Pangripta Jurnal Ilmiah Kajian Perencanaan Pembangunan
https://jurnalpangriptav3.malangkota.go.id/pangripta

E-ISSN: 2615-5702, P-ISSN: 2620-5785
Vol. 8, No. 2, page 128 - 142

Toward Effective Disaster Management and Urban Planning: A GIS-Based Spatial Analysis of Historical Disaster Data in Malang Municipality

M. Kahfi Maulana Anggara[1*], Rian Agusdian[2], Gilang Aulia Herlambang[3], Fajar Setiawan Yuliano[4]

[1]Regional Disaster Management Agency (BPBD) of DKI Jakarta Province, Indonesia
Research conducted while the author was working at BPBD of Malang Municipality
[2]Regional Disaster Management Agency (BPBD) of Malang Municipality, Indonesia
[3]Geomatics Engineering, Sepuluh Nopember Institute of Technology, Indonesia
[4]Regional Planning and Development Agency of Malang Municipality, Indonesia

Abstract

The provision of data and information today is essential not only for generating statistical figures but also for supporting decision-making based on in-depth analysis. In the context of disaster management, spatial data plays a crucial role in identifying the distribution, characteristics, and patterns of affected areas. This research aims to analyze the historical records of disaster events in Malang Municipality spatially using a Geographic Information System (GIS). The data used consists of disaster incidents from 2020 to 2024, which were processed into spatial format and analyzed through spatial join functions to generate distribution maps and frequency summaries by administrative region. The results show that Klojen District recorded the highest number of disaster events with 360 incidents (169 floods, 123 extreme weather events, and 68 landslides). The distribution patterns indicate that floods are scattered randomly, landslides are concentrated along rivers and slopes, while extreme weather events show both linear patterns along roads with dense vegetation and random patterns in residential areas due to the dynamic nature of wind. These findings highlight the importance of preparedness and spatially-based mitigation strategies that consider the characteristics of the affected areas and historical disaster data.

Article Info

Keywords:
Spatial Analysis;
Disaster;
GIS;
Malang Municipality

Corresponding Author:
M. Kahfi Maulana Anggara
(m.kahfi.ma@gmail.com)

Received: 08-07-2025
Revised: 21-08-2025
Accepted: 27-08-2025
Published: 05-09-2025

1. Introduction

The formulation of government strategies and policies at the regional level requires comprehensive statistical data to ensure that goals and targets are accurately achieved. This includes disaster-related data, as disaster events can significantly impact development and the socioeconomic conditions of affected communities. Therefore, evidence-based policymaking is essential to minimize both the consequences and potential future risks. The economic toll of disasters is staggering, disrupting livelihoods, straining local economies, and undermining development gains (Riyadh et al., 2024).

Disasters have become a defining feature of 21st-century life, with their frequency and severity steadily increasing. Societies are becoming more vulnerable to environmental hazards such as floods, droughts, and landslides (Riyadh et al., 2024). Historical disaster data must be continuously monitored and analyzed to generate new insights into past and current conditions, while also anticipating future threats (BNPB, 2023a). Furthermore, the Presidential Regulation of the Republic of Indonesia No. 12 of 2025 concerning the National Medium-Term Development Plan (RPJMN) 2025–2029 emphasizes the enforcement of spatial planning based on disaster mitigation through improved effectiveness of spatial utilization control instruments (Government of Indonesia, 2024).

To make disaster data more comprehensible, spatial analysis using Geographic

Information Systems (GIS) is a valuable method for visualization and interpretation. GIS-based spatial analysis enables the transformation of complex data into visually intuitive outputs, aiding in clearer understanding and more informed decision-making. Visualizatio techniques such as diagrams, histograms, box plots, heat maps, and scatter plots are particularly effective in communicating patterns and trends (Sudipa et al., 2023).

Maps serve a wide range of functions. While they are commonly used for navigation and boundary delineation, they also serve as tools to represent spatial relationships and geographic phenomena. For geographers, the most critical use of maps is to identify and explain spatial structures and variations across a given area (Unwin et al., 2024). In the context of disaster data, map-based visualizations and histograms are especially suitable for presenting the distribution and trends of disaster occurrences in specific areas. Spatial data derived from historical records can be processed using GIS software such as ArcGIS 10.8, which facilitates spatial-based analysis (Budiyanto, 2020). These outputs can assist government agencies in evaluating progress and formulating evidence-based disaster risk reduction policies (BNPB, 2024).

GIS has become an essential tool in supporting sustainable development planning, particularly through spatial database integration and analysis. It allows policymakers and planners to incorporate spatial factors into decision-making processes, taking into account environmental, socioeconomic, political, and technological dimensions. GIS-based analysis enables users to answer conceptual, locational, conditional, and relational questions, and to conduct assessments related to land suitability, disaster risk, and spatial trends (Purwanto, 2019).

The application of GIS in disaster studies is grounded in spatial theory, which emphasizes that geographic phenomena cannot be fully understood without considering their spatial distribution and interrelationships (Tobler, 1970). Tobler's First Law of Geography, stating that "everything is related to everything else, but near things are more related than distant things," provides a theoretical foundation for analyzing disaster patterns. This perspective aligns with the hazard-of-place model proposed by Cutter (1996), which integrates physical exposure, social vulnerability, and place-based characteristics to explain disaster risk. By adopting these theoretical frameworks, GIS is not only a tool for visualization but also a methodological approach for linking spatial structures with vulnerability and resilience, thereby enhancing the validity of disaster risk assessments.

According to Indonesia's Disaster Risk Index (IRBI), Malang Municipality in 2024 falls under the medium-risk category. Since 2015, the risk index has shown a downward trend, from 113.60 in 2015 to 78.21 in 2024. This positive trend is attributed to increased community capacity and reduced vulnerability levels (BNPB, 2024). Despite this progress, Malang remains highly exposed to hazards such as floods, landslides, and extreme weather, due to its geographical characteristics.

Based on data from the Regional Disaster Management Agency (BPBD) of Malang Municipality, a total of 1,439 disaster events were recorded between 2020 and 2024. The estimated economic loss peaked in 2021 at IDR 6.1 billion, compared to IDR 2.3 billion in 2020, but declined in the following years to IDR 2.1 billion (2022), IDR 1.4 billion (2023), and IDR 1 billion (2024). These trends demonstrate the need for improved disaster preparedness and mitigation measures, supported by accurate data and appropriate analysis methods.

The objective of this article is to demonstrate how Geographic Information Systems (GIS) can be used to analyze disaster data through spatial representation. This research highlights how GIS facilitates the mapping of disaster locations over a defined period, enabling the analysis of spatial patterns and geographical interrelationships based on the characteristics of affected areas. As Unwin et al. (2024) noted, spatial problems are addressed through the types of data used, map representations, and analytical procedures that help detect spatial patterns. Wise (2014) also emphasized the importance of separating attribute and spatial data, enabling efficient storage and spatial analysis of points, lines, and polygons in geodatabases.

