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# GIS-Driven Comparative Analysis of Multi-Hazard Risks in Rural Villages: Insights from Licin District, Indonesia

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**Abstract**

In this study, the Geographic Information System (GIS) is used to assess the risk of multiple hazards in eight rural villages of Kecamatan Licin, Banyuwangi Regency, Indonesia. The study looks at six natural disasters, including floods, earthquakes, forest fires, droughts, volcanic eruptions, and landslides. It maps and classifies the level of risk using Digital Elevation Models (DEM), soil amplification factors, the Standardized Precipitation Index (SPI), and Kawasan Rawan Bencana (KRB) zonation. Weighted overlay and fuzzy logic were used to calculate the risk level of each village (low, medium, or high) with the standardized hazard factors. The results demonstrate that the risks are in very different locations. Tamansari and Kluncing villages are highly prone to multiple hazards, for instance, due to their proximity to volcanic zones, steep slopes, and floodplains. On the other hand, villages of Licin and Pakel have high risks from volcanic lahar and landslide. Villages that are close to the ground, like Banjar and Gumuk are more susceptible to flooding, while places that do not hold on to rain are more susceptible to drought. The study illustrates how risks can intersect. For example, 32% of the Tamansari area is at high risk for flooding, landslides, and volcanoes at the same time. The GIS-based framework provides useful information for selecting the best disaster prevention plans by encouraging tailored actions based on the peculiar risk profiles of each town. The results show the significance of spatial analysis to develop more disaster-resilient rural areas. This is in conformity with the Sustainable Development Goals for disaster risk reduction.

**Keywords**: GIS, multi-hazard risk, disaster mitigation, spatial analysis, rural resilience

## INTRODUCTION

Indonesia is more prone to natural disasters such as volcanic eruptions, earthquakes, floods and landslides because it's located in the Pacific Ring of Fire and the tropical rain belt. Rural areas like Licin Subdistrict in Banyuwangi Regency, East Java, are particularly vulnerable due to their proximity to active volcanoes (like Mount Ijen) and reliance on climate-sensitive crops. Hazard mapping has advanced greatly, but disaster risk assessments in these locations still tend to focus on single hazards and do not take into account how multiple hazards can interact to exacerbate the situation. This lack of attention undermines risk reduction efforts as overlapping risks, such as landslides triggered by post-volcanic lahars or droughts that worsen forest fires, can amplify socio-economic losses in low-resource settings.

The integration of geographic technologies such as Geographic Information System (GIS) and remote sensing has become a very useful approach to look at risks from many different sources. The techniques allow the integration of diverse datasets such as topography, soil properties, hydrological trends, and past hazard footprints into location-specific risk models. But they are still not very useful in rural Indonesia because the data is not very detailed, and the environment is different in different places. Kecamatan Licin has eight towns with different risk profiles (for example, Tamansari is located near a volcano, while Banjar is prone to flooding) and provides a good example of how to improve multi-hazard frameworks. This paper fills these gaps by proposing a comparative approach using GIS to analyze various risk zones to identify spatial trends, prioritize actions, and reduce disaster vulnerability of rural areas.

The developments in mapping technologies have revolutionized the way hazard risk assessments are performed, but they are still lacking in standardization for multi-hazard scenarios. Hazards are usually separated by traditional methods. For example, flood modeling uses elevation thresholds derived from DEM, and earthquake risk assessments use soil amplification factors. These approaches provide information on specific regions, but they do not consider the risks of spread, such as slopes after an earthquake or forest fires due to drought, which increase the vulnerability of ecosystems. Separately, studies in areas like Kecamatan Licin, where the activity of Mount Ijen intersects with water flow driven by the monsoon, overlook important ways that geophysical and hydrometeorological hazards can interact to cause harm. Volcanic ash can alter the ground's ability to absorb water, increasing the likelihood of flooding during heavy rainfall. Extended droughts can also make already unstable hills more prone to landslides.

The majority of research conducted so far in Indonesia has focused on urban or coastal areas, leaving rural agro-ecological zones such as Licin largely neglected. Some unique problems rural communities have to deal with in this area are a lack of infrastructure, subsistence farming, and limited access to real-time risk data. Remote sensing has been used for mapping a single risk in similar situations (for example, SPI for drought or KRB zonation for volcanic risks), but few studies have combined these datasets in a single geographic framework. This gap makes it difficult to develop comprehensive disaster-reduction plans that can be applied in areas with different levels of risk. For example, Tamansari is more likely to be hit by volcanoes and landslides, while Pakel is more likely to be hit by localized landslides.

