaps remain in education, impact assessment, and community involvement (Aminah et al., 2020).

One of the primary triggers of forest fires in Indonesia is the land-clearing process. The land-clearing process widely carried out in Indonesia is by burning forests (Rozani et al., 2023). This practice is used because it is seen as an easy and cost-effective way to prepare land (Mohammad et al., 2023; Morante-Carballo et al., 2022*)*. Forest and land fires are conditions where forests and land are hit by fire, resulting in forest and land damage that causes economic losses and environmental value. Forest and land fires often cause smoke disasters that can disrupt the activities and health of the surrounding community.

Based on data from the Ministry of Environment and Forestry, there was an increase in forest and land fires in 2014 and 2015, from 1.77 million Ha to 2.61 million Ha of forest and land burning in Indonesia. Then, in 2015-2024, 7,601,579.69 ha of forest and land were burned. Riau Province is one of the provinces in Indonesia that often experiences forest fires, either due to natural processes or human actions. Forest and land fires are recurring problems in Riau, with significant environmental, economic, and social consequences. The leading cause of these fires is land clearing for agriculture and plantations, especially for oil palm plantations, which often use the burn-and-slash method. This method involves cutting and burning vegetation to clear land before planting, which seems profitable in the short term but has devastating impacts in the long term (Yusuf et al., 2019).

Riau's vast peatland areas, which are highly flammable, especially during the dry season, further exacerbate the problem. Peatland fires burn at high intensity and can smolder underground for long periods, releasing large amounts of carbon dioxide and hazardous pollutants. Conversion of peatlands for agriculture through drainage increases

the risk of fire. Socioeconomic factors, such as poverty and limited access to resources, contribute to the continuation of slash-and-burn practices. Rapid population growth and migration also increase pressure on land resources, leading to more land clearing and increased fire risk. Weak government policy enforcement, including inadequate land management policies, unclear land tenure rights, and weak enforcement of land clearing and fire prevention regulations, also contribute to the recurrent fires in Riau (Wasis et al., 2019).

The impact of these fires harms three aspects of sustainability: environment, economy, and society. In the environmental aspect, fires cause deforestation, habitat loss, decreased biodiversity, land degradation, and air and water pollution. Peatland fires release large amounts of stored carbon, contributing to climate change. From 2014 to 2019, Riau's forest area decreased significantly, with deforestation reaching 3,500,637 hectares in 2019. Fires destroy flora and fauna, which disrupts the balance of the ecosystem.

Economically, Riau experienced a loss of timber resources, decreased agricultural productivity, and disruption to industries such as tourism, transportation, and manufacturing due to fires. Socially, the fires caused public health problems due to air pollution, community displacement, and loss of cultural heritage. Air pollution leads to respiratory problems and other health issues, predominantly affecting vulnerable groups (Mustofa et al., 2022; Siregar et al., 2022).

Forest fires occur in various locations in Indonesia, not only in Riau Province. Bromo Tengger Semeru National Park (TNBTS), one of 55 national parks in Indonesia, has experienced a fire incident due to human negligence. This research will focus on the fire that occurred in 2023 in the Mount Bromo area.

Geographically, TNBTS is located between 7°54'–8°13' LS and 112°51'–113°04' BT, covering administrative areas in 4 districts: Malang, Lumajang, Probolinggo, and Pasuruan. The area of TNBTS reaches 50,276.60 hectares and is managed by the Bromo Tengger Semeru National Park Center (BBTNBTS). With a height between 750 to 3,676 meters above sea level, this area has the highest peak on Java Island, Mount Semeru (Hadiwijoyo, 2023).

Bromo Tengger Semeru National Park (TNBTS) is an essential national park in Indonesia. TNBTS is in the province of East Java and is known for its high biodiversity and unique natural scenery. The park encompasses various ecosystems, namely montane forest (mountain forest), volcanic crater, savanna (grassland), and caldera (sea of sand), making it a haven for various species of plants and animals (Aini & Sukojo, 2016; Ummah et al., 2024).

TNBTS has biodiversity, including more than 1,000 plant species, including 226 orchid species, and a variety of herpetofauna, including reptiles and amphibians. The variety of topography and vegetation in this national park contributes to the richness of species, providing an environmental mosaic that can be inhabited by a variety of species (Putri et al., 2024).

TNBTS also has high cultural and economic value. The national park is home to the Tengger people, an indigenous community whose culture and traditions are deeply tied to the natural environment. They depend on the park's resources for their livelihoods and play a vital role in maintaining ecological balance. In addition, tourism is an essential aspect of TNBTS, attracting domestic and international visitors to its stunning natural beauty, unique landscapes, and cultural experiences. Revenue generated from tourism contributes significantly to the local economy and employs the people living in and around the park (Haliim, 2018).

However, TNBTS faces serious threats, especially from human-caused forest fires. The Mount Bromo incident in 2023 was a severe case of environmental damage due to human negligence, resulting in significant financial losses and social problems. The incident occurred at the Teletubbies Hill tourist attraction, located within the Bromo Tengger Semeru National Park, in September 2023 (Ummah et al., 2024).

The fire was sparked using flares during a pre-wedding photoshoot. The photography team brought five flares, four of which were successfully lit. However, the fifth flare was damaged and exploded, causing the fire to spread rapidly to the dry grass in the savannah.

The couple had only purchased tickets online for regular visitors and had yet to obtain the necessary permit, known as Simaksi, for commercial activities inside the national park. This was a deliberate violation to avoid higher fees, and the detailed information required for Simaksi (Cristiana, 2024).

The fire caused damage to approximately 1,487 hectares of land, with estimated material losses of 5.4 billion Rupiah. This incident has substantially impacted the Mount Bromo area's ecology, economy, and society. This damage resulted in a significant loss of biodiversity and fauna, affecting various plant and animal species, including endemic and endangered ones. Due to this fire, the Edelweiss flower and the Javan Langur are threatened with extinction. The fire destroyed the existing flora and fauna and posed a long-term threat to the sustainability and quality of natural resources, impacting the entire ecosystem's balance. Not only did it harm environmental aspects, but it also impacted economic and social aspects in the TNBTS area.

The economic impact of the fires has also been profound, especially on the local tourism industry, which is a vital source of income for the community. The closure of TNBTS for 13 days resulted in an 80% drop in hotel occupancy, causing significant losses for businesses that rely on tourism. Local businesses such as car rentals, restaurants, and souvenir shops were hit particularly hard (Suhardono et al., 2024). The loss of non-tax state revenues exacerbated this economic impact and affected the national economy. Total economic losses are estimated at IDR 89.76 billion, which includes lost tourism revenue, firefighting costs, and ecosystem restoration costs (Rozani et al., 2023).