2. Methods

The research was carried out in Malang Municipality, situated in East Java Province, Indonesia. Astronomically, the city is situated between 112.06° to 112.07° East Longitude and 7.06° to 8.02° South Latitude. Malang Municipality is bordered by several districts within Malang Regency: to the north by Singosari and Karangploso Districts, to the east by Pakis and Tumpang Districts, to the south by Tajinan and Pakisaji Districts, and to the west by Wagir and Dau Districts. The total area of Malang Municipality is approximately 111.08 km², comprising five administrative districts: Kedungkandang, Sukun, Klojen, Blimbing, and Lowokwaru (BPS Kota Malang, 2024).

In terms of its physical geography, Malang Municipality is located on a highland plateau at an elevation ranging from 440 to 667 meters above sea level, and is traversed by major rivers such as the Brantas River, Metro River, and several smaller tributaries. Additionally, the city lies in proximity to active volcanoes including Mount Semeru, Mount Bromo, and Mount Kelud. These geographic and geological conditions expose Malang Municipality to various natural hazards, particularly landslides, floods, and extreme weather events.

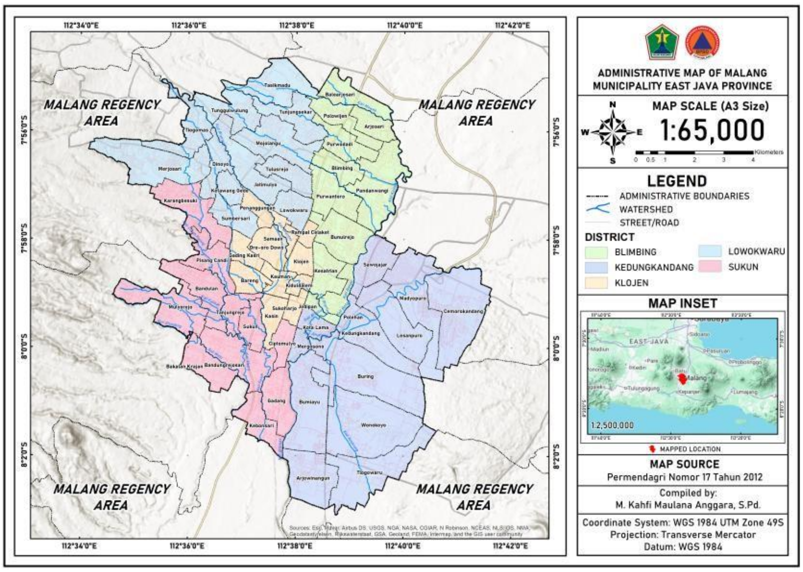

Figure 1. Administrative Map of Malang Municipality

Source: Regional Disaster Management Agency (BPBD) of Malang Municipality, 2025

This research employed a spatial analysis approach utilizing Geographic Information System (GIS) software. The data used in the analysis consisted of both primary and secondary sources. The primary data were obtained from the disaster incident records compiled by Pusdalops-PB of the Regional Disaster Management Agency (BPBD) of Malang Municipality, covering the period from 2020 to 2024. The secondary data were collected from relevant government agencies and supplemented by literature review from previous studies and academic publications.

The population of this research comprised all disaster events recorded by Pusdalops-PB of the Malang Municipal Disaster Management Agency during 2020–2024 (N = 1,439 events). A total sampling approach (census) was applied to include all records that met the following inclusion criteria: (1) events reported between 2020 and 2024; (2) availability of location information in the form of coordinates or address suitable for geocoding; and (3) presence of essential attributes such as date, disaster type, administrative location, and estimated economic loss. Exclusion criteria included duplicate records or records lacking location information that could not be recovered. In cases where missing location data were significant, alternative strategies involved (a) manual geocoding of addresses using official maps or gazetteers, or (b) stratified sampling based on disaster type and administrative unit to ensure representativeness.

ArcGIS 10.8 was selected for its comprehensive functionality, including geocoding, spatial data management (geodatabase), spatial statistics (Global Moran's I, Getis-Ord Gi*, Kernel Density), raster and vector analysis (Spatial Analyst), and workflow automation (ModelBuilder, arcpy). These features ensure high analytical precision and reproducibility. Furthermore, ArcGIS provides cartographic outputs of professional quality, facilitating communication of findings to local government stakeholders. While open-source alternatives such as QGIS could be considered in contexts with limited licensing, ArcGIS offers more integrated toolsets suited for this study's analytical requirements.

All datasets were processed within GIS software to produce geospatial data that served as the basis for the spatial analysis conducted in this research. Geospatial data refers to information about objects, events, or phenomena that have a location on the surface of the Earth (Stock & Guesgen, 2016). The spatial analysis aimed to identify distribution patterns, concentrations, and relationships between disaster events and geographic or environmental variables.

Recent developments in spatial analysis increasingly involve quantitative techniques to test hypotheses regarding spatial variation. Historically, the compilation of maps and the statistical analysis of mapped phenomena have developed in relative isolation. However, as noted by Hagerstrand (1973, p. 69), recent advances in quantitative geography can be seen as an in-depth study of the patterns formed by points, lines, areas, and surfaces represented on maps or defined by coordinates in two- or three-dimensional space (Unwin et al., 2024).

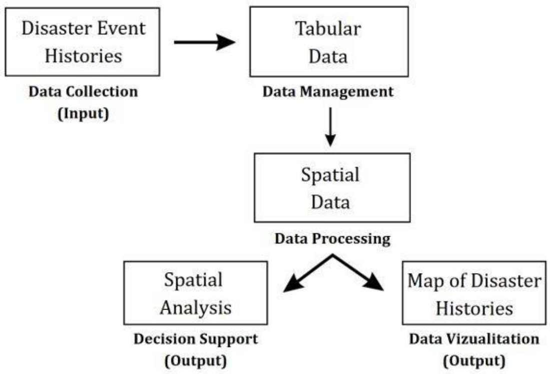

Figure 2. Research methodology workflow

The principal dataset comprises spatially referenced disaster events within Malang Municipality, specifically encompassing flood, landslide, and extreme weather incidents recorded over the five-year period from 2020 to 2024. Initially available in tabular form, these data were systematically converted into geospatial formats (shapefiles) using ArcGIS 10.8, enabling their integration into spatial analytical workflows. This transformation facilitated the visualization of disaster point distributions across the research area and allowed for further spatial interrogation of event concentrations in relation to underlying geographic and environmental characteristics..

Subsequent analytical procedures involved the application of spatial join techniques to integrate disaster point data with administrative boundary layers, resulting in aggregated frequency metrics at the district level. This method enabled a more structured spatial assessment of disaster occurrences and their geographic associations. Spatial analysis functions not only as a cartographic exercise but also as a methodological tool for identifying spatial patterns, relational proximities, and contextual insights that inform disaster risk assessment and planning efforts. (BNPB, 2023b).

Data collection in this research involved both primary and secondary sources. Primary data were derived from disaster incident records obtained through the Disaster Operations Control Center (Pusdalops-PB) of the Malang Municipal Disaster Management Agency (BPBD). Secondary data were sourced from technical institutions such as the Meteorology, Climatology, and Geophysics Agency (BMKG), the Geological Agency's Center for Volcanology and Geological Hazard Mitigation (PVMBG), and related governmental agencies. The data processing stage involved converting attribute records into geospatial point features, which were then subjected to spatial analysis using GIS techniques. This analytical framework enabled the identification of spatial trends, frequency distributions, and vulnerability hotspots, which were subsequently visualized through thematic maps to enhance interpretability and support evidence-based disaster mitigation strategies (England et al., 2024).