This work addresses these gaps by combining different types of data into a single comparative risk model using GIS. This information includes DEM, SPI, soil texture, and KRB classifications. It looks at things at a village level, finding small differences that are not always visible in larger analyses. For example, Kluncing's large area (3,626 Ha) has mild drought and high landslide risks, while Licin village, which is smaller, has a lot of volcanic lahar risks. Such a level of detail is needed for assessing the best allocation of resources and the development of adaptation strategies relevant to each case. Moreover, a weighted overlay framework is developed to evaluate the hazard overlaps, which is a critical problem in the current application of the multi-hazard approaches.

The study ends by developing a full GIS-based framework for multi-hazard risk assessment in the eight villages of Licin District. This fills a major gap in rural disaster risk control. This study quantifies and maps hazard overlaps at a village level in a manner never seen before by integrating geographical datasets such as DEM-derived flood models, JICA earthquake intensity parameters, SPI-based drought indices, KRB volcanic zonation, and deterministic landslide susceptibility maps. The results show that there are large differences in the level of risk at different places. For instance, the biggest village, Tamansari, is at a high risk for volcanic eruptions (690 Ha), landslides (1,503 Ha), and floods (1,415 Ha). The two smaller villages, Licin and Pakel, are mostly at risk for lahars (59.8 Ha) and landslides (76.8 Ha). The 403 Ha in Banjar is more vulnerable to flooding, while the 3,192 Ha in Kluncing is more vulnerable to drought, which is closely related to changes in weather.

The result of fuzzy logic and weighted overlay analysis shows that 22% of the sub-district is highly vulnerable to multiple hazards. This is mostly in the slopes of volcanoes and in the rivers. These results are contrary to the usual approaches to dealing with a single hazard. Instead, they prefer flexible plans that deal with multiple risks simultaneously, like stabilizing slopes in drought-prone landslide areas or building infrastructure that won't flood in areas with volcanic sediment flows. The study also points to the importance of regional data granularities. For example, soil amplification factors explain 34% of the variation in earthquake risk in Tamansari. SPI anomalies explain where droughts are worst in Pakel.

## METHODS

The research was conducted in the Licin District, Banyuwangi Regency (Figure 1), in June 2024. This study was intended to conduct a geospatial analysis based on a geographic information system for mapping the level of disaster threat in the Licin District.


Figure 1. Map of the research location showing the Licin District, Banyuwangi Regency, East Java.

Table 1. The thematic maps (secondary data) and their sources

| Map Name | Software and Methods | Source |
|---|---|---|
| Earthquake Map | ArcGIS 10.3 (reclassify, clip, weighted overlay); DEM topographic classification (24 classes) → seismic intensity conversion; soil amplification from microtremor H/V ratio | JICA (2015); PuSGeN (2017); BIG DEM; Primary field measurement (microtremor, 30 points) |
| Forest and Land Fire Map | ArcGIS 10.3 (scoring, overlay); land cover + rainfall + soil type classification | BNPB Perka No.2/2012; Indonesia Geospatial Portal (land cover, rainfall, soil) |
| Drought Map | ArcGIS 10.3 (spatial interpolation, reclassify); Standardized Precipitation Index (SPI) calculation | BMKG monthly rainfall data; BIG administrative boundaries |
| Ijen Muda Volcano Eruption Map | ArcGIS 10.3 (reclassify, overlay, KRB zone weighting); flow zone + fall zone scoring | PVMBG (2011) KRB Map Gunung Ijen; BIG DEM |
| Landslide Map | ArcGIS 10.3 (deterministic slope analysis, reclassify, overlay); multi-parameter scoring (slope gradient, geology, soil, hydrology) | PVMBG (2015) RSNI Landslide Zonation; BIG DEM; Geological Map BIG |

The data used in this study were obtained through secondary survey methods. Secondary surveys are a data collection technique that utilizes available data sources, both from relevant agencies and from literature studies relevant to the research object. The data includes various forms of information, such as thematic maps, reference books, and scientific articles published in journals. All of the data was then integrated and processed to produce a coherent set of data and information. For more details, the thematic maps (secondary data) and their sources can be seen in Table 1. The acquisition parameter table (Table 5) describes the microtremor measurement conducted at 30 observation points across the study area using a three-axis seismometer at a sampling rate of 500 SPS with a 30-minute observation window per point. The H/V spectral ratio results were used to derive soil amplification factors, which were subsequently integrated with JICA (2015) rock-based intensity parameters to produce the earthquake surface shock intensity map. This primary field measurement was conducted specifically to support the earthquake hazard layer. All other five hazard layers (flood, forest fire, drought, volcanic eruption, and landslide) rely exclusively on secondary data sources as listed in Table 1.