In addition to the immediate environmental and economic damage, fires have social and public health implications. Deteriorating air quality due to smoke and heat poses respiratory health risks to residents. The fires also negatively impact nearby agriculture, threatening food security and livelihoods. The incidents also cause psychological stress among communities, increasing anxiety over economic losses and uncertainty about the future.

This incident highlights the complex relationship between human actions and environmental consequences. Seemingly trivial activities, such as using flares for photography, can have disastrous consequences for fragile ecosystems. It highlights the need for stricter regulation, better enforcement, and increased public awareness of responsible behavior in national parks. Protecting Indonesia's natural heritage requires a proactive approach that involves collaboration between authorities, communities, and visitors.

The importance of enforcing a strong regulatory legal framework to protect the natural resources of TNBTS, referring to Indonesian laws that focus on environmental protection and conservation, such as Law No. 5 of 1990 on Conservation of Biological Natural Resources and Ecosystems and Law No. 41 of 1999 on Forestry. These laws outline the responsibilities of the national park authority, BB-TNBTS, in managing and maintaining the park and regulating activities within the park boundaries. However, there are challenges in enforcing these laws and calls for stronger measures to prevent illegal activities and promote responsible behavior, especially tourism-related ones. The 2023 fires are a stark reminder of the need to strengthen law enforcement and raise awareness of the importance of protecting TNBTS's unique and valuable ecosystems. This research aims to analyze the impact and recovery review on the environment, economy, and society from the fire incident in Bromo Tengger Semeru National Park after the incident that occurred during the pre-wedding.

2. Methods

2.1 Time and location of research

The research was conducted in Bromo Tengger Semeru National Park, East Java Province, from October–December 2024. The research location is presented in Fig. 1.

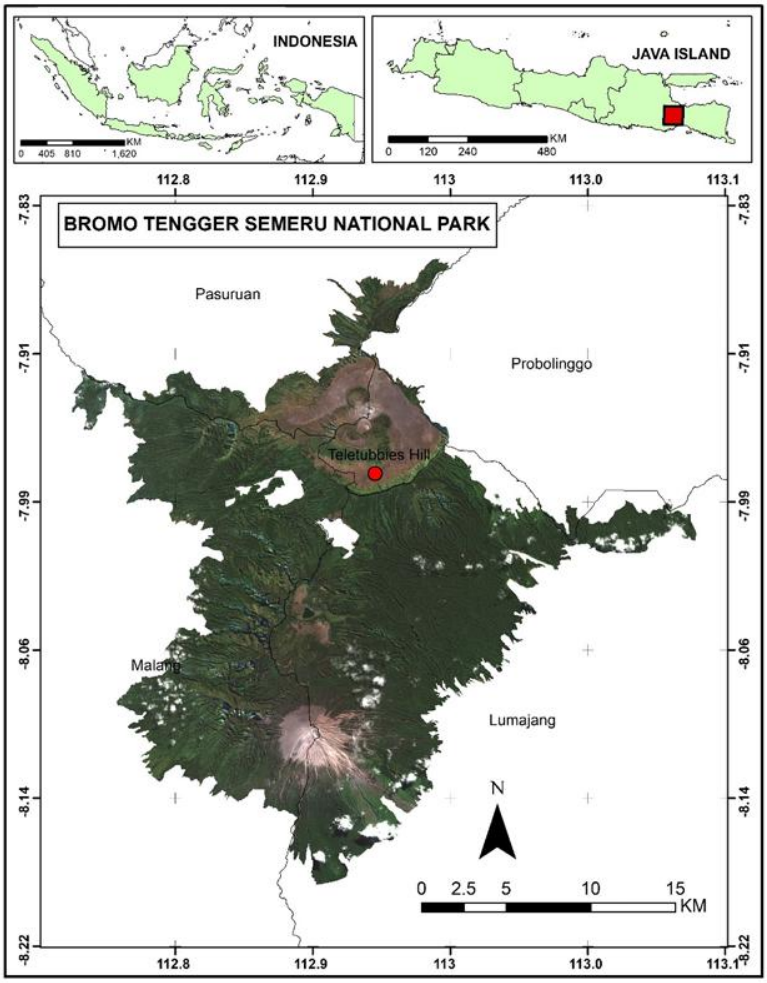

Fig. 1. Research Location
(Suhardono et al., 2024)

2.2 Descriptive analysis

The research method used in this research is a descriptive analysis method. The descriptive analysis method describes the condition of the area before, during, and after the fire in Bromo Tengger Semeru National Park. Secondary data collection was carried out using Landsat 8 satellite imagery. This imagery was chosen because of its accessibility, high spatial resolution, and broad spectral range (Aini & Sukojo, 2016; Ibrahim et al., 2024). This analysis uses the Delta Normalized Burn Ratio (dNBR), a technique that can assess the severity of a fire by comparing conditions before and after the fire, dNBR values, obtained from specific spectral bands and calculated using established formulas, are categorized into severity levels according to the United States Geological Survey (USGS) criteria (Giddey et al., 2022). After analyzing the severity level of forest fire, the density of vegetation before, during, and after the wildfire needs to be analyzed to visualize the difference in density of vegetation at three different times. The tool that is used is the Normalized Difference Vegetation Index (NDVI) (Li et al., 2021; Liu et al., 2022).

Besides, this research also considers the effect on social (local, national, and international) by seeing Google Trends. Google Trends is a tool that allows users to explore search data to see how frequently specific queries are made on the Google search engine over time. This tool provides a visual representation of the interest in particular keywords and topics, comparing them across different geographical locations and time frames. Google Trends normalizes search data to make comparisons between terms easier, using a scale from 0 to 100 to represent the relative popularity of a search term.

The NDVI index serves as an indicator of vegetation greenness. NDVI is commonly used to characterize plant health, biomass, and water content. This tool helps quantify the density and greenness of vegetation based on the difference in reflectance between the near-infrared and red bands of the electromagnetic spectrum (Lee et al., 2024; Li et al., 2021). NDVI is calculated by taking the ratio of NIR to red, as described in Equation 1. This index is commonly employed in research to detect burn areas due to its reliable results (Morante-Carballo et al., 2022).

$$NDVI = \frac{\text{NIR}-\text{RED}}{\text{NIR}+\text{RED}} \quad \text{(Eq. 1)}$$

The NBR index is another commonly used tool for fire assessments. Develop the Landsat 8 OLI index, which incorporates NIR and SWIR data. This index is suggested as the standard for evaluating burn severity in medium to large fires (Ibrahim et al., 2024). Despite its usefulness, the NBR index has limitations in detecting and mapping burned areas. It may struggle to differentiate between burned and unburned vegetation, especially when fires occur during the dry season, leaving little green vegetation. In such situations, alternative methods like TIR imaging might be more effective for identifying and mapping burned areas.

