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RESEARCH ARTICLE

Potential of UAV-Generated Orthophotos in Assessing Environmental Vulnerability to Landslides in Ngasinan Village, Purworejo Regency, Central Java

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Abstract. Ngasinan Village in Bener District, Purworejo Regency, has mountainous and sloping topography, which increases the risk of landslides. However, there is currently no available information regarding the village's environmental vulnerability to landslides, which is essential for disaster mitigation planning. This study aims to assess the environmental vulnerability to landslides in Ngasinan Village using orthophotos as an alternative to a census. The primary data used in this research include aerial photographs taken by an unmanned aerial vehicle (UAV) and Ground Control Points (GCPs) to ensure the accuracy of the orthophotos. The vulnerability parameters analyzed include socio-economic and physical environmental aspects. Aerial photo interpretation was used to identify building structures, the type of predominant walls, building age, building area, electricity usage, and distance from proper roads. The Digital Terrain Model (DTM) was used to extract parameters such as topographic clusters, topographic elevation, distance to steep slopes, and distance to very steep slopes. Environmental vulnerability analysis was conducted using interview data and questionnaires from research samples. The results show that Ngasinan Village falls into the medium vulnerability class. Orthophotos proved to be an accurate data source for assessing environmental vulnerability to landslides, with an accuracy rate of 86.66%. Furthermore, information on the vulnerability of houses to landslides can be obtained more easily and quickly through observation and interpretation of orthophotos compared to the census method.

1. Introduction

Landslides are one of the frequent hydrometeorological disasters in Indonesia, alongside floods and tornadoes. Landslides represent a significant natural threat as they can result in fatalities, property damage, and loss of agricultural land (Guru et al., 2017, Darrozes et al., 2018, Case & Sarkar, 2019). This hazard primarily affects rural communities residing on hillsides, who often live in poverty, have inadequate access to basic services, and are heavily dependent on natural resources (Luo et al., 2021, Mirdda et al., 2022).

Landslides are influenced by various factors, including geomorphic and hydrological aspects. Geomorphic factors include slope gradient, slope shape, aspect and elevation, slope steepness, and soil thickness. Hydrological factors involve rainfall, soil hydrology, infiltration, subsurface flow, pore water pressure, vegetation, evapotranspiration, and root strength (Haneberg, 2007). High rainfall can cause surface runoff on hillsides, where water infiltrating into natural or man-made slopes can trigger slope instability, surface erosion, and ultimately landslide (Luo et al., 2020).

Ngasinan Village, located in the Kodil and Bogowonto Sub-Watersheds, experiences an average annual rainfall of 2,859 mm over the past nine years. The area has thick soil material (Surya et al., 2019), and the combination of thick and sloped soil makes it highly susceptible to large-scale landslides. Although land use in Ngasinan Village is dominated by mixed gardens with high vegetation density, landslides in this village tend to occur in areas with steep to very steep slopes, particularly in agricultural land with low vegetation density, residential areas, and roads. Therefore, the focus of environmental vulnerability assessment in this village is on residential areas.

Environmental vulnerability to landslides can be defined as the inability of communities to prevent, mitigate, prepare for, and respond to landslide threats, influenced by biological, geographical, legal, economic, political, cultural, and technological conditions (BNPB, 2012). Data from BNPB shows that the impacts of landslides include included damage to residential houses, educational facilities, health facilities, places of worship, offices, and public facilities (BNPB, 2008). Over the past thirteen years, thousands of houses have been damaged by landslides in Indonesia annually. Tabel 1. shows the most of houses damaged in 2017 reached 7.917 buildings, and total of houses damaged by landslides in Indonesia in 2010-2022 (BNPB, 2023).

The lack of environmental vulnerability data at the village level provides the basis for this study. This research aims to (1) assess the environmental vulnerability to landslides in

Table 1. Number of Houses Damaged Due to Landslides in Indonesia in 2010-2022

Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Numbers	2.962	7.007	1.346	2.305	4.516	1.494	3.114	7.917	3.238	1.763	3.303	3.367	2.083

Data source: BNPB, processed (2023).