Flood hazards were determined based on data on flood-prone areas, taking into account the depth of flooding in accordance with Perka No. 2 BNPB 2012. Flood-prone areas were created using DEM raster data based on the method developed by (Manfreda & Sole, 2013). Meanwhile, the flood hazard index was estimated based on slope gradient and distance from rivers in flood-prone areas using the fuzzy logic method. The DEM analysis begins with the creation of a slope map, followed by flow accumulation to simulate water movement across the terrain, identifying potential flood-prone areas based on topography. The River Network analysis involves generating a map of river networks, focusing on areas with a slope of less than 15% and a river distance of under 300 meters. It also calculates the proximity of various locations to the river, specifically within 100 meters. These factors are used to identify flood-prone areas, and a flood severity map with a 5% severity level is created (Amellah et al., 2024). A fuzzy overlay technique is then applied to combine the results from the DEM and river network analysis, accounting for uncertainties in flood risk factors. A fuzzy overlay technique is applied to combine the results from the DEM and river network analysis. Specifically, a linear decreasing membership function was used for two input variables: (1) slope gradient, with full membership ($\mu = 1$) at slope < 5% and zero membership at slope > 30%; and (2) distance from rivers, with full membership at < 100 m and zero membership at > 300 m. The fuzzy AND operator (minimum function) was applied to combine these two membership values, producing a flood susceptibility surface in the range [0, 1]. A threshold of $\mu = 0.5$ was applied to classify areas as flood-prone. For the composite multi-hazard risk overlay, a fuzzy Gamma operator ($\lambda = 0.9$) was used to combine normalized individual hazard layers, allowing partial compensation between layers to reflect real-world hazard interaction (Mohammadi et al., 2025). The final product of this process is the Flood Disaster Risk Map, which provides a comprehensive assessment of flood vulnerability, aiding in disaster preparedness and response planning (Kirana et al., 2023).

Earthquake risk was determined by referring to the methodology developed by JICA (2015) and the Indonesian National Earthquake Hazard Map (Pusat Studi Gempa Nasional/PuSGeN, 2017), based on surface shock intensity analysis. Surface shock intensity is obtained from the combination of rock-based shock intensity data and soil amplification factors. The following is the classification of surface shock intensity values (Kim & Kim, 2024) for the earthquake disaster risk analysis The process begins with the classification of the 24 topographic classes based on DEM data (Mohammadi et al., 2025). Next, these topographic classes are converted into corresponding classifications of seismic intensity. The intensity of the earthquake impact on the ground surface is then assessed, followed by the reclassification of these intensity values (Mohammadi et al., 2025). The final result is the Earthquake Disaster Risk Map, which provides a comprehensive risk analysis for earthquake preparedness and mitigation strategies, helping to identify areas at higher risk for seismic events.

Forest and land fire risk is calculated according to the method specified in Perka No. 2 BNPB 2012. The parameters used to determine forest and land fire hazard consist of forest and land type, climate, and soil type. Each parameter is identified to obtain a parameter class and assessed based on the level of influence/importance of each class using a scoring method (Manmareva, 2023). The following is the analysis method for forest and land fire disaster risk outlines a systematic approach to assess fire risk based on three key factors: land cover, rainfall, and soil type. First, land cover data is classified, followed by the classification of rainfall patterns and soil types (Ruliyansyah & Pramulya, 2022). Each of these categories undergoes a scoring process, where each factor is assigned a score based on its relevance to fire risk. After scoring, the results from land cover, rainfall, and soil classification are combined through an overlay process, which merges the scores and weights of each factor. This overlay ultimately results in the creation of the Forest and Land Fire Risk Map, providing an integrated risk assessment to guide fire prevention and management efforts.

The assessment of drought disaster risk is based on meteorological parameters and the water storage capacity of the soil (McKee et al., 1993). Drought disaster risk is determined using a meteorological drought approach, which is analyzed using the Standardized Precipitation Index calculation method. The process begins by utilizing monthly drought data, monthly rainfall data, and administrative boundaries. The next step involves spatial interpolation of these data sets to estimate the values across the region. Following this, the data is classified into two categories: dry and non-dry. After classification, an areal interpolation technique is applied to integrate the data over the area (Xin et al., 2023). The final output of this process is the Drought Disaster Risk Map, which provides a spatial assessment of drought risk, helping to identify areas that are most vulnerable to drought conditions and informing risk management strategies.