The effectiveness of different spectral bands and indices in detecting burned areas can also be influenced by factors such as vegetation type, regrowth rates, and the timing of the fire. Moreover, cloud cover and shadows can interfere with the observation of burned areas. Another drawback of NBR is its sensitivity to burn age; as burn scars age, NBR values decrease, which can complicate the accurate mapping of older burns. In these cases, remote sensing methods like visible/near-infrared (VNIR) imaging may provide better results for detecting and mapping older burn scars (Suwanprasit & Shahnawaz, 2024). The equations to calculate NBR and dNBR are described in Equation 2 and Equation 3 respectively.

$$\text{e}NBR = \frac{\text{NIR}-\text{SWIR2}}{\text{NIR}+\text{SWIR2}} \quad \text{(Eq. 2)}$$

$$dNBR = (prefire\ NBR) - (postfire\ NBR) \quad \text{(Eq. 3)}$$

Burn severity maps were created by identifying fire-affected areas where subtle changes in vegetation phenology were detected. The pre-fire image was taken 4 days before the fire, while the post-fire image was taken a year later. It was assumed that most of the fire's impact on the land surface would be visible within one week. Given this, it was anticipated that any changes in the forest ecosystem's phenology within a week would be noticeable unless influenced by other disturbances (e.g., fire). The differences between pre-fire, during-fire, and post-fire imagery reflect the extent of the changes caused by the fire. As mentioned earlier, the fire occurred from September 6th-14th 2023, with post-fire imagery captured from November 15th-19th 2024. Since the period between the pre-and during-fire imagery was only a week, any significant changes in vegetation phenology in the research area could be attributed to the fire. Burn severity was classified as high, low, or unburned based on the burn spectral indices (Ibrahim et al., 2024). The severity of the burn areas and the severity density of vegetation are calculated using a raster calculator in ArcMap.

The initial stage of this research began with quantitative analysis to provide a precise visualization and measurement of the impact of fire on the landscape. To enrich the quantitative dimension, this research uses Google Trends data to measure public interest and reactions related to fires. This descriptive data analysis provides insight into the social and economic implications of the incident, providing a broader context for understanding its significance.

The diverse data collected was systematically analyzed through thematic coding and grouping, focusing on crucial aspects such as the chronology of the fire, its underlying causes, and its environmental impacts. Triangulation, a technique involving cross-

referencing information from multiple sources, was used to ensure the reliability and validity of the research findings. Furthermore, a comprehensive literature review was conducted to provide a broader context, placing the specific incident within the broader global challenges and concerns related to forest fires and conservation efforts. This multi-level approach, integrating quantitative data analysis with quantitative data, ensured a robust understanding and multifaceted impact of the Bromo incident.

3. Results and Discussion

3.1 Environmental impact

The forest fire at Mount Bromo has had a wide range of environmental impacts, significantly affecting the region's natural resources and ecological balance. The fire destroyed a significant amount of land, with estimates ranging from 50 hectares to 504 hectares, and even up to 1,487 hectares when considering the accumulation of multiple fire incidents in the area (Uhai et al., 2024). This extensive land damage has led to severe disruption of the unique ecosystems within the national park, impacting its biodiversity and conservation efforts. The destruction of vegetation and habitats poses a long-term threat to the region's ecological health.

Beyond the immediate devastation, the Bromo fire has caused significant environmental degradation, threatening the sustainability and quality of natural resources. The fires have also affected the air quality due to smoke and high temperatures, which can lead to respiratory issues and other health problems for local populations. The release of pollutants, such as carbon dioxide, carbon monoxide, and particulate matter, into the air further compounds the negative environmental effects. Additionally, a clean water crisis has emerged in nearby villages due to burned water pipes, impacting approximately 600 people or 210 families, and the fires have led to erosion at a depth of 5-10cm (Suhardono et al., 2024).

The long-term consequences of the fire include potential disruptions to the ecosystem balance and the regional economy. The loss of flora and fauna, combined with altered natural processes, has the potential to affect sectors reliant on natural resources. The fires damaged important flora, such as Edelweiss flowers and Malelo grass, which reduced plant diversity and affected habitats and food sources for various animal species, threatening animal diversity, such as the Javan Hawk-eagle and Javan Langur. The continuity and availability of these resources are also threatened, requiring a reassessment of conservation and utilization strategies. The incident serves as a stark reminder of the vulnerability of forest ecosystems to human-induced disruptions, highlighting the need for a comprehensive understanding of these vulnerabilities and robust preventative measures.

3.1.1 Analysis of satellite imagery results and delta normalized burn ratio

Satellite imagery captured during the time of the fire revealed a stark transformation in the Bromo area. The region, which was usually lush and green, had turned a blackish-brown color, indicating the severity and extent of the fire. The darkened landscape clearly showed the areas that had been scorched, painting a vivid picture of the fire's impact on the environment.

Remarkably, just two months after the fire, the satellite images show a different view. The once-blackened areas began to show signs of recovery, with green hues returning to the landscape. This rapid change was captured in updated satellite images, which showed the previously blackish-brown areas transitioning to blue. The blue coloration in the imagery indicated a significant increase in land cover by plants, suggesting that vegetation was rebounding, and the ecosystem was beginning to heal.

This recovery highlights the resilience of the natural environment in the Bromo area. The return of greenery in a short time after such a devastating fire is a testament to the regenerative capabilities of the local flora. It also underscores the importance of continuous

monitoring through satellite imagery, which provides valuable data on environmental changes and recovery processes. The ability to visualize the progression from destruction to renewal offers hope and insight into the dynamics of ecological restoration.

Remote sensing, utilizing satellite imagery and spectral indices, is crucial for understanding the impact of fires and subsequent vegetation recovery, as seen in the Bromo region. The color changes observed in satellite images reflect significant ecological changes caused by fire and the following recovery processes. Immediately after a fire, satellite images show a blackish-brown color, indicating a burn scar, due to the presence of charred materials and ash that absorb most visible light. This is related to spectral changes, including a decrease in near-infrared (NIR) reflectance due to vegetation loss and an increase in shortwave-infrared (SWIR) reflectance from reduced moisture and exposed soil. Indices such as the Burned Area Index (BAI), Normalized Burn Ratio (NBR), and delta Normalized Burn Ratio (dNBR) are used to quantify these changes, by highlighting the charcoal signal and measuring spectral differences before and after the fire. The dNBR is particularly useful for calculating the magnitude of the fire impact by measuring the difference between pre-fire and post-fire NBR values.