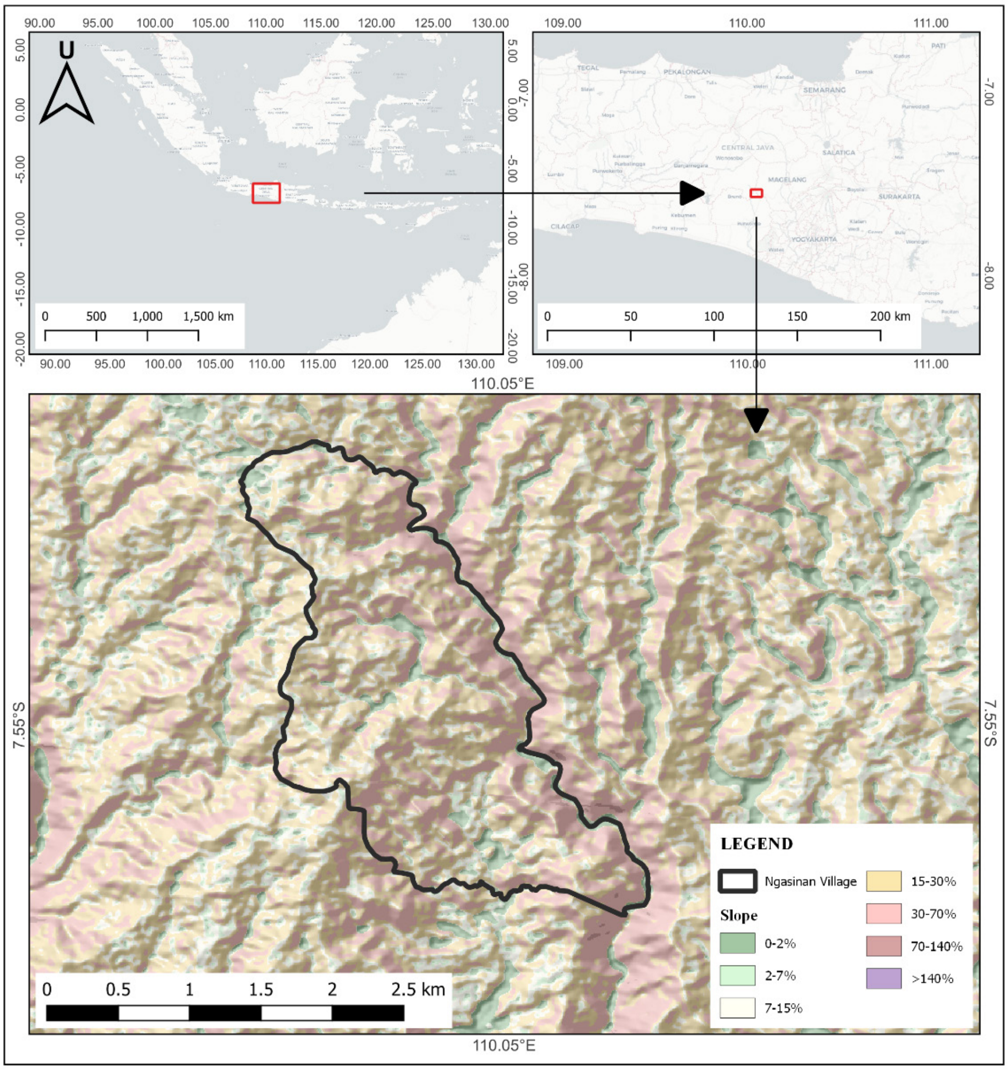

Figure 1. Map of Study Site of Ngasinan Village in the Bener District of the Purworejo Regency

Desa Ngasinan using orthophotos, and (2) determine the distribution of house vulnerability to landslides in the village. The assessment covers both social-economic and physical dimensions, with the analysis conducted based on data collected through interviews and questionnaires. The results will be classified into low, medium, and high vulnerability categories. The analytical methods employed in this study are adaptations of those used in previous research.