3. Results and Discussion

Geographic Information Systems (GIS) are computer-based information systems designed to digitally represent and analyze geographic features and phenomena occurring on the Earth's surface. GIS enables the integration of spatial data (location-based) and non-spatial data (attribute-based), allowing users to examine complex geographic relationships. A defining feature of GIS is its analytical capability, particularly spatial analysis, which incorporates the dimension of space or geography into data interpretation. Spatial analysis involves integrating two or more datasets to generate new information based on the relationships between them, including methods such as statistical evaluation and overlay techniques.

Spatial analysis was conducted using historical disaster data from 2020 to 2024, which had been transformed into point-based spatial data and integrated with the polygon-based administrative boundaries of Malang Municipality. The application of GIS in spatial analysis enables implicit patterns to become explicit and reveals previously unobservable insights (Purwanto, 2019). The process includes data transformation, manipulation, and the use of analytical models to support decision-making and uncover patterns or anomalies that might otherwise remain undetected. The analysis focuses on the spatial distribution and characteristics of floods, landslides, and extreme weather events in relation to the physical geography of affected areas and their corresponding mitigation strategies.

The Presidential Regulation of the Republic of Indonesia Number 12 of 2025 concerning the National Medium-Term Development Plan (RPJMN) 2025–2029 emphasizes that disaster mitigation and preparedness must be prioritized across all regions, particularly in high-risk areas. This effort is crucial to protect communities and reduce the impacts of disasters. Efficient and targeted disaster risk management plays a central role in strengthening societal resilience and safeguarding both lives and livelihoods. These objectives are supported by improved spatial planning, reduced disaster vulnerability, enhanced emergency response and post-disaster recovery capacities, strengthened human resource competency in disaster management, and the development of disaster-resilient infrastructure.

Flood

Flooding is defined as a condition in which an area or land surface becomes inundated due to an increase in water volume (BNPB, 2023b). Floods are among the most frequent and persistent natural hazards in Indonesia, particularly during the rainy season (Khaidir I., 2019). They generally occur as a result of insufficient soil infiltration capacity, which hinders the absorption of excess surface water (Mauliana et al., 2017). Additional contributing factors include high rainfall intensity and land use conversion, such as the transformation of agricultural areas into residential, commercial, or industrial zones (Soebroto et al., 2015). Furthermore, river overflow can result from stream discharge exceeding the river's maximum capacity, leading to inundation in surrounding areas (Noor et al., 2013).

Based on disaster event records obtained during the research period, a total of 670 flood incidents were documented in Malang Municipality between 2020 and 2024, confirming its status as one of the most recurrent hazards affecting the area throughout the observed timeframe.

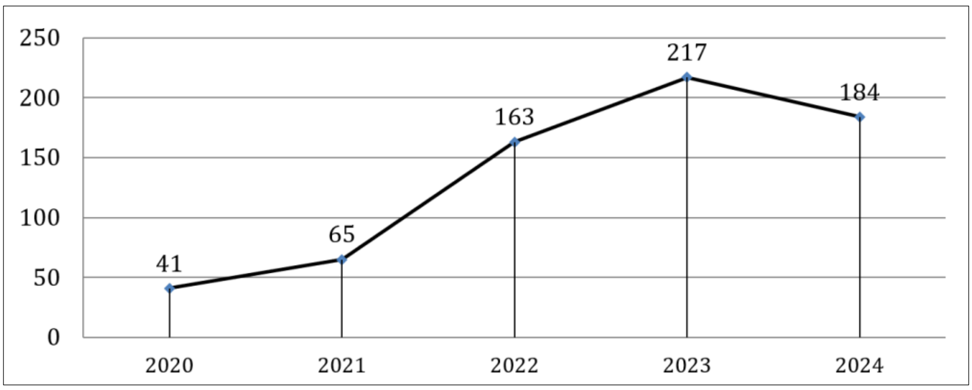

Figure 3. Graph of Flood Histories in Malang Municipality trough 2020-2024.
Source: Analysis result, 2025

From 2020 to 2023, the frequency of flood events in Malang Municipality showed a consistent upward trend, with 41 incidents recorded in 2020, 65 in 2021, 163 in 2022, and peaking at 217 in 2023. However, in 2024, the number of flood incidents decreased to 184. The sharp increase in 2023 can be attributed to several factors, particularly the increase in annual rainfall, as indicated by the emergence of new flood-affected locations that had not experienced such events in previous years. Another significant factor was the ongoing drainage improvement projects, which temporarily reduced the capacity of several drainage systems in flood-prone areas, leading to localized inundation. The decline in flood frequency in 2024 is partly due to the completion of these drainage infrastructure projects, which restored the full capacity of the drainage systems in various critical locations.

According to Suherlan (2001, as cited in Alakesi, 2020), flood occurrences are generally influenced by two major categories of factors: meteorological factors (such as rainfall intensity, distribution, frequency, and duration) and watershed characteristics, including land slope, elevation, soil texture, and land use. Field observations in Malang further revealed that in addition to meteorological conditions and topographic factors, floods were also caused by human-induced issues such as the accumulation of garbage and debris that blocked water flow and caused overflow into roads and residential areas.

The high frequency of flood events is directly correlated with the intensity of rainfall. Notably, heavy rainfall not only in Malang Municipality but also in upstream areas such as Batu City and Malang Regency significantly contributes to flooding in the city. This is primarily due to the hydrological influence of the Brantas River, which originates in Batu City, and the Amprong River, which originates in Malang Regency. Both rivers pass through Malang Municipality, and intense rainfall in their upstream catchments can lead to elevated water levels downstream. The situation becomes particularly critical when high rainfall occurs simultaneously in both the upstream areas and within Malang Municipality itself, leading to severe flooding along these river corridors.

The historical disaster data from 2020 to 2024 were processed into a map using GIS software, as shown in the following figure.

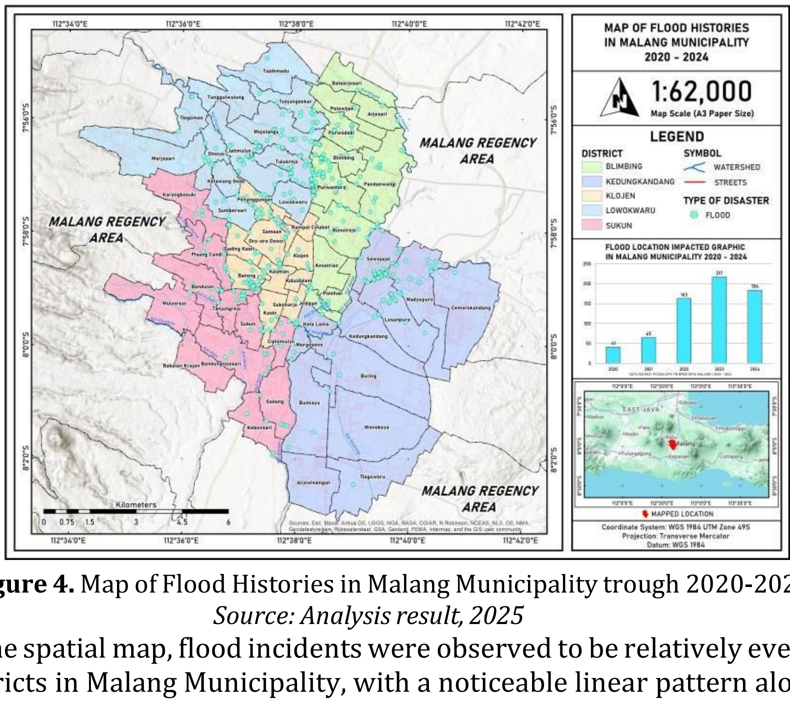

Figure 4. Map of Flood Histories in Malang Municipality trough 2020-2024.
Source: Analysis result, 2025