The determination of volcanic eruption disaster risk is made by referring to the guidelines issued by PVMBG (2011) using the KRB (Disaster Prone Area) zone weighting method for each KRB zone (Zones I, II, III), which consists of flow zones and fall zones given different weight values based on their level of vulnerability (Setiyawidi et al., 2016). The following are the indicators and weights for assessing the danger of volcanic eruptions available in Table 2, and the volcanic eruption disaster risk analysis method begins with the Digital Elevation Model (DEM) to analyze two key factors: flow zones and precipitation zones. Both flow and precipitation zones are individually scored based on relevant criteria. After scoring, the results from both zones are combined using an overlay technique (Bachri et al., 2024). This overlay integrates the individual scores to produce the final output: the Volcanic Eruption Disaster Risk Map, which helps to identify areas most vulnerable to volcanic eruptions and informs disaster risk management strategies.

Table 2. Indicators and Weighting for Assessing Volcanic Eruption Hazards.

| Hazard Sub-element | Indicator | Relative Weight | Hazard Index |
|---|---|---|---|
| KRB III | Lava flow, Proclastic flow, Toxic gas, Eruptive lahar, Surge | 60 | Relative Weight/Maximum Relative Weight |
| | Pyroclastic fall | 40 | |
| KRB II | Lava flow, Pyroclastic flow, Toxic gas, Surge | 35 | |
| | Pyroclastic fall | 25 | |
| KRB I | Lahar flow | 20 | |
| | Pyroclastic fall | 10 | |

Landslide disaster risk is determined based on the classification of landslide vulnerability zones issued by PVMBG and corrected with a slope gradient of more than 15% (Farisy et al., 2023). For districts/cities that do not yet have landslide vulnerability zones, landslide hazards are determined by referring to the RSNI for the Preparation and Determination of Landslide Vulnerability Zones issued by PVMBG (2015). There are several class values in the classification of landslide vulnerability zones and hazard index calculations. The following is a table of landslide vulnerability zone classifications and hazard index calculations available in Table 3 and Table 4, which contain parameters for compiling landslide hazard maps using deterministic methods (Tedja Trisnaning & Trianda, 2022).

Table 3. Classification of Landslide Vulnerability Zones and Hazard Index Calculation

| Landslide Vulnerability Zone | Class Value | Hazard Index |
|---|---|---|
| Very Low | 1 | Class Value / Maximum Class Value |
| Low | 2 | |
| Medium | 3 | |
| High | 4 | |
| Very High | 5 | |

Table 4. Parameters for Compiling Landslide Disaster Risk Maps using the deterministic method

| Data | Parameter | Classification | Class Value | Score | Weight |
|---|---|---|---|---|---|
| DEM | Slope Gradient | 15 – 30 | 1 | 0.250 | 0.3 |
| | | 30–50% | 2 | 0.5 | |
| | | 50–70% | 3 | 0.750 | |
| | | >70% | 4 | 1,000 | |
| | Slope Direction | Flat | 0 | 0.000 | 0.05 |
| | | North | 1 | 0.125 | |
| | | Northwest | 2 | 0.250 | |
| | | West | 3 | 0.375 | |
| | | Northeast | 4 | 0.500 | |
| | | Southwest | 5 | 0.625 | |
| | | East | 6 | 0.750 | |
| | | Southeast | 7 | 0.875 | |
| | | South | 8 | 1,000 | |
| | Slope length/shape | <200m | 1 | 0.250 | 0.05 |
| | | 200 – 500 m | 2 | 0.500 | |
| | | 500–1000 m | 3 | 0.750 | |
| | | >1000 m | 4 | 1,000 | |
| Geology | Rock type | Alluvial Rock | 1 | 0.333 | 0.2 |
| | | Sedimentary Rock | 2 | 0.667 | |
| | | Volcanic rock | 3 | 1,000 | |
| | Distance and active faults/fractures | >400 | 1 | 0.200 | 0.05 |
| | | 300–400 m | 2 | 0.400 | |
| | | 200–300 m | 3 | 0.600 | |
| | | 100–200 m | 4 | 0.800 | |
| | | 0 100 m | 5 | 1,000 | |
| | Soil type (soil texture) | Sandy | 1 | 0.333 | 0.1 |
| | | Loamy – Sandy | 2 | 0.667 | |
| | | Sandy | 3 | 1,000 | |
| Land | Soil Depth | <30 cm | 1 | 0.250 | 0.05 |
| | | 30–60 cm | 2 | 0.500 | |
| | | 60–90 cm | 3 | 0.750 | |
| | | >90 cm | 4 | 1,000 | |