Traditional methods of assessing building vulnerability to landslides include field observation, census, and medium-scale mapping, as conducted by Noveberian et al. (2017), Mendonca & Silva (2020), and Gao et al. (2022). However, census-based research requires substantial time and cost. Fariz (2019) assessed physical building vulnerability to landslides using small-format aerial photographs, while Setyawan (2016) conducted landslide risk assessments through the interpretation of small-format 2D aerial photographs. Given the close relationship between landslides and the socio-economic systems and physical conditions of households in mountainous regions, Mirdda et al. (2022) recommend combining Geographic Information Systems (GIS) and participatory approaches for household vulnerability assessments. Ebert et al. (2009) evaluated urban social vulnerability with physical approaches and contextual analysis using GIS data, while Assis Dias et al. (2020) integrated various vulnerability categories, including age, gender, per capita income, and infrastructure facilities at the municipal level.

In this context, data collection through orthophotos offers an efficient and innovative solution. Orthophotos, obtained from aerial photographs using drones, enable a comprehensive and rapid assessment of settlement characteristics. This method combines accurate visual approaches to identify and analyze relevant environmental elements, such as building structures and land use. Using orthophotos allows for a faster and more accurate assessment of house vulnerability to landslides compared to traditional census methods. Orthophotos provide detailed visual data that facilitate the creation of vulnerability maps, which can aid in more effective disaster risk planning and management.

2. Methods

Study Area

The research area is Desa Ngasinan in Bener District, Purworejo Regency, which directly borders Wonosobo Regency and Magelang Regency (Figure 1). Desa Ngasinan covers an area of 4.54 km^2 and is divided into six hamlets with a population of 664 households and 2,124 people. The morphology of Desa Ngasinan consists of upper and middle slopes of hills. The slope classification of the area includes flat regions (7.99%), gently sloping (15.40%), moderately steep (25.70%), steep (32.20%), and very steep (18.69%).

Data Collection Method

The research employs aerial imagery data, acquired using a DJI Phantom 4 Pro drone. Table 2 outlines the specifications of the unmanned aerial vehicle (UAV) and camera used. Flight paths were planned before capturing aerial photos, based on the area and location of the study. Flight path planning utilized the DJI Go and Pix4D Capture applications. Ground Control Points (GCP) were marked using a GPS GNSS (Global Positioning System Geodetic Global Navigation Satellite System) Navcom SF-3040, which is a receiver with centimeter-level accuracy. Measurements were conducted using Real Time Kinematic (RTK) methods.

GCP locations were chosen in areas with open vegetation cover. The distribution of GCPs considered both the edge and center of the study area, as well as varying site characteristics. Location features such as ridges, valleys, or relatively flat areas resulted in varying distances between GCPs (see Figure 2). Independent Check Points (ICP) were used to test the accuracy of geometrically corrected images against the GCPs. The orthophoto of Desa Ngasinan has a Horizontal Root Mean Square Error (RMSE) of 0.52 and a CE90 value of 0.79. The Vertical Root Mean Square Error (RMSE) is 1.15, and the LE90 value is 1.89. The orthophoto has a CE90 value suitable for mapping at a scale of 1:5,000 and an LE90 value suitable for mapping at a scale of 1:10,000 (BIG, 2014; BIG, 2018). The distribution of ICPs is shown in Figure 2.

Orthophoto interpretation

Orthophotos and Digital Terrain Models (DTM) were used to interpret objects in the study area. Object digitization from the orthophotos utilized image interpretation keys. A total of 627 residential buildings were interpreted. The interpretation key for assessing socio-economic vulnerability employed a physical approach using geoinformatics. The interpretation key was developed based on interviews, questionnaires, and field observations of 72 sample houses in Desa Ngasinan. This key was then applied to 525 buildings, with validation performed on 30 houses.

The interpretation key for assessing socio-economic vulnerability consists of six parameters: building structure, type of predominant wall, building age, building area, distance to an accessible road, and electricity consumption level. Building structure is assessed based on roof shape, with common roof types being limasan, kampung pelana (gable), and srotongan. The type of predominant wall is interpreted using roof shape associations. Buildings with limasan and pelana roof types, and those with clay tile, metal, or asbestos roofs, are interpreted to have walls made of brick, hebel, or batako. Wooden and mixed bamboo walls are associated with older building models and simpler house designs without canopies or additional structures, and clay tile roofs with dark brown or uneven colors. Roof color is used as a proxy for physical vulnerability; light brown, bright, and clean roofs indicate good material quality and average building age under 30 years, while roofs older than 30 years typically show dark brown colors with uneven shades.