Based on the spatial map, flood incidents were observed to be relatively evenly distributed across all districts in Malang Municipality, with a noticeable linear pattern along the Brantas River and Amprong River watersheds, as well as certain major road segments. Spatial analysis using the spatial join tool revealed that between 2020 and 2024, a total of 670 flood incidents occurred across the municipality, with the highest number recorded in Klojen District (169 incidents), followed by Lowokwaru (154 incidents), Blimbing (138 incidents), Kedungkandang (113 incidents), and Sukun (96 incidents). On average, the highest annual flood occurrences in each district were recorded in 2023, with a mean of 43.4 incidents.

Klojen District recorded the highest number of flood events during the observation period, primarily due to its relatively flat topographic characteristics compared to the surrounding districts. Additionally, as the urban core of the city, Klojen has a high population density, which contributes to elevated flood risk through suboptimal environmental practices. Key contributing factors include the development of residential structures along riverbanks and the obstruction of drainage channels, both of which reduce the natural flow capacity of surface runoff. The presence of the Brantas River, which flows through the district, further increases the likelihood of flash flooding, particularly after heavy rainfall in upstream areas. Subdistricts such as Penanggungan, Samaan, Oro-Oro Dowo, Kiduldalem, and Bareng have consistently been identified as areas with frequent flood impacts in historical disaster records.

Sukun District recorded the lowest number of flood events. This is largely attributable to its hydrological context, as only a small section of the Brantas River passes through this area. Field observations and disaster reports indicate that flooding in Sukun is mostly caused by the overflow of Kali Kasin and drainage channels along main roads. Despite having the lowest number of flood events among all districts, Sukun still requires attention due to an increasing trend observed from 2020 to 2024. Policy interventions such as improved spatial planning around Kali Kasin and the upgrading of drainage infrastructure in frequently affected road segments could significantly reduce future flood risk in this district.

The types of flooding observed in Malang Municipality primarily include inundation floods, surface runoff, and localized river overflows. Areas affected by inundation are typically located in topographic depressions, where water tends to accumulate due to poor gravitational flow. River overflows generally occur only during periods of high-intensity rainfall sustained over an extended duration. As rainfall subsides, floodwaters tend to recede relatively quickly. According to incident reports compiled by the Malang Municipal Disaster Management Agency (BPBD), there has been no record of floods persisting for multiple consecutive days during the observation period.

Based on this analysis, it is essential to optimize the urban drainage system, particularly in low-lying areas and natural basins, to improve runoff discharge and reduce water accumulation. In addition to improving drainage capacity, river normalization and sediment dredging are recommended to maintain flow efficiency. The construction of retention basins (embung) in flood-prone locations may serve as a long-term mitigation strategy to regulate excess surface water and prevent overflow. This recommendation is supported by a recent report from CV Citiplan (2024) on disaster vulnerability profiling across urban villages (kelurahan) in Malang, which emphasized the importance of drainage reinforcement in districts frequently affected by rainfall-induced flooding and river overflow.

From a policy perspective, flood mitigation should also be supported through strict enforcement of spatial planning regulations, including the control of land-use conversion, particularly from agricultural to residential use, as has been observed in areas such as Bareng Urban Village. It is equally important to mandate the integration of neighborhood-scale drainage systems in all new development projects and impose penalties on constructions that obstruct water channels or riverbanks. The enhancement of early warning systems (EWS) is another critical component for minimizing disaster impacts. Although the Malang City Government has installed EWS infrastructure at several flood-prone sites, the system has not yet reached full operational effectiveness. Improvements are needed to ensure direct public dissemination, such as through SMS blast notifications, and to provide real-time, web-based monitoring of flood conditions that can be accessed by both authorities and residents.

Landslides

The landform and morphological characteristics of Malang Municipality are predominantly flat, particularly in the central zone extending from the north to the south, where slope gradients range between 0–8%. In the western part of the city, the terrain becomes slightly steeper, with slopes ranging from 8–15%, while the far western area—particularly in Karangbesuki Urban Village and its surroundings in Lowokwaru District—features slope gradients of 15–25%. Similarly, in the eastern part of the city, especially in Kedungkandang District, slopes vary between 8–15%, increasing to 15–25% in the easternmost areas such as Buring Urban Village. The topographic conditions of Malang, characterized by slopes exceeding 25% in certain locations and river basins situated near steep and deep upstream segments, contribute significantly to landslide susceptibility. The absence of slope reinforcement along riverbanks further exacerbates this risk. During the rainy season, local and partial landslides are often triggered by erosion at the base of the slopes combined with increased soil mass due to rainfall accumulation (CV Citiplan, 2024).

Landslides are defined as the downward movement of soil and/or rock masses resulting from the disturbance of slope stability (Wiyono, 2008). According to the Center for Volcanology and Geological Hazard Mitigation (PVMBG), Malang Municipality falls within a low to moderate landslide susceptibility zone. Areas with moderate susceptibility are primarily located along the Brantas River Basin, particularly in Lowokwaru and Sukun Districts. In these zones, landslide events are likely to occur during periods of above-normal rainfall, especially in areas adjacent to river valleys, cliffs, road cut slopes, or locations where slope stability has been compromised (PVMBG, 2025).

Lowokwaru and Sukun are two of the five districts in Malang Municipality classified as moderately vulnerable to landslides, while the remaining three districts fall under the low vulnerability category (PVMBG, 2025). The dominant types of landslides in Malang include translational slides and falls. Translational slides occur when masses of soil and rock move along a planar or slightly undulating slip surface, and this type is frequently observed in Klojen and Sukun Districts. In contrast, fall-type landslides involve the detachment and downward movement of eroded soil masses, typically occurring along the Brantas River corridor, where steep slopes and riverbank instability are more prevalent.

The historical landslide data from 2020 to 2024 were compiled and subsequently processed into a map using Geographic Information System (GIS) software, as presented in the following figure.