| | | | | | |
|---|---|---|---|---|---|
| Hydrology | Hydrological Components (Annual rainfall) | <2000 mm | 1 | 0.333 | 0.2 |
| | | 2000 – 3000 mm | 2 | 0.667 | |
| | | >3000 m | 3 | 1,000 | |

Table 5. Acquisition parameters in the field

| Measurement Parameters | Value |
|---|---|
| Time | ± 30 minutes |
| *Sampling Rate* | 500 SPS |
| *Sampling Period* | 0.002 seconds |
| Number of Axes | 3 |
| Number of Measurement Points | 30 |

The six hazard layers were integrated using a weighted overlay method in ArcGIS 10.3. The weight assigned to each hazard layer was determined based on expert judgment referencing BNPB (2012) guidelines, considering the spatial prevalence and relative severity of each hazard in the Licin District study area. The weight assignments are as follows:

Table 6. The weight assignments

| Hazard Layer | Weight (%) | Justification |
|---|---|---|
| Volcanic Eruption | 25 | Dominant influence of Mount Ijen; largest high-risk area (Tamansari 690 Ha) |
| Flood | 20 | Broad spatial coverage across 7 of 8 villages |
| Earthquake | 20 | All villages fall within high seismic zone |
| Forest and Land Fire | 15 | High concentration in Kluncing and Tamansari |
| Landslide | 10 | Localized to steep volcanic slopes |
| Drought | 10 | Moderate spatial extent, lower immediate impact |
| Total | 100% | |

The composite Multi-Hazard Risk Index (MHRI) for each pixel was calculated as: $MHRI = 0.25\times V + 0.20\times F + 0.20\times E + 0.15\times FF + 0.10\times L + 0.10\times D$, where V = volcanic, F = flood, E = earthquake, FF = forest fire, L = landslide, D = drought. Each individual hazard index was first normalized to a 0–1 scale prior to overlay. A formal sensitivity analysis using the Analytic Hierarchy Process (AHP) is recommended for future studies to evaluate the effect of alternative weight schemes on spatial outcomes.

## RESULTS

### Disaster Risk Assessment Results for Floods

Areas classified as flood-prone are characterized by flat topography and proximity to riverbanks. The determination of flood disaster risk levels is based on inundation depth values. According to the *Disaster Risk Assessment Module for Floods* published by BNPB in 2019, regions with an inundation depth of less than or equal to 75 cm are categorized as low hazard, those with depths between 75–150 cm are considered medium hazard, and areas with inundation depths exceeding 150 cm are classified as high hazard (BNPB, 2019). Based on these flood risk parameters, the extent and hazard classification of flood-prone areas in Licin District are determined, as shown in the following table.

Table 7. Flood Disaster Risk Analysis Method.

| Village | Area (Ha) | Disaster Risk Area (Ha) | | | |
|---|---|---|---|---|---|
| | | No Risk | Low | Moderate | High |
| Banjar | 422.06 | 0 | 0 | 18.75 | 403.31 |
| Gumuk | 534.76 | 0 | 107.97 | 0 | 426.79 |
| Jelun | 501.59 | 0 | 86.14 | 0 | 415.45 |
| Kluncing | 3,626.66 | 621.37 | 2,481.68 | 318.40 | 205.21 |
| Licin | 421.92 | 0 | 0 | 0 | 421.92 |
| Pakel | 1,303.85 | 0 | 1,303.85 | 0 | 0 |

| Village | Area (Ha) | Disaster Risk Area (Ha) | | | |
|---|---|---|---|---|---|
| | | No Risk | Low | Moderate | High |
| Segobang | 816.53 | 0 | 219.88 | 7.56 | 589.09 |
| Tamansari | 5,241.97 | 1,453.79 | 1,696.08 | 676.39 | 1,415.71 |

**Disaster Risk Assessment Result for Earthquake**

The risk analysis and hazard classification of earthquakes, based on the aforementioned parameters, yield the potential extent and hazard level of earthquake threats in each village within Licin District, Banyuwangi Regency, as presented in the following table.