Table 2. UAV and Sensor Details

Detailed description	Aerial Photo 2022
UAV	
Flying height	150 m
Relative total flight time	540 minute
Coverage area	7.37 km^2
Estimate speed	10 m/s
Autopilot	Autopilot
Distance from launchpad to coverage area	900 m
Sensor	Visible sensor
Camera	
Image dimension (pixels)	2.41 x 2.41 µm
Focal length (mm)	8.8
Number of images	4684
Image overlay	4677
Images synchronized with GPS	447
Error tie points (pixels)	0.161
Format	Frame
Pixel size (µm)	2.41 x 2.41
Angular field of view	Vertical angle 90°
Survey	
Ground sampling distance (m/pix)	0.0495

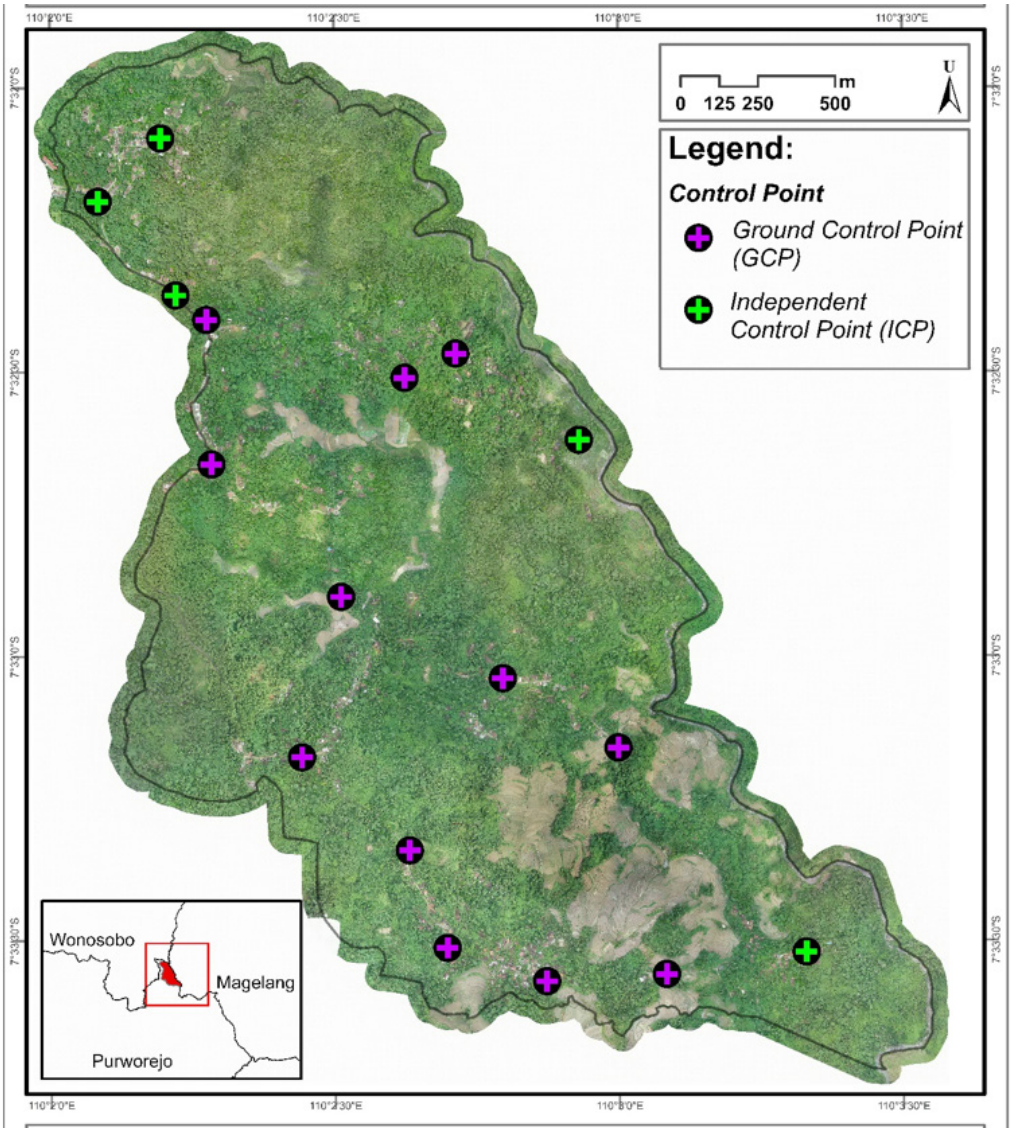

Figure 2. Distribution Map of GCP and ICP Points in the Study Area

Table 3. Assessment of Environmental Vulnerability

	Dimension of Environmental Vulnerability	Parameter	Ranking	Number of Houses (units)
		Social-Economic Vulnerability		
1.	Building Structure	Roof Type: Limasan	1	34
		Roof Type: Pelana	2	586
		Roof Type: Srotongan	3	7
2.	Widest Wall Type	Wall Type: Brick (Bata, Hebel, Batako) with Limasan and Pelana Roof	1	592
		Wood (Wood and Bamboo) with Srotongan or Pelana Gandeng Roof	2	35
3.	Building Age	Roof Color: Light (Age ≤30 years)	1	559
		Roof Color: Dark (Age >30 years)	2	68