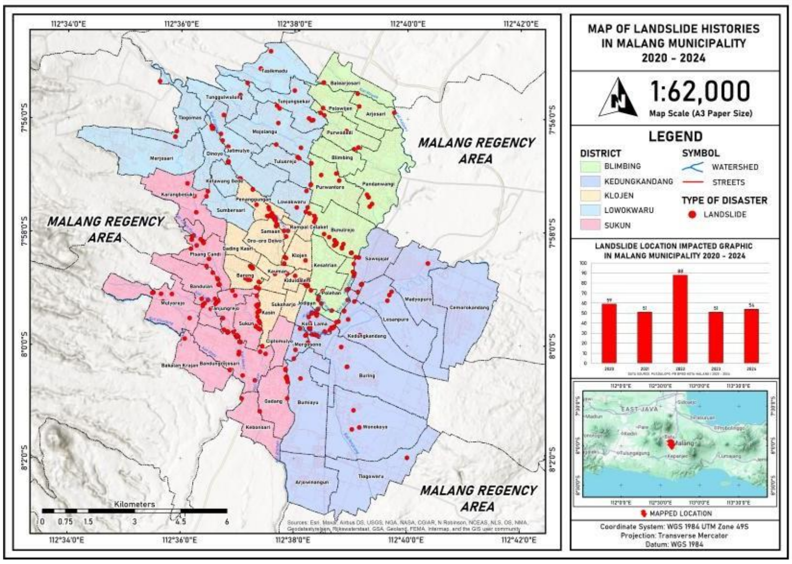

Figure 5. Map of Landslide Histories in Malang Municipality trough 2020-2024.

Source: Analysis result, 2025

Spatial data analysis revealed that landslide events in Malang Municipality were distributed across all districts, exhibiting a longitudinal pattern predominantly along the Brantas and Amprong River Basins, as well as in areas with relatively steep slopes. A closer examination shows that a greater number of landslides occurred in riparian zones (along riverbanks) than in areas solely characterized by high slope gradients. This indicates the significant influence of riverbank erosion caused by strong stream currents, which progressively undermine slope stability and reduce the soil's structural integrity, leading to slope failures.

High rainfall intensity also emerged as a key triggering factor for landslides, as it increases both river discharge and soil saturation, ultimately reducing soil cohesion. Salsabila et al. (2023) found that excessive rainfall increases the weight of surface soil layers, thus accelerating translational slides, particularly in residential areas near rivers. In addition, meandering sections of river channels tend to erode the outer banks, making slopes steeper and more prone to failure. Simbolangi (2017) noted that in such areas, if the subsurface is composed of weakly consolidated rocks and thick, soft weathered soil layers, landslides are more likely to occur due to lateral erosion and poor mechanical resistance.

The spatial analysis of landslide incidents during the 2020–2024 observation period recorded a total of 303 events across the city. Sukun District accounted for the highest number, with 85 landslides, followed by Klojen (68), Blimbing (59), Kedungkandang (54), and Lowokwaru (37). The highest annual average of landslide events across districts occurred in 2022, with a mean of 17.6 incidents. These results indicate that Sukun was the most frequently affected area, while Lowokwaru recorded the fewest incidents over the five-year period.

Based on historical data from 2020 to 2024, landslide incidents in Malang Municipality reached their highest annual frequency in 2022, with 81 recorded events. In comparison, 51 events were reported in both 2020 and 2023. The sharp increase in 2022 corresponds with the peak of abnormally high rainfall patterns, which were influenced by the positive phase of the El Nin˜o–Southern Oscillation (ENSO) and the negative phase of the Indian Ocean Dipole (IOD). These coupled climatic anomalies significantly contributed to increased soil moisture and instability across vulnerable slope areas, thereby intensifying landslide occurrences during that year.

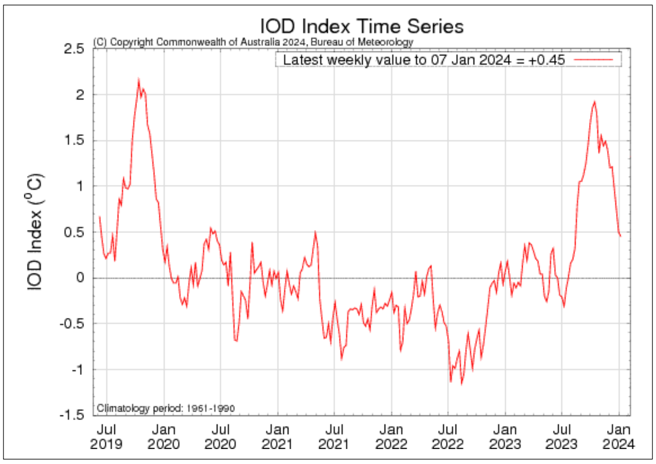

Figure 6. IOD Index Time Series 2019 - 2024
Source: Analysis result, 2025

The visualized data confirms that 2022 corresponded with a negative phase of the Indian Ocean Dipole (IOD), which amplified the effects of La Nin˜a, leading to intensified rainfall and making 2022 the year with the highest precipitation between 2020 and 2024. A study by Harahap (2023) conducted a direct analysis and reported a rainfall increase of approximately 54–90% compared to climatological norms. Another research presented a temporal analysis of the El Nin˜o–Southern Oscillation (ENSO) phenomenon across the past decade, highlighting that La Nin˜a episodes—including that of 2022—produced significantly higher precipitation (Yuniasih et al., 2023).

The increase in landslide occurrences is closely associated with these extreme rainfall levels, as hydrometeorological factors play a critical role in triggering slope failures in vulnerable areas. High water content reduces soil cohesion, both vertically and laterally, causing the landmass to become unstable. Landslides are a form of mass movement involving soil, rock, or a combination of both, moving downslope due to a disturbance in slope stability (Couture, 2011).

Landslide events were most prevalent in Sukun and Klojen Districts, which are traversed by several major rivers with fast-flowing currents and steep, unreinforced riverbanks. The absence of slope protection measures such as retaining walls increases susceptibility to landslides in these areas. Moreover, the presence of dense residential settlements along riverbanks exacerbates instability, as buildings constructed near the edge contribute additional loading while reducing the land's natural drainage and infiltration capacity. Rainwater that fails to percolate into the soil increases surface runoff, which gradually erodes topsoil and weakens its binding structure, eventually resulting in slope failure. The most severe damages and losses caused by landslides have occurred in riparian areas, where these conditions converge.

Policy measures are urgently needed to reduce future impacts based on this spatial and climatic analysis. Violations of spatial planning regulations (such as the construction of settlements in river buffer zones) have been shown to significantly increase disaster frequency and intensity (Jazuli, 2017). Therefore, stronger enforcement of zoning laws and integration of disaster risk considerations into spatial development planning are essential to minimizing vulnerability in high-risk areas.

Extreme Weather

Throughout the 2020–2024 observation period, Malang Municipality consistently experienced the intensification of extreme weather events, largely influenced by regional and global atmospheric dynamics. Phenomena such as the Madden–Julian Oscillation (MJO), equatorial Rossby waves, and sea surface temperature anomalies associated with neutral to La Nin˜a conditions in the El Nin˜o–Southern Oscillation (ENSO) region served as key atmospheric drivers. These dynamics triggered the formation of deep convective clouds, which led to episodes of heavy rainfall, strong winds, and lightning, particularly during seasonal transition periods. A study by the Meteorology, Climatology, and Geophysics Agency (BMKG, 2023a) indicated that active phases of MJO (phases 3 to 5) over southern Indonesia significantly contributed to increased rainfall, particularly in areas with complex topography such as Malang Municipality, which is surrounded by mountainous terrain.

Extreme weather is widely recognized as one of the consequences of ongoing climate change. According to the Implementation Guidelines for the Standard of Disaster Event and Impact Data (Regulation No. 7 of 2023), extreme weather is defined as an abnormal and atypical atmospheric phenomenon marked by irregularities in rainfall, wind direction and speed, temperature, humidity, and visibility. These conditions pose considerable risks to both life and property. Events classified under extreme weather disasters include tornadoes, strong winds, tropical cyclones, hailstorms, extreme temperatures, and related atmospheric disturbances (BNPB, 2023b).