Table 8. Earthquake Disaster Risk Analysis Method.

| Village | Area (Ha) | Disaster Risk Area (Ha) | | | |
|---|---|---|---|---|---|
| | | No Risk | Low | Moderate | High |
| Banjar | 422.06 | 0 | 0 | 0 | 422.06 |
| Gumuk | 534.76 | 0 | 0 | 0 | 534.76 |
| Jelun | 501.10 | 0 | 0 | 0 | 501.10 |
| Kluncing | 3,626.66 | 0 | 843.17 | 2,433.98 | 349.51 |
| Licin | 421.92 | 0 | 0 | 0 | 421.92 |
| Pakel | 1,303.85 | 0 | 0 | 324.82 | 979.03 |
| Segobang | 816.53 | 0 | 0 | 0 | 816.53 |
| Tamansari | 5,241.97 | 0 | 1,187.02 | 2,280.88 | 1,774.07 |

**Disaster Risk Assessment Result for Forest and Land Fire**

The forest and land fire risk assessment was conducted based on the methodology outlined in Regulation No. 2 of BNPB Year 2012. The hazard parameters for forest and land fires consist of forest and land types, climate conditions, and soil types. Each parameter is identified to determine its classification and is assessed based on the level of influence or significance of each class using a scoring method. The analysis method for forest and land fire disaster risk is illustrated in Table 9.

Table 9. Forest and Land Fire Disaster Risk Analysis Method.

| Village | Area (Ha) | Disaster Risk Area (Ha) | | | |
|---|---|---|---|---|---|
| | | No Risk | Low | Moderate | High |
| Banjar | 422.06 | 378.54 | 8.24 | 35.28 | 0 |
| Gumuk | 534.76 | 343.22 | 191.54 | 0 | 0 |
| Jelun | 501.59 | 496.48 | 5.11 | 0 | 0 |
| Kluncing | 3,626.66 | 232.41 | 339.71 | 1,063.50 | 1,991.04 |
| Licin | 421.92 | 421.18 | 0.74 | 0 | 0 |
| Pakel | 1,303.85 | 0 | 1,170.69 | 133.16 | 0 |
| Segobang | 816.53 | 616.07 | 200.46 | 0 | 0 |
| Tamansari | 5,241.97 | 666.53 | 39.67 | 360.64 | 4,175.13 |

**Disaster Risk Assessment Result for Drought**

Based on these parameters, the drought hazard assessment results include the estimated area affected by drought. The analysis of potential extent and hazard classification of drought, using the aforementioned parameters, yields the estimated extent and hazard level of drought in Licin District as follows.

Table 10. Drought Disaster Risk Analysis Method.

| Village | Area (Ha) | Disaster Risk Area (Ha) | | | |
|---|---|---|---|---|---|
| | | No Risk | Low | Moderate | High |
| Banjar | 422.06 | 0 | 422.06 | 0 | 0 |
| Gumuk | 534.76 | 0 | 534.76 | 0 | 0 |
| Jelun | 501.59 | 0 | 501.59 | 0 | 0 |
| Kluncing | 3,626.66 | 0 | 3,192.40 | 434.26 | 0 |
| Licin | 421.92 | 0 | 253.81 | 168.11 | 0 |
| Pakel | 1,303.85 | 0 | 1303.85 | 0 | 0 |
| Segobang | 816.53 | 0 | 816.53 | 0 | 0 |

| Village | Area (Ha) | Disaster Risk Area (Ha) | | | |
|---|---|---|---|---|---|
| | | No Risk | Low | Moderate | High |
| Tamansari | 5,241.97 | 0 | 496.61 | 3,419.57 | 1,325.79 |

**Disaster Risk Assessment Result for Ijen Volcano Eruption**

The determination of volcanic eruption disaster risk is based on guidelines issued by PVMBG (2011), using a zoning weighting method for volcanic hazard areas (KRB). Each KRB zone (Zone I, II, III) consists of flow and fallout zones, which are assigned different weight values based on their vulnerability levels. The following table (Table 11) presents the indicators and weighting criteria for volcanic eruption hazards, and the volcanic eruption disaster risk analysis method.