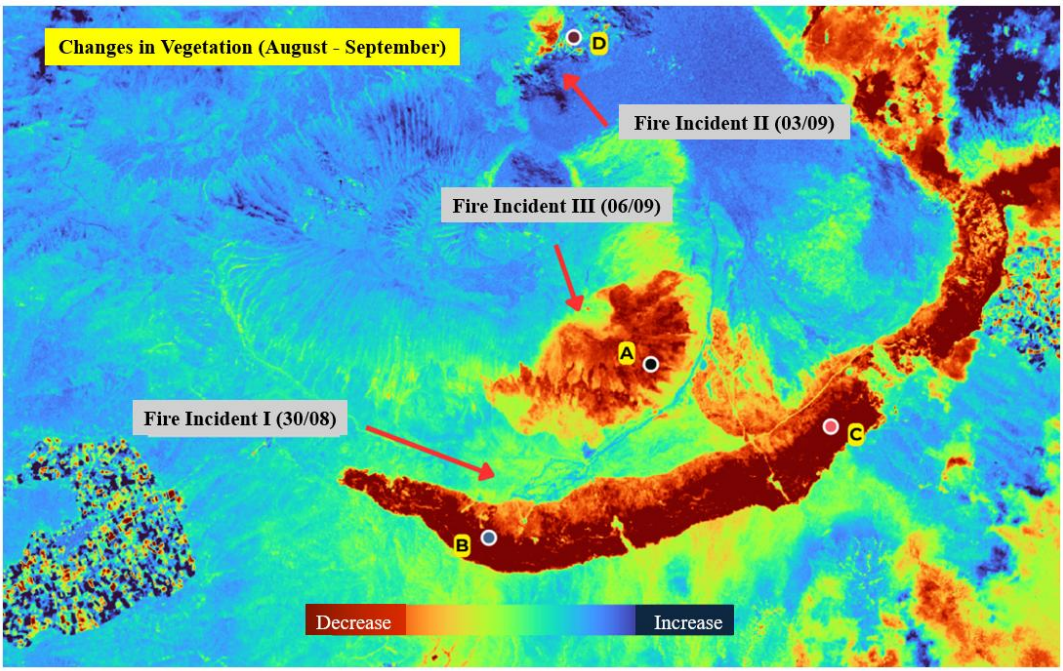

Fig. 2. Phases during the fire forest in Bromo Tengger Semeru National Park (GISACT, 2023)

From Fig. 2, the use of remote sensing satellite technology enables forest and land monitoring in near real-time, with wide area coverage and the ability to collect data from a distance. This approach was applied in observing the Bromo fire incident that occurred in September. Based on the Sentinel-2 satellite imagery we used, a visual change in color can be seen in the Bromo area, which turned brownish-black in the image dated September 7, 2023. This color change indicates that a fire had occurred in the area.

The map (Fig. 3) pinpoints three major fire incidents—Fire Incident I on August 30th, Fire Incident II on September 3rd, and Fire Incident III on September 6th—along with marked observation points labeled A through D. The darkest red areas, particularly concentrated around the caldera and the southern section of the park (near Point B), show significant vegetation loss, indicating areas most affected by the fire. In contrast, some regions in green to blue tones, especially further from the fire points, show signs of vegetation recovery. This spatial analysis, derived from remote sensing data, effectively captures the burn severity and early recovery of vegetation, helping assess the ecological impact and regeneration process following the Bromo fire events.

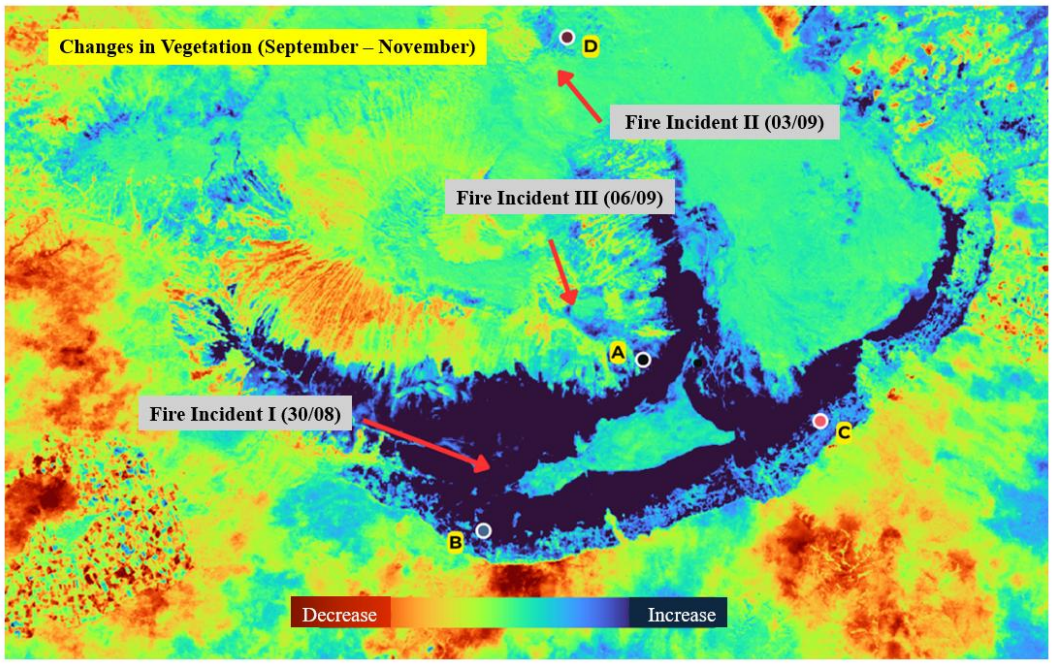

Fig. 3. Phases recovery after fire forest in Bromo Tengger Semeru National Park (GISACT, 2023)

3.1.2 Analysis of normalized difference vegetation index

Imagery from Landsat 8, provided by the United States Geological Survey (USGS), is meticulously analyzed using the Normalized Difference Vegetation Index (NDVI). This sophisticated analysis is performed utilizing a raster calculator in ArcMap, a powerful Geographic Information System (GIS) tool that allows for precise computation and visualization of vegetation changes over time. The NDVI is a crucial index that measures and monitors plant health by comparing the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs).

In this research, the imagery is assessed at three critical stages: pre-fire, during the fire, and post-fire. This temporal analysis provides a comprehensive view of how the fire impacted the vegetation over time. The NDVI values are calculated for each of these stages, offering a clear picture of the vegetation's health and coverage before, during, and after the fire.