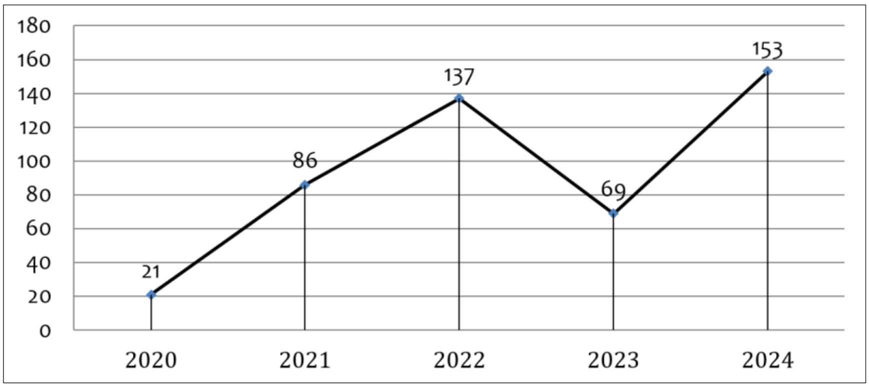

Figure 7. Graph of Extreme Weather Histories in Malang Municipality trough 2020-2024.
Source: Analysis result, 2025

Based on the recorded data on extreme weather events in Malang City from 2020 to 2024, there is a noticeable fluctuation influenced by regional and global atmospheric dynamics. In 2020, the number of extreme events was relatively low (21 incidents), largely due to the weak La Nin˜a that only emerged in the final quarter of the year. A significant increase occurred in 2021 (86 events) and peaked in 2022 (137 events), coinciding with the presence of moderate La Nin˜a conditions, active equatorial Rossby waves, and the Madden–Julian Oscillation (MJO) in its wet phases, all of which enhanced convective cloud formation (BMKG, 2023b). The Meteorological Station at Juanda further reported that these atmospheric disturbances triggered moderate to heavy rainfall accompanied by strong winds, particularly during the transition season and the onset of the rainy season (Kominfo Provinsi Jawa Timur, 2024).

In 2023, the number of events decreased to 69, aligned with neutral ENSO conditions and more stable rainfall patterns. However, in 2024, the number of events rose sharply to a five-year high (153 events), driven by record-breaking global surface temperature anomalies (NASA, 2024), as well as the occurrence of "wet drought" episodes and active atmospheric disturbances such as MJO and Kelvin waves. These factors contributed to heavy rainfall and sudden strong winds even during the dry season (BMKG, 2024). These findings suggest that the frequency of extreme weather events in Malang City is closely linked to the interaction between large-scale climate variability and local geographic features, particularly the city's mountainous topography, which exacerbates the impacts of convective weather systems.

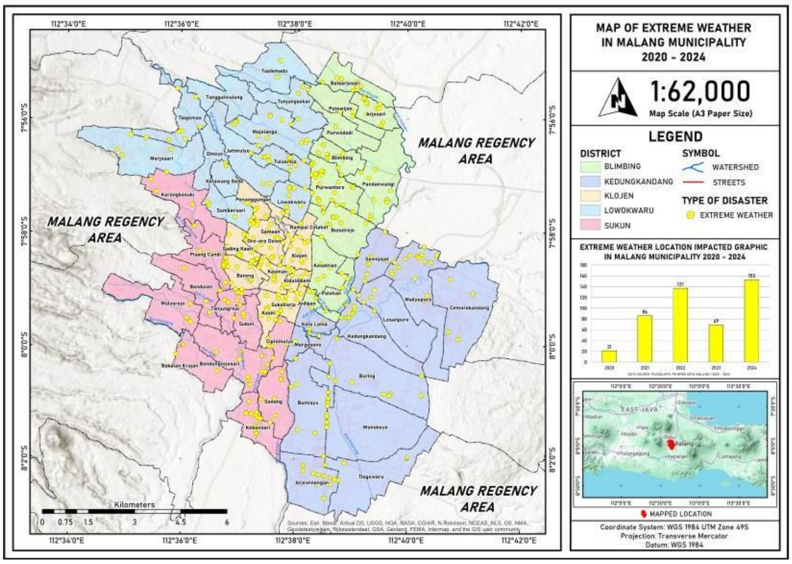

Figure 8. Map of Landslide Histories in Malang Municipality trough 2020-2024.
Source: Analysis result, 2025

The spatial distribution of extreme weather incidents in Malang Municipality between 2020 and 2024 reveals two dominant patterns. First, many events follow a linear trajectory along major roadways, indicating a strong correlation with the presence of large roadside trees that are vulnerable to strong winds. These linear patterns are predominantly observed in districts such as Blimbing, Lowokwaru, and central Klojen. Second, a more random spatial pattern is evident across densely populated residential areas, where strong wind events have frequently caused rooftop damages, particularly in Sukun and parts of Kedungkandang. This dual-pattern phenomenon illustrates the varying impact mechanisms of extreme weather-treefall in open urban corridors and direct wind-induced damage in compact housing zones. Temporally, the data indicates a fluctuating yet overall increasing trend in the frequency of extreme weather events. Reported incidents rose sharply from 21 cases in 2020 to a peak of 153 in 2024, with significant spikes observed in 2022 and 2024. Among the five administrative districts, Klojen recorded the highest cumulative cases (123 incidents), followed by Blimbing (101) and Kedungkandang (96). These districts not only represent core urban zones but also combine dense infrastructure with vulnerable green spaces, making them more susceptible to compounded hazards during climatic extremes.

Importantly, the occurrence and spatial extent of extreme weather events remain difficult to predict due to the dynamic and rapidly changing nature of atmospheric systems. This inherent unpredictability presents a critical challenge for urban disaster preparedness and demands the integration of historical incident data, spatial vulnerability assessments, and real-time meteorological monitoring. Incorporating these elements into disaster risk governance can support early action frameworks and enhance urban resilience against future extreme weather events.

This analysis underscores the urgent need for integrated urban risk reduction strategies. One of the key interventions is the proactive and systematic management of urban trees, particularly those located along high-risk corridors. Trees that are aging, oversized, or densely canopied should be prioritized for regular monitoring due to their vulnerability to toppling during heavy rain and strong winds. Relevant municipal agencies should establish routine inspection mechanisms to assess the health and stability of such trees, especially in locations with high public activity, dense traffic, or critical infrastructure. These efforts aim to reduce both direct damage from falling trees and the indirect risks posed to public safety and urban mobility.

In parallel, the structural reinforcement of rooftops and other vulnerable building components in densely populated settlements is essential to mitigate the impact of wind-driven damages. Targeted audits, retrofitting programs, and improved construction standards can strengthen community resilience in areas with lightweight housing structures. The implementation of localized early warning systems, tailored to the micro-climatic conditions of urban neighborhoods, is also necessary to improve preparedness and response. These systems should be supported by spatial vulnerability analysis, real-time meteorological data, and efficient dissemination channels. Together, these data-informed and context-sensitive measures form the foundation for a resilient urban environment in the face of increasing extreme weather hazards.