4.	Building Area:	Building Plot Area >200 m^2	1	147
		Building Plot Area >200 m^2	2	379
		Building Plot Area ≤100 m^2	3	101
5.	Distance to Access Road (paved/ embanked for 4-wheel vehicles)	Distance to paved/embanked road ≤50 m	1	468
		Distance to paved/embanked road 50-100 m	2	109
		Distance to paved/embanked road >100 m	3	50
6.	Electricity Consumption Level:	High, with satellite dish	1	283
		Low, without satellite dish	2	344

		Physical Environmental Vulnerability		
1.	Building Cluster in Topographic Conditions	Flat Land, clustered	1	103
		Ridge Land, aligned	2	113
		Sloped Land, dispersed	3	411
2.	Building Position Relative to Elevation:	Elevation ≤450 meters above sea level	1	71
		Elevation 450-550 meters above sea level	2	183
		Elevation >550 meters above sea level	3	373
3.	Distance of Building from Steep Slope	Distance from steep slope >15 m	1	83
		Distance from steep slope 5-15 m	2	102
		Distance from steep slope ≤5 m	3	442
4.	Distance of Building from Very Steep Slope	Distance from very steep slope >35 m	1	116
		Distance from very steep slope 15-35 m	2	173
		Distance from very steep slope ≤15 m	3	338
		House Vulnerability Class to Landslides		
		Low	≤ 18	235
		Moderate	19-21	315
		High	≥22	77