During the pre-fire period, the area is characterized by dense, healthy vegetation, as indicated by high NDVI values. However, during the fire, there is a marked increase in areas with no vegetation and low vegetation cover. This significant change is captured in the imagery, highlighting the immediate and devastating impact of the fire on the forested areas. The fire's intensity and spread are evident from the expanded zones of barren and low vegetation.

In stark contrast, the regions that once exhibited high vegetation density before the fire experienced a drastic reduction. These areas, which were once lush and thriving, transformed into zones characterized by low to slightly low vegetation cover. The NDVI values during the fire period reflect this dramatic shift, with previously green, healthy areas now appearing in shades that indicate reduced plant health and cover.

Post-fire imagery reveals the beginnings of recovery, although the landscape remains significantly altered. The NDVI values start to show some improvement as vegetation begins to regrow, but the areas of high vegetation have not yet returned to their pre-fire state. This stage is crucial for understanding the resilience of the ecosystem and the initial stages of natural regeneration.

By comparing NDVI values across these three stages, the extent of the fire's impact on the vegetation cover becomes clear. The substantial decrease in high vegetation areas

underscores the fire's severity, while the increased barren and low vegetation zones indicate significant ecological disturbance. This detailed analysis highlights the value of NDVI and satellite imagery in monitoring and understanding the environmental impacts of wildfires.

The temporal analysis using NDVI provides essential insights into the dynamics of vegetation change caused by wildfires. It allows researchers, ecologists, and land managers to visualize and quantify the extent of damage, aiding in the development of effective restoration and management strategies. This approach underscores the importance of satellite imagery and advanced GIS tools in environmental monitoring and ecological research.

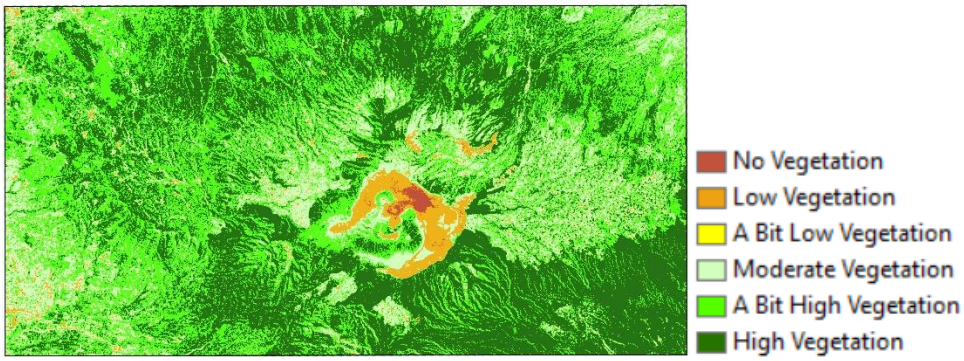

Fig. 4. The Density of Vegetation in Bromo Tengger Semeru National Park Before Fire Forest (September 2nd of 2023)

Based on Fig. 4, illustrates the vegetation density in Bromo Tengger Semeru National Park prior to the forest fire that occurred on September 2nd, 2023. Based on the color legend, the brown areas indicate the absence of vegetation. The orange and yellow areas represent regions with low to slightly low vegetation density. Meanwhile, the light green to dark green areas reflects moderate to high levels of vegetation density.

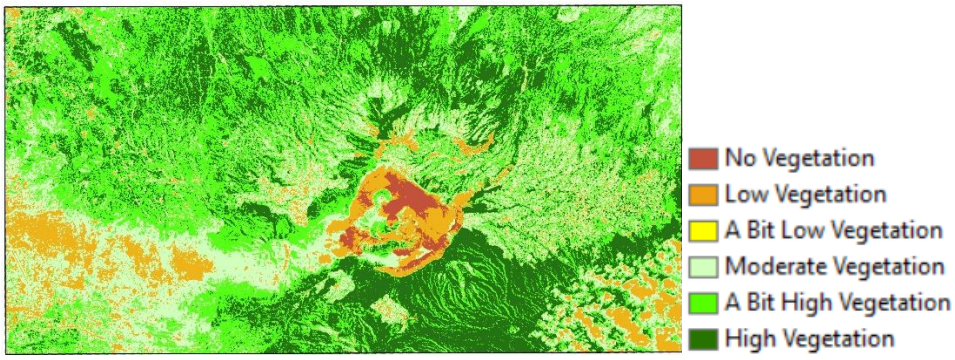

Fig. 5. The Density of Vegetation in Bromo Tengger Semeru National Park During Fire Forest (September 10th-18th of 2023)

Fig. 5 illustrates the vegetation density in Bromo Tengger Semeru National Park during the forest fire event, which occurred between September 10th and 18th, 2023. Based on the color legend, the brown areas indicate zones with no vegetation. The orange and yellow areas signify regions with low to slightly low vegetation density. The light green to dark green areas represent moderate to high vegetation density.

Fig. 6 shows the vegetation density in Bromo Tengger Semeru National Park after the forest fire, during the period of November 15th to 19th, 2024. According to the color legend, the brown areas represent zones with no vegetation, while the orange and yellow regions indicate areas with low to slightly low vegetation density. Meanwhile, light green to dark green areas signify moderate to high vegetation coverage.

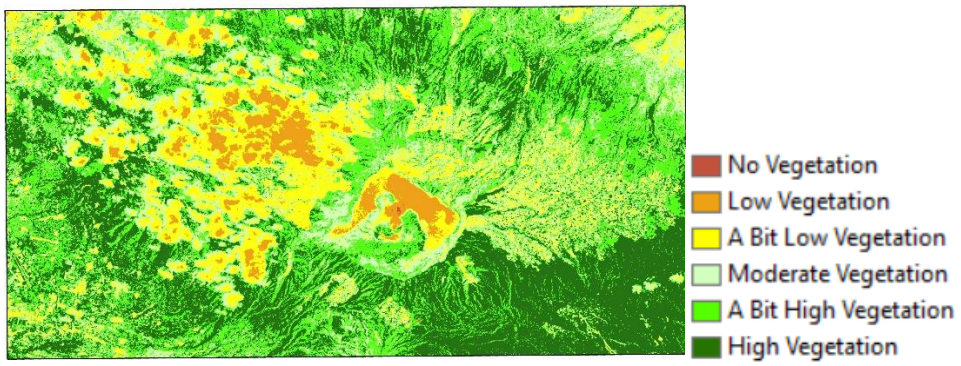

Fig. 6. The Density of Vegetation in Bromo Tengger Semeru National Park After Fire Forest (November 15th-19th of 2024)

3.1.3 Economic impact

The fire in Bromo Tengger Semeru National Park in September 2023, caused by a pre-wedding photo shoot flare, significantly impacted local businesses, especially in the tourism sector. The park's closure led to a decline in tourism activity, with hotel occupancy rates dropping by up to 80% due to cancellations. Accommodation businesses, food stalls, and souvenir shops suffered significant losses, while demand for guide services also decreased, impacting their livelihoods. Economic losses were estimated at IDR 89.76 billion (around USD 377,000) (Suhardono et al., 2024).