4. Conclusion

Based on the results of the analysis, spatial methods utilizing Geographic Information System (GIS) technology offer a new perspective on disaster data by transforming it into spatial representations. Historical disaster data, which was originally available in tabular format, can be transformed into spatial point data, enabling the identification of the spatial distribution of disaster occurrences. Furthermore, the point data can be analyzed using spatial join tools with administrative boundaries to calculate the frequency of disaster events in each area. From this analysis, it was found that out of a total of 1,439 disaster events recorded between 2020 and 2024, Klojen District experienced the highest number of incidents, accounting for 360 events (25.01%). In contrast, Lowokwaru and Sukun districts had the lowest number of incidents, with 259 events each (17.99%).

Spatial analysis of historical disaster events in Malang Municipality has been successfully conducted through the application of GIS, which enabled the conversion of tabular data into spatial data and its visualization into maps. Spatial data is crucial for all stages of disaster management, yet high-quality spatial data remains limited—particularly at the local level in developing countries. Strengthening the use of GIS for disaster management requires substantial data collection efforts, which must be supported by effective spatial data infrastructure (SDI) policies to ensure interoperability, accessibility, and consistent data standards.

The spatial pattern of disaster event locations in Malang Municipality appears to be dispersed across all five administrative districts. Among the disaster types analyzed, landslide events show the most discernible pattern, primarily forming a linear distribution along riverbanks and in areas characterized by dense contours and moderate-to-high slopes. Similarly, the distribution of extreme weather events also follows a linear pattern, as most affected areas are located along roadways lined with large, dense trees, making them vulnerable to strong winds. In contrast, flood events exhibit a more random distribution, with several points occurring along road segments and some within residential areas, as confirmed through spatial analysis and incident reports.

In light of these findings, both structural and non-structural mitigation efforts must be continuously implemented, tailored to the specific characteristics and geographic context of each disaster type. Risk reduction strategies should be guided by the Disaster Management Plan (RPB) and integrated into the Regional Medium-Term Development Plan (RPJMD) to ensure that disaster response efforts in Malang Municipality are effective, well-coordinated, and proactive in minimizing future damages, losses, and casualties.

Areas identified as high-risk zones should be carefully evaluated in spatial planning policies. Regions with high disaster vulnerability should be designated as protected areas within spatial land use planning, rather than being allocated for cultivation or development. If such areas must be developed, they should be accompanied by enhanced adaptation strategies and risk reduction measures to reduce the potential for disaster-induced losses and damage.

An integrated disaster management framework ensures that all phases—including prevention, mitigation, preparedness, emergency response, and recovery—are planned and coordinated across all levels of regional development. In the post-disaster phase, the implementation of Post-Disaster Needs Assessment (PDNA) and the formulation of the Rehabilitation and Reconstruction Plan (R3P) must adopt the principle of “build back better, safer, and sustainable,” grounded in disaster risk reduction while preserving local wisdom.

"The implications of this study highlight the need for the Malang City Government to strengthen the integration of spatial data into disaster management policies, particularly through the development of standardized and accessible Spatial Data Infrastructure (SDI) across institutions. This is crucial to ensure effectiveness in spatial planning, the designation of disaster-prone zones, and evidence-based decision-making. Furthermore, future research is recommended to develop spatially based predictive models that incorporate climate, socio-economic, and land use change variables, so that risk analysis can be carried out more comprehensively and proactively in addressing potential disasters in the future."

References

Alkaesi, F. (2020). *Analisis spasial kerawanan bencana hidrometeorologi di Kabupaten Bogor* [Tesis, Program Studi Manajemen Lingkungan, Sekolah Pascasarjana, Universitas Pakuan]. Universitas Pakuan. https://lib-pasca.unpak.ac.id/index.php?id=14197

Angriani, F. dan Kumalawati, R. (2016). *Pemetaan Bahaya Banjir Kabupaten Hulu Sungai Tengah Provinsi Kalimantan Selatan.* SPATIAL. 16(2), pp. 21–26.

Azzam, Tarek & David Robinson. (2013). *GIS in Evaluation: Utilizing the Power of Geographic Information Systems to Represent Evaluation Data*. SAGE Publications Volume 34, Issue 2. https://doi.org/10.1177/1098214012461710.

Badan Meteorologi, Klimatologi, dan Geofisika. (2023a). *Buletin Iklim Wilayah Jawa Timur: Dinamika Atmosfer dan Curah Hujan Ekstrem Tahun 2020–2023*. BMKG Stasiun Klimatologi Karangploso.

Badan Meteorologi, Klimatologi, dan Geofisika. (2023b). *Catatan Iklim Tahunan 2022–2023: Analisis Curah Hujan dan Cuaca Ekstrem di Indonesia* [Annual Climate Report 2022–2023: Rainfall and Extreme Weather Analysis in Indonesia]. Badan Meteorologi, Klimatologi, dan Geofisika (BMKG).

Badan Meteorologi, Klimatologi, dan Geofisika. (2024). *Infographic: Analysis of Extreme Rainfall Events in 2024 (East Java Regional Climate Center)*. Retrieved from https://staklim-jatim.bmkg.go.id/index.php/profil/meteorologi/list-of-all-tags/infografis-dasarian-analisis-kejadian-hujan-ekstrem-tahun-2024

Badan Nasional Penanggulangan Bencana. (2012). *Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012 tentang Pedoman Umum Pengkajian Risiko Bencana*. Jakarta: Badan Nasional Penanggulangan Bencana.

Badan Nasional Penanggulangan Bencana. (2017). *Buku Saku Tanggap Tangkas Tangguh menghadapi Bencana*. Jakarta: Badan Nasional Penanggulangan Bencana.

Badan Nasional Penanggulangan Bencana. (2023a). *Indonesian disaster risk (RBI risiko bencana Indonesia)* (Vol. 1). Badan Nasional Penanggulangan Bencana.

Badan Nasional Penanggulangan Bencana. (2023b). *Petunjuk pelaksanaan standar data kejadian dan dampak bencana (Peraturan Kepala BNPB Nomor 7 Tahun 2023)* [Implementation guidelines for the standard of disaster event and impact data (Regulation No. 7 of 2023)]. https://data.bnpb.go.id/dataset/juklak-standar-data-kejadian-dan-dampak-bencana.

Badan Nasional Penanggulangan Bencana. (2024)*. IRBI Indeks Risiko Bencana Indonesia Tahun 2024*. Jakarta: Badan Nasional Penanggulangan Bencana. ISSN 2985-6922.

Badan Pusat Statistik Kota Malang. (2024). *Kota Malang dalam Angka 2025*. Kota Malang: BPS Kota Malang.

British Geological Survey. (2011). *Landslide assessment*. Natural Environment Research Council. Geo Reports. Mam Tor Derbyshire UK.

Budiyanto, D., Trisya Septiana, & Mona Arif Muda. (2020). *Pemanfaatan Analisis Spasial untuk Pemetaan Risiko Bencana Alam Tsunami Menggunakan Pengolahan Data Spasial Sistem Informasi Geografis (Studi Kasus: Di Pesisir Lampung Selatan, Provinsi Lampung)*. Banjarmasin: Jurnal KLIK ULM Vol 7, No 2. http://dx.doi.org/10.20527/klik.v7i2.324

Couture R., (2011). *Landslide Terminology Nationanal Technical Guidelines and Best Practices on Landslides*. Geological Survey of Canada Open File 6824, 12p

CV Citiplan. (2024). *Laporan akhir penyusunan profil kerawanan bencana per-kelurahan se-Kota Malang (SPM sub urusan bencana)*. Pemerintah Kota Malang.