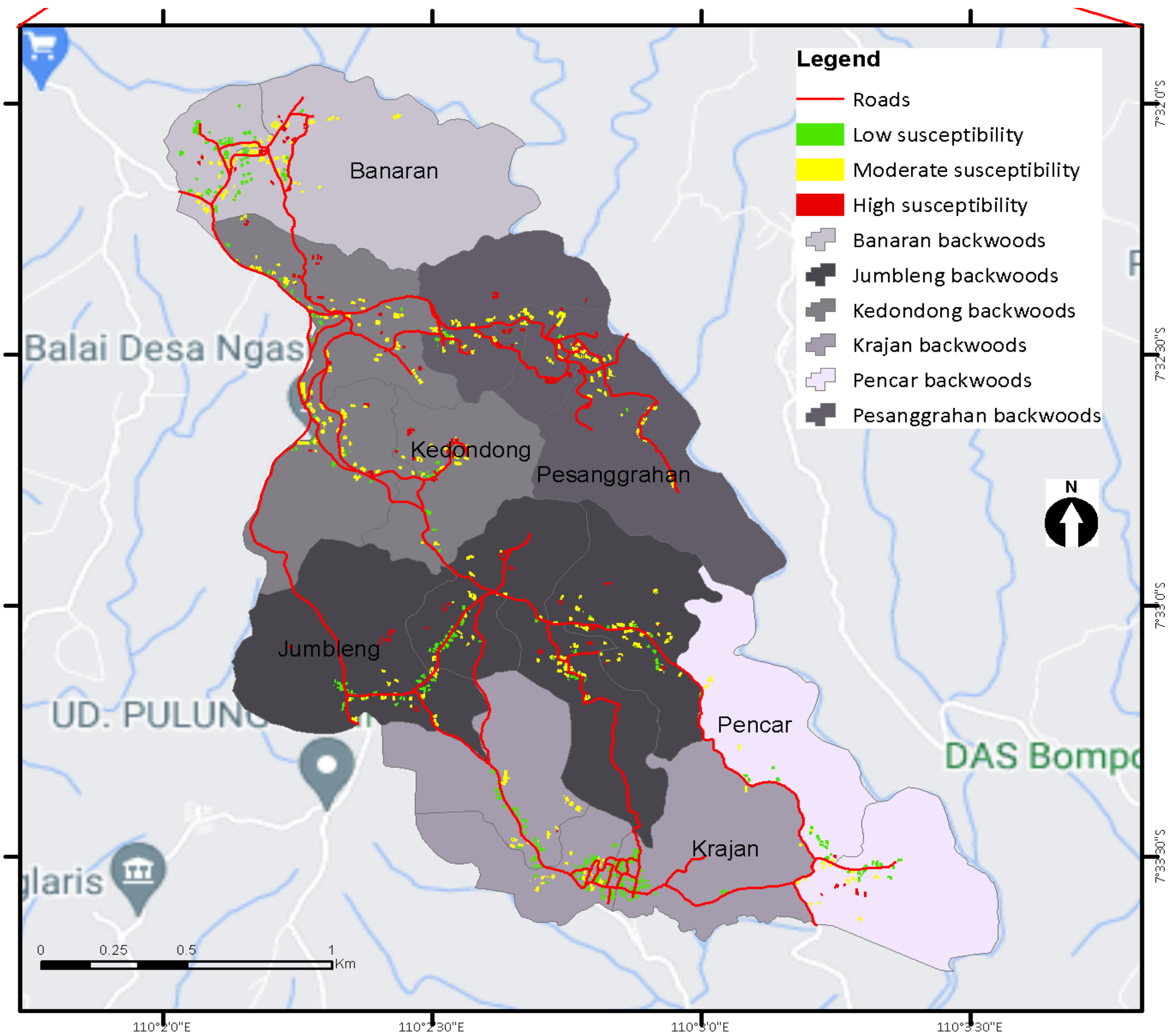

Figure 3. Map of the Distribution of House Vulnerability Classes to Landslides

Building area is determined by measuring the footprint of the house. Distance to an accessible road is the shortest distance between the building footprint and a paved or concrete road suitable for four-wheeled vehicles. High electricity consumption is interpreted from the presence of satellite dishes on houses. The physical environmental vulnerability assessment includes slope class data, topographic elevation, and distance from steep and very steep slopes. Physical environmental vulnerability is determined by clustering building positions, elevation, and proximity to steep slopes.

Environmental vulnerability assessment

Each environmental vulnerability parameter is ranked, with ranking 1 indicating the lowest vulnerability, ranking 2 indicating moderate vulnerability, and ranking 3 indicating the highest vulnerability. The parameters for environmental vulnerability assessment, their rankings, and the number of houses corresponding to each parameter are presented in Table 3. The total rankings are classified into low, moderate, and high vulnerability classes.

3. Results and Discussion

The assessment of environmental vulnerability to landslides in Ngasinan Village, Bener District, Purworejo Regency, reveals that the area is predominantly categorized as having moderate vulnerability. Specifically, 315 houses fall into the moderate vulnerability category, 215 into the low category, and 77 into the high category, as detailed in Table 3. The socio-economic parameters indicate that while the physical condition of most houses in Ngasinan Village is generally good, the positioning of these buildings relative to the environment places a significant number of them in the high-vulnerability category. The distribution of houses across different vulnerability classes is visually represented in Figure 3.