The jeep rental business, which relies heavily on park access, has drastically declined as thousands of jeeps sit idle. In addition to the immediate impacts, the fires raise concerns about long-term economic sustainability, with potential adverse effects on the ecosystem and Mount Bromo's reputation as a tourist destination. The incident highlights the vulnerability of local businesses to environmental incidents. Comprehensive recovery efforts, including ecosystem rehabilitation and rebuilding the area's reputation, are needed to mitigate the long-term economic impacts (Ummah et al., 2024).

Visitors to TNBTS have declined since the major fire in 2023; until 2024, the arrival of local and foreign tourists only met 40-60% of the total quota prepared. To overcome the decline in tourists, it is necessary to strengthen publications and promotions to convince potential tourists who will visit this national park located in East Java. Through social media, various parties can promote that TNBTS is ready to welcome tourists back by offering natural beauty and safety during their visit (Uhai et al., 2024).

3.1.4 Social impact

The forest fire at Mount Bromo has had extensive social impacts, disrupting the lives and livelihoods of the surrounding communities. The social disruption caused by the fire extends to the community's social functions, particularly for businesses and tourism managers. People working in the area have lost their ability to earn income due to the closure of the park. The incident has also led to increased stress and anxiety, particularly among those dependent on tourism and agriculture.

The fire has affected not only their economic stability but also their access to basic resources like clean water, adding to their burden. The long-term social impacts include the emotional distress caused by the disaster and the challenge of restoring their communities (Rozani et al., 2023). The society that gets the biggest impact is the Tengger people. Tengger community are the indigenous people of Bromo Tengger Semeru National Park (TNBTS). The lives of this community are highly dependent on the resources in the national park area because they live in villages located within the national park area. The majority of the Tengger community work background is as farmers. The destruction of the TNBTS area due to fires not only eliminates economic benefits, but the destruction of nature indicates the

destruction of sacred sites in the traditional areas of the Tengger community, thus eroding their identity (Halim, 2018).

3.1.4.1 Analysis results from google trends

In September 2023, Google Trends data revealed a significant rise in search traffic related to the Mount Bromo wildfire, reflecting widespread public interest and concern. The wildfire, which was triggered by a pre-wedding photo shoot, drew considerable attention and resulted in a marked spike in searches for Mount Bromo. This surge in interest underscores the heightened public awareness and anxiety during this period, as people sought to understand the unfolding situation.

The increase in search activity was particularly evident around the time of the incident. As news of the wildfire spread, people turned to Google to find information on the cause, effects, and updates on the blaze. This behavior highlights the role of search engines as a primary source of information during emergencies. The peak in search traffic corresponded with the days immediately following the fire, illustrating the public's swift and intense reaction to the emergency.

Regions close to Mount Bromo, which is East Java, exhibited especially high search interest. However, the heightened interest likely extended beyond local areas to broader national and even international audiences. This widespread interest reflects both local concerns and the power of media coverage in disseminating news globally. The wildfire's unique cause—a pre-wedding photo shoot gone wrong—added an unusual and compelling element to the story, further fueling public curiosity and media coverage.

Public curiosity is shown by the data from Google Trends in the period of September 2023, the time after the incident occurred. Google Trends recorded a sharp increase in searches for specific phrases like “Bromo”, *"kebakaran Bromo"* (Bromo fire), *“kebakaran gunung bromo”* (Mount Bromo Fire), *“kebakaran Bromo prewedding”* (Mount Bromo Fire Pre-Wedding), and *“kebakaran hutan di Bromo”* (forest fire of Bromo). This pattern indicates that people were seeking information not only about the wildfire itself but also about its unusual cause. The incident's novelty likely contributed to the viral spread of information, as people shared news articles, social media posts, and other content related to the fire.

Fig. 7 and 8 in this research provide a detailed illustration of this trend, showing the surge in related queries and the specific terms people searched for during this event. The data reveals how quickly and broadly information about the wildfire spread, driven by both local interest and global connectivity.

The spike in searches following the Mount Bromo wildfire demonstrates how digital platforms like Google Trends can serve as valuable tools for gauging public interest and concern during environmental crises. The rapid increase in search activity highlights the importance of timely and accurate information dissemination, as people rely on the internet to stay informed about critical events. This case also underscores the impact of unique and unusual causes on public interest, as the pre-wedding photo shoot element of the wildfire story captured widespread attention.

The Google Trends data from September 2023 provides a compelling snapshot of how the Mount Bromo wildfire captured public interest. The significant rise in search traffic reflects the public's urgent need for information during the crisis and illustrates the powerful role of digital platforms in shaping public awareness and understanding of environmental events.

Fig. 7 presents Google Trends data related to the keyword “Pre Wedding Bromo” from August 4th to December 4th, 2023. The graph indicates fluctuations in public interest over time, with several sharp spikes in search activity. The highest level of interest occurred shortly after early August 2023, marked by a peak that reached maximum search volume. This surge was likely driven by public reactions to the news surrounding the Mount Bromo fire, which reportedly originated from a pre-wedding photo shoot. Additional spikes

followed in quick succession, reflecting continued attention, possibly due to media coverage and social media discussions. However, after mid-October, search interest dropped significantly and remained consistently low through December. This trend suggests that while the incident gained significant short-term attention, public interest quickly declined once the immediate media coverage subsided.

Fig. 7. Google trends results for searching for Mount Bromo Fire in 2023

Fig. 8 displays Google Trends results for the most searched keywords related to the 2023 Bromo fire. The list is ranked by search popularity, with values ranging from 0 to 100, where 100 represents peak popularity. The keyword "bromo" ranks the highest with a score of 100, indicating it was the most searched term, likely reflecting general interest in Mount Bromo during the fire incident. The keyword "*bromo kebakaran"* follows closely with a score of 95, showing significant public concern and attention toward the fire event.