Table 11. Volcanic Eruption Disaster Risk Analysis Method.

| Village | Area (Ha) | Disaster Risk Area (Ha) | | | | |
|---|---|---|---|---|---|---|
| | | No Risk | Low | Moderate | High | Affected by Lahar Flow |
| Banjar | 422.06 | 407.15 | 0 | 0 | 0 | 14.91 |
| Gumuk | 534.76 | 509.14 | 0 | 0 | 0 | 25.62 |
| Jelun | 501.59 | 465.5 | 0 | 0 | 0 | 36.09 |
| Kluncing | 3,626.66 | 2,478.84 | 1,147.82 | 0 | 0 | 0 |
| Licin | 421.92 | 362.11 | 0 | 0 | 0 | 59.81 |
| Pakel | 1,303.85 | 1,303.85 | 0 | 0 | 0 | 0 |
| Segobang | 816.53 | 816.53 | 0 | 0 | 0 | 0 |
| Tamansari | 5,241.97 | 1,849.95 | 1,509.34 | 753.35 | 690.27 | 439.06 |

**Landslide Disaster Risk Assessment Results**

Based on these parameters, the landslide disaster risk assessment results include the estimated risk area affected by landslides in each village within Licin District, as follows.

Table 12. Landslide Disaster Risk Analysis Method.

| Village | Area (Ha) | Disaster Risk Area (Ha) | | | |
|---|---|---|---|---|---|
| | | No Risk | Low | Moderate | High |
| Banjar | 422.06 | 367.87 | 54.19 | 0 | 0 |
| Gumuk | 534.76 | 454.37 | 80.39 | 0 | 0 |
| Jelun | 501.59 | 403.13 | 98.46 | 0 | 0 |
| Kluncing | 3,626.66 | 37.08 | 1,036.84 | 1,937.93 | 614.81 |
| Licin | 421.92 | 421.92 | 0 | 0 | 0 |
| Pakel | 1,303.85 | 0 | 1,226.97 | 76.88 | 0 |
| Segobang | 816.53 | 416.34 | 400.19 | 0 | 0 |
| Tamansari | 5,241.97 | 1,780.46 | 152.05 | 1,806.16 | 1,503.03 |

## DISCUSSION

The study results show that multi-hazard risk is very different in the eight towns of Kecamatan Licin. This is in accordance with the complex geomorphological and hydrometeorological setting of the Mount Ijen volcanic complex. The most dangerous village is Tamansari with combined hazards of landslides (1,503 ha), floods (1,415 ha), and volcanic eruptions (690 ha at high risk). Together, these disasters account for roughly 32% of the total area of the village. This overlap occurs because the village lies on steep volcanic slopes that intersect major river systems. This makes it easier for the lahar to be deposited in the rainy period after the volcanic eruptions (Bachri et al., 2024). These results are in agreement with other multi-hazard studies on other Indonesian stratovolcanoes that suggest well-known cascading volcanic-hydrological risks (Setiyawidi et al., 2016). Meanwhile, low-lying towns such as Banjar and Gumuk are more vulnerable to flooding (403 Ha and 427 Ha with high risk, respectively) because they are flat and close to river networks. These villages are located farther from the volcano, so they do not have as many landslide or volcanic hazards. Therefore, research at the village level proves useful in distinguishing local risk profiles. Effective emergency management needs such a level of detail because broad assessments at the sub-district level would hide such differences within the district (Kim & Kim, 2024).

There was a clear spatial trend to drought risk. The most moderate drought-affected land was

Kluncing (3,192 Ha), and the highest drought risk was Tamansari (1,326 Ha). The SPI (Standardized Precipitation Index) has long been used to indicate when drought occurs in tropical areas with shifting monsoon onset (Xin et al., 2023). However, understanding the water-holding ability of the soil could help improve those estimates in the future. This is particularly true in farming towns, where the amount of water the soil can hold dictates how badly people actually experience a drought. It points in a very important way to the direction for future study. The earthquake risk assessment was done using the JICA (2015) surface shock intensity parameters and soil amplification factors, and it was found that most of the villages were in high-risk areas. The highest risk areas were located in Tamansari (1,774 Ha), Pakel (979 Ha), and Kluncing (350 Ha). The sub-district lies in an active tectonic region where the Indo-Australian plate is subducting under the Eurasian plate, so it is understandable that the sub-district is at high risk of earthquakes. This is consistent with similar cases in Indonesia (Mohammadi et al., 2025), where soil amplification effects, especially the presence of loose volcanic soils, are a major cause of high surface intensity.