Delaforce, Wayne, Rich, Bruce, Savage, Bernadette, Adkins, Barbara, Hall, Carly, & Caldeweyher, Daniel. (2005). *GIS as a Tool for Decision Making and Evaluation*. In Bailey, C & Barnett, K

(Eds.). *Social Change in the 21st Century Conference Proceedings, 2005*. Australia: Queensland University of Technology, pp. 1-14.

England, T. G. (2024, January 9). *Using GIS to enhance decision-making*. ME&A Corporate Headquarters. https://www.meandahq.com/using-gis-to-enhance-decision-making/

Government of Indonesia. (2007). *Law of the Republic of Indonesia Number 24 of 2007 concerning disaster management.* Sekretariat Negara.

Government of Indonesia. (2020). *Presidential Regulation of the Republic of Indonesia Number 18 of 2020 concerning the National Medium-Term Development Plan 2020–2024*. https://peraturan.bpk.go.id/Details/135375/perpres-no-18-tahun-2020

Government of Indonesia. (2025). *Presidential Regulation of the Republic of Indonesia Number 12 of 2025 concerning the National Medium-Term Development Plan 2025–2029*. https://peraturan.bpk.go.id/Details/314638/perpres-no-12-tahun-2025

Harahap, W. N., Yuniasih, B., & Gunawan, S. (2023). *Dampak La Niña 2021–2022 terhadap peningkatan curah hujan.* AGROISTA: Jurnal Agroteknologi, 7(1), 26–32. https://doi.org/10.55180/agi.v7i1.364

Haryani, N. S., dan Zubaidah, A. (2012). Dinamika Siklon Tropis di Asia Tenggara menggunakan Data Penginderaan Jauh. 324: 54-58.

Intergovernmental Panel on Climate Change. (2012). *Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press.

Jazuli, A. (2017). *Penegakan Hukum Penataan Ruang Dalam Rangka Mewujudkan Pembangunan Berkelanjutan.* Jurnal Rechts Vinding: Media Pembinaan Hukum Nasional, 6(2), 263-282. doi: http://dx.doi.org/10.33331/rechtsvinding.v6i2.156

Khaidir, Indra. (2019). *Mitigasi Bencana Banjir Untuk Mengurangi Dampak Terhadap Lingkungan dan Kehidupan Sosial Masyarakat.* Jurnal Rekayasa, 8(2), pp 154-160.

Kominfo Provinsi Jawa Timur. (2024, January 17). *BMKG Juanda: Waspadai Cuaca Ekstrem di Jatim Periode 17–23 Januari 2024* [BMKG Juanda: Beware of Extreme Weather in East Java, January 17–23, 2024]. Retrieved from https://kominfo.jatimprov.go.id/berita/bmkg-juanda-waspadai-cuaca-ekstrim-di-jatim-periode-17-23-januari-2024

Mauliana, Sri M, Muryani Chatarina, Nugraha Setya. (2017). *Studi Kerentanan dan Mitigasi Bencana Banjir di Kecamatan Puring Kabupaten Kebumen Tahun 2016*. Jurnal GeoEco. 3(2). 157 – 163.

NASA. (2024). *2024 Sets New Global Temperature Record*. NASA Climate Change: Vital Signs of the Planet. Retrieved from https://climate.nasa.gov/news/

Noor, M, A. & Utomo, B. (2013). *Studi Kapasitas Sungai Riam Kiwa Menggunakan HEC-RAS 4.1.0.* Jurnal Info Teknik. 14(1), pp 81-91

Nurkhalifah, F., Yusup Nur Khakim, M., Affandi, A. K., et al. (2024). *Analisis terhadap dinamika curah hujan di Kota Palembang tahun 2019–2023 dan kaitannya dengan fenomena ENSO dan IOD.* Jurnal Penelitian Sains, 26(3).

Purwanto. (2019). *Geographic information system: Theory and practice with ArcGIS 10 [Sistem informasi geografi: Teori dan praktik dengan ArcGIS 10]*. Malang: Baskara Media.

Pusat Vulkanologi dan Mitigasi Bencana Geologi. (2025). *Wilayah Potensi Gerakan Tanah Di Provinsi Jawa Timur*. Bandung: PVMBG.

Renger R., Cimetta A., Pettrgrove S., Rogan S. (2002). *Geographic information systems (GIS) as an evaluation tool.* American Journal of Evaluation, 23, 469–479.

Riyadh, Ahmad M., Thomas J. Cova, Simon C. Brewer, Timothy W. Collins, Richard M. Medina, Laura Siebeneck, & Alexander Hohl, (2024). *Spatial analysis of disaster resilience research: A bibliometric study*. International Journal of Disaster Risk Reduction, Volume 113, ISSN 2212-4209, https://doi.org/10.1016/j.ijdrr.2024.104896.

Simbolangi, L. (2017). *Identifikasi Jenis Dan Karakteristik Longsor Di Daerah Aliran Sungai (Das) Lisu Kabupaten Barru*. Skripsi Unhas. Makassar.

Soebroto, A. A., Cholissodin, I., Wihandika, R. C., Frestantiya, M. T., & Arief, Z. El. (2015). *Prediksi tinggi muka air (TMA) untuk deteksi dini bencana banjir menggunakan SVR-TVIWPSO*. Jurnal Teknologi Informasi Dan Ilmu Komputer.

Stock, K., & Guesgen, H. W. (2016). *Geospatial reasoning with open data. In R. Layton, P. Watters, & R. Dazeley (Eds.), Automating open source intelligence: Algorithms for OSINT (pp. 171–204).*

Elsevier. https://doi.org/10.1016/B978-0-12-802916-9.00010-5
Sudipa, I Gede Iwan., dkk. (2023). Teknik Visualisasi Data. Jambi: Sonpedia Publishing.
Unwin, David. (2024). *Introductory Spatial Analysis.* London & New York: Routledge. https://doi.org/10.4324/9781003488354
Utami, N. D. (2019). Kajian Dampak Perubahan Iklim Terhadap Degradasi Tanah. Jurnal Alami, 3(2), 122-131.
Wirjohamidjojo, S. & Swarinoto, Y.S (2013). *Iklim Kawasan Indonesia*. Jakarta: Badan Meteorologi Klimatologi dan Geofisika.
Wise, S. M. (2014). *GIS fundamentals* (2nd ed.). Boca Raton: CRC Press. https://doi.org/10.1201/9781315380568
Wiyono, S. (2008). *Analisis penyebab tanah longsor di daerah pegunungan*. *Jurnal Geografi Indonesia, 10*(2), 45–56.
Yuniasih, B., Harahap, W. N., & Wardana, D. A. S. (2023). *Anomali iklim El Niño dan La Niña di Indonesia pada 2013–2022.* AGROISTA: Jurnal Agroteknologi, 6(2), 136–143. https://doi.org/10.55180/agi.v6i2.332