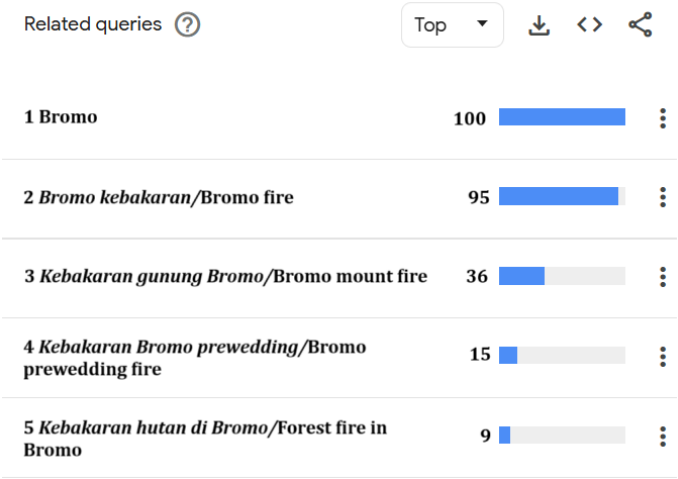

Fig. 8. Google trends results for keywords related to the 2023 Bromo Fire

The terms *"kebakaran gunung bromo"* and *"kebakaran bromo prewedding"* received lower but still notable attention, scoring 36 and 15 respectively, suggesting that specific details about the fire's cause and location were also of public interest. Lastly, *"kebakaran hutan di bromo"* scored 9, indicating relatively low search volume, though it still shows that some users specifically searched for information about the forest fire aspect. Overall, the

trend data reflects a high level of public interest in the Bromo fire, particularly in relation to its impact and possible connection to a pre-wedding photo shoot.

4. Conclusions

The Mount Bromo forest fire, caused by a pre-wedding photoshoot, resulted in significant negative impacts across environmental, economic, and social dimensions, emphasizing the need for stronger protective measures. The environmental aspect of a fire caused substantial damage to the park's ecosystems, impacting biodiversity and the health of natural resources. While there is evidence of natural recovery, continuous monitoring is crucial to manage the long-term effects. The use of remote sensing tools is vital in this monitoring effort. Mitigation is needed to prevent not only the environmental impact but also the economic & social loss. Due to this incident, the local tourism sector experienced significant losses due to the park's closure and decline in visitors. A comprehensive recovery strategy is needed, including restoration of the ecosystem and rebuilding the area's reputation as a tourist destination. The social effect is that the fire caused major disruptions to the lives and livelihoods of the communities, especially the Tengger community, and also resulted in increased public concern. This highlights the need for community support, as well as a better understanding of the human impact on the environment.

Overall, the conclusion is that the incident underscores the critical need for stricter regulations, better enforcement, and increased public awareness of responsible behavior in national parks. The research implies that protecting Indonesia's natural heritage requires a proactive and collaborative approach among authorities, communities, and visitors, alongside continuous assessment of the long-term ecological and economic impacts.

Acknowledgement
This research is part of one of the subjects while pursuing a master's in environmental science at the Universitas Indonesia, School of Environmental Science. I thank my lecturer Mr. Herdis Herdiansyah for guiding my research and helping me in the writing process

Author Contribution
M.P.N. have equally contributed to the conception, writing, and revision of this article, ensuring its accuracy and integrity.

Funding
This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflicts of Interest
The author declare no conflict of interest.

Open Access

References

Aini, N., & Sukojo, B. M. (2016). Pemanfaatan Data Landsat-8 dan MODIS untuk Identifikasi Daerah Bekas Terbakar Menggunakan Metode NDVI (Studi Kasus: Kawasan Gunung Bromo). *Jurnal Teknik ITS*, *5*(2), A830-A836. http://ejurnal.its.ac.id/index.php/teknik/article/viewFile/17155/3027

Aminah, K. C. Y., Perdinan, & Perdinan. (2020). Forest fires and management efforts in Indonesia (a review). *IOP Conference Series: Earth and Environmental Science*, *504*(1). https://doi.org/10.1088/1755-1315/504/1/012013

Bhakuni, H. (2021). Beyond Anthropocentrism. *Source: Health and Human Rights*, *23*(2), 7–12. https://doi.org/10.2307/48636250

Budiastuti, M. T. S., Purnomo, D., & Setyaningrum, D. (2021). Agroforestry system as the best vegetation management to face forest degradation in Indonesia. *Reviews in Agricultural Science*, *10*, 14-23. https://doi.org/https://doi.org/10.7831/ras.10.0_14

Cristiana, E. (2024). *Perlindungan Kawasan Taman Nasional Menurut Undang-Undang Nomor 5 Tahun 1990 tentang Konservasi Sumber Daya Alam Hayati dan Ekosistemnya (Analisis Kasus Kebakaran Bromo Tengger Semeru)*. *10*(1), 56–66. https://doi.org/10.52947/morality.v10i1.422

Giddey, B. L., Baard, J. A., & Kraaij, T. (2022). Verification of the differenced Normalised Burn Ratio (dNBR) as an index of fire severity in Afrotemperate Forest. *South African Journal of Botany*, *146*, 348–353. https://doi.org/10.1016/j.sajb.2021.11.005

GISACT. (2023). *Bromo Mountain Fire.* GISACT. https://gisact.io/opinion/1

Hadiwijoyo, E. (2023). Pola Kebakaran Hutan di Areal Konservasi Studi Kasus di Taman Nasional Bromo Tengger Semeru. *Jurnal Silvikultur Tropika*, *14*(02). https://firms.modaps.eosdis.nasa.gov/

Haliim, W. (2018). Dinamika Implementasi Kebijakan Konservasi Lahan Taman Nasional Bromo Tengger Semeru. *Jurnal Borneo Administrator*, *14*(1), 53–68. https://doi.org/10.24258/jba.v14i1.327

Ibrahim, S. A., Kose, M., Adamu, B., & Jega, I. M. (2024). Remote sensing for assessing the impact of forest fire severity on ecological and socio-economic activities in Kozan District, Turkey. *Journal of Environmental Studies and Sciences*, 1-13. https://doi.org/10.1007/s13412-024-00951-z

Juráni, M. (2021). Anthropocentrism on the Stage. *Critical Stages*, (24). https://www.critical-stages.org/24/anthropocentrism-on-the-stage/

Lapola, D. M., Pinho, P., Barlow, J., Aragão, L. E. O. C., Berenguer, E., Carmenta, R., Liddy, H. M., Seixas, H., Silva, C. V. J., Silva-Junior, C. H. L., Alencar, A. A. C., Anderson, L. O., Armenteras, D., 15, P., Brovkin, V., Calders, K., Chambers, J., Chini, L., Costa, M. H., Faria, B. L., Fearnside, P. M., Ferreira, J., Gatti, L., Gutierre-Velez, V. H., Han, Z., Hibbard, K., Koven, C., Lawrence, P., Ponngratz, J., Portela, B. T. T., Rounsevell, M., Ruani, A. C., Schaldach, R., Silva, S. S. D., Randow, C. V., & Walker, A. W.S. (2019). *The Drivers and Impacts of Amazon Forest Degradation*. *Science*, *379*(6630), eabp8622. https://doi.org/https://doi.org/10.1126/science.abp8622