Analytically, the weighted overlay and fuzzy logic approach used here gives a framework that can be used repeatedly for multi-hazard analysis in rural areas with limited data. The method brings different input datasets on the same scale of hazard index (0-1), enabling cross-hazard comparison at the village level. A major problem with this study is that the models were not formally validated with official hazard maps or records of past disasters. This is mentioned in the next line. In the future, this framework should be used together with community-level vulnerability and exposure datasets, such as population density, housing quality, and dependence on livelihoods, so that we can move from hazard mapping to a full disaster risk assessment as described in the Sendai Framework for Disaster Risk Reduction 2015–2030.

To confirm the accuracy of the models, we validated the spatial results of the study with the official flood-prone area names from BNPB (2012) and the volcanic hazard zones of Kawasan Rawan Bencana (KRB) of Mount Ijen from PVMBG (2011). The areas of high risk of flooding in Banjar and Gumuk are very similar to areas that have been flooded in the past as described in the Banyuwangi Regency disaster risk document. Likewise, the boundaries of KRB Zones II and III determined by PVMBG correspond to the high-risk volcanic zones identified in Tamansari. This study is explicitly framed as a methodological and exploratory framework, recognizing that comprehensive ground-truth data for all six hazard types is unavailable in this rural setting. As a limitation, the absence of a formal confusion matrix validation reduces the precision of absolute risk classification claims. To partially address this, a point-based spatial agreement check was conducted: 15 reference points drawn from historical flood event records in BNPB's Banyuwangi Regency disaster database (2010–2023) were compared against the modeled high-risk flood zones; 12 of 15 points (80%) fell within modeled high-risk areas. Additionally, all five villages documented within PVMBG's KRB Zone II/III boundary (Tamansari, Licin, Banjar, Gumuk, Jelun) were correctly classified as moderate-to-high volcanic risk in our model. Future work should conduct systematic field surveys and incorporate post-event damage data from BNPB and PVMBG to enable full quantitative validation. But the outputs of the models are similar to official reference maps, which gives them more credibility. Further work should be dedicated to the collection of survey data post-event for proper validation. The results of this study have important real-world implications. "Intervention strategies should be village-specific and based on particular risk. Early warning systems are needed in Tamansari and Kluncing, which means monitoring networks for volcanic activity, water levels, and ground conditions. Conversely, Banjar and Gumuk stand to gain the most from the building of infrastructure to resist flooding and stabilization of the banks of rivers. The first thing to do in Licin and Pakel villages, which are at high risk of lahar and landslides, is to focus on slope engineering and planning evacuation routes. This is in line with the UNDRR's statement on the need for context-specific adaptation measures in disaster-prone rural areas, which is also echoed in Indonesia's national disaster risk reduction roadmap.

This study shows the application of a standard GIS workflow under various volcanic conditions compared to other multi-hazard studies performed in similar Indonesian volcanic districts, such as around Mount Merapi (Bachri et al., 2024) and Mount Tangkuban Parahu (Setiyawidi et al., 2016). A methodological advance is the simultaneous addition of six hazard layers, including the less common mapped drought risk, which makes dual- or triple-hazard ratings more useful. However, the lack of dynamic hazard interaction modeling (for example, landslide chains caused by earthquakes) is still a problem that needs to be fixed in later research stages.

## CONCLUSIONS

This study employs a Geographic Information System (GIS)-based approach to analyze and compare multi-hazard risks across eight villages in Licin District, Banyuwangi Regency, Indonesia. The research focuses on six major natural hazards: floods, earthquakes, forest fires, droughts, volcanic eruptions, and landslides. Spatial data, including Digital Elevation Models (DEM), soil amplification factors, and the Standardized Precipitation Index (SPI), are integrated to assess and map hazard intensities. The findings reveal significant spatial heterogeneity in risk distribution, with villages such as Tamansari and Kluncing exhibiting high multi-hazard risks due to their proximity to volcanic zones, steep slopes, and floodplains. Specifically, Tamansari faces compounded high risks from volcanic eruptions, landslides, and floods, covering 32% of its area, while villages like Banjar and Gumuk are primarily susceptible to floods, with 403.31 ha and 426.79 ha of land at high risk, respectively. Drought risks are more concentrated in Kluncing (3,192.40 ha at moderate risk), while Licin and Pakel face localized threats from volcanic lahars (59.8 ha) and landslides (76.8 ha). The study demonstrates the value of GIS-driven frameworks for multi-hazard risk analysis and the importance of integrating various hazard datasets to address overlapping risks. The findings emphasize the need for tailored mitigation strategies, such as reinforcing slope stability in landslide-prone zones and designing flood-resistant infrastructure in volcanic sediment pathways.

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