Lee, K., van Leeuwen, W. J. D., Gillan, J. K., & Falk, D. A. (2024). Examining the Impacts of Pre-Fire Forest Conditions on Burn Severity Using Multiple Remote Sensing Platforms. *Remote Sensing*, *16*(10). https://doi.org/10.3390/rs16101803

Li, S., Xu, L., Jing, Y., Yin, H., Li, X., & Guan, X. (2021). High-quality vegetation index product generation: A review of NDVI time series reconstruction techniques. *International*

Journal of Applied Earth Observation and Geoinformation, *105*, 102640. https://doi.org/10.1016/j.jag.2021.102640

Liu, Y., Li, Z., Chen, Y., Li, Y., Li, H., Xia, Q., & Kayumba, P. M. (2022). Evaluation of consistency among three NDVI products applied to High Mountain Asia in 2000–2015. *Remote Sensing of Environment*, *269*, 112821. https://doi.org/10.1016/j.rse.2021.112821

Mohammad, L., Bandyopadhyay, J., Sk, R., Mondal, I., Nguyen, T. T., Lama, G. F. C., & Anh, D. T. (2023). Estimation of agricultural burned affected area using NDVI and dNBR satellite-based empirical models. *Journal of Environmental Management*, *343*, 118226. https://doi.org/10.1016/j.jenvman.2023.118226

Morante-Carballo, F., Bravo-Montero, Lady, Carrión-Mero, P., Velastegui-Montoya, A., & Berrezueta, E. (2022). Forest Fire Assessment Using Remote Sensing to Support the Development of an Action Plan Proposal in Ecuador. *Remote Sensing*, *14*(8). https://doi.org/10.3390/rs14081783

Mustofa, M. H., Syaufina, L., & Puspaningsih, N. (2022). The estimated total area of forest fire in Siak Regency, Riau Province during the early period of the COVID-19 outbreak. *IOP Conference Series: Earth and Environmental Science*, *1027*(1). https://doi.org/10.1088/1755-1315/1027/1/012008

Poerwantika, T. R., & Hatami, M. I. (2021). Deforestasi Amazon Pada Era Bolsonaro (2019). *Indonesian Journal of International Relations*, *5*(2), 184–217. https://doi.org/10.32787/ijir.v5i2.205

Prăvălie, R., Sîrodoev, I., Nita, I. A., Patriche, C., Dumitraşcu, M., Roşca, B., Tişcovschi, A., Bandoc, G., Săvulescu, I., Mănoiu, V., & Birsan, M. V. (2022). NDVI-based ecological dynamics of forest vegetation and its relationship to climate change in Romania during 1987–2018. *Ecological Indicators*, *136*, 108629. https://doi.org/10.1016/j.ecolind.2022.108629

Putri, N. R., Zuhria, F. A., & Sinaga, D. J. (2024). Penegakan hukum lingkungan terhadap kasus kebakaran hutan dan lahan di kawasan Taman Nasional Bromo. *Kultura: Jurnal Ilmu Hukum, Sosial, Dan Humaniora*, *2*(8), 300–313. https://jurnal.kolibi.org/index.php/kultura/article/view/2227

Rozani, F. F., Nuroktaviany, F., Nurjaman, I., & Fajar, I. A. (2023). Analisis Kasus Kebakaran di Kawasan Lahan Gunung Bromo Dalam Penggunaan Flare Saat Foto Pre-Wedding Dalam Perspektif Hukum Pidana Islam. *Jurnal Kajian Agama Dan Dakwah*, *1*(2). https://doi.org/10.333/Tashdiq.v1i1.571

Siregar, S., Idiawati, N., Lestari, P., Berekute, A. K., Pan, W. C., & Yu, K. P. (2022). Chemical Composition, Source Appointment and Health Risk of PM2.5 and PM2.5-10 during Forest and Peatland Fires in Riau, Indonesia. *Aerosol and Air Quality Research*, *22*(9). https://doi.org/10.4209/aaqr.220015

Suhardono, S., Fitria, L., Suryawan, I. W. K., Septiariva, I. Y., Mulyana, R., Sari, M. M., Ulhasanah, N., & Prayogo, W. (2024). Human Activities and Forest Fires in Indonesia: An Analysis of the Bromo Incident and Implications for Conservation Tourism. *Trees, Forests and People*, *15*, 100509. https://doi.org/10.1016/j.tfp.2024.100509

Suwanprasit, C., & Shahnawaz. (2024). Mapping burned areas in Thailand using Sentinel-2 imagery and OBIA techniques. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-60512-w

Uhai, S., Indriani, N., Darmiati, M., Diwyarthi, S., & Putri, N. R. (2024). Revenge Tourism: Strategy To Increase The Number Of Tourist To Mount Bromo After The Fire. *Reslaj: Religion Education Social Laa Roiba Journal*, *6*(3), 2462-2470. https://journal.laaroiba.com/index.php/reslaj/article/view/6228

Ummah, S. K., Rahmawati, Z. E., Antari, M. S., Sundari, D. P., Aini, K., & Prastiwi, M. I. (2024). Dampak Kebakaran Gunung Bromo Terhadap Kerugian Ekonomi Pengusaha Lokal di Sekitarnya. *SOSIETAS*, *13*(1), 57–70. https://doi.org/10.17509/sosietas.v13i1.59644

Wasis, B., Robi, D., & Waldi, D. (2019). Dampak Kebakaran Hutan Terhadap Flora dan Sifat Tanah Mineral di Kawasan Hutan Kabupaten Pelalawan Provinsi Riau. *Jurnal Silvikultur Tropika*, *10*(1), 40–44. https://doi.org/10.29244/j-siltrop.10.1.40-44

Yusuf, A., Hapsoh, H., Siregar, S. H., & Nurrochmat, D. R. (2019). Analisis kebakaran hutan dan lahan di Provinsi Riau. *Dinamika Lingkungan Indonesia*, *6*(2), 67-84. https://doi.org/http://dx.doi.org/10.31258/dli.6.2.p.67-84

Biographies of Author

Mayabella Puspita Nugraha, School of Environmental Science, Universitas Indonesia, Jakarta, 10430, Indonesia.

- Email: mayabella.nugrahaa@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A