The architecture of houses in the study area reflects the local Javanese style, typical of buildings found in hilly rural areas. The **limasan** roof style (Figure 4.a) is indicative of buildings with robust construction and high-quality materials. This roof type is supported by a strong structural framework, with walls typically made of brick or concrete, a deeply set foundation, and reinforced concrete joints. Similarly, the **gable** roof (Figure 4.b) also has a sturdy support structure, which can be made of either concrete or wood. The walls of these houses are constructed from various materials such as brick, concrete, or adobe, with varying degrees of quality. The foundation is well-embedded, and the joints are reinforced with concrete. On the other hand, the **srotongan** roof (Figure 4.c) is generally associated with less durable structures, often using wood and bamboo for the roof support, with walls made of wood or woven bamboo. These houses typically have foundations above ground and lack reinforced concrete joints.

The study's findings show that houses with **limasan** or **gable** roofs and concrete structures have a lower susceptibility to landslides compared to those with **srotongan** roofs and wooden or bamboo structures. Better building structures usually correlate with the use of higher-quality roofing materials. Good quality roofs retain a bright hue even as they age, which is an indicator of their durability. A well-maintained roof, supported by a strong building structure, enhances the capacity of the house to withstand external loads. These findings are consistent with previous research conducted by Setyawan (2016), Subasinghe & Kawasaki (2021), and Agliata et al. (2022).

Houses categorized under high vulnerability are generally located far from proper access roads (Figure 6). Proximity to well-maintained roads reduces the socio-economic and environmental vulnerability of households. However, in Ngasinan Village, some communities still rely on dirt roads

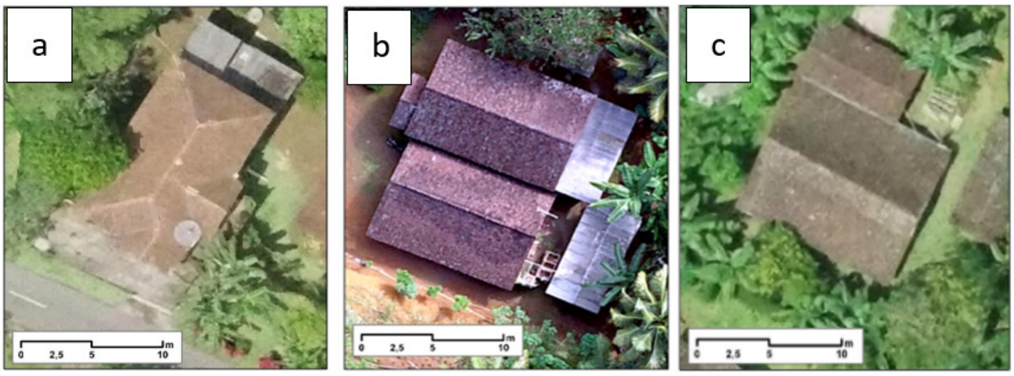

Figure 4. Roof Types: a) Limasan Roof, b) Gable Roof, c) Srotongan Roof

Figure 5. Srotongan Roof Structure: House with Wood and Bamboo Walls

with gentle to steep slopes, and in some areas, the roads are only accessible by foot. Constructing well-built houses and providing affordable socioeconomic facilities are crucial for improving the comfort and quality of life for these families.

In addition to poor road access, many houses are situated near steep and very steep slopes, which are prone to landslides (Figure 7). These houses, often located in clusters on sloping terrain, are generally not served by proper road access or drainage networks. The surrounding slopes typically have low vegetation density and exposed soil, both of which increase the risk of landslides. Landslides on these steep slopes pose a significant threat to nearby buildings, potentially causing structural damage or even destruction. Moreover, very steep slopes with sparse vegetation present a high risk of landslides, particularly in areas where community roads are present, as landslides can block access routes and further isolate the community.

The positioning of buildings on flat ground at elevations below 450 meters above sea level (masl) appears to be safer from the threat of landslides. However, buildings located at elevations between 450-550 masl, and particularly those above 550 masl, are increasingly vulnerable. Higher elevations often correlate with steeper slopes and less flat terrain, as evidenced by the denser and more winding contour lines (Figure 8). Many of these settlements were originally established by cutting into the slopes, which further exacerbates their vulnerability to landslides.

The assessment of economic vulnerability through orthophoto analysis also reveals that all households in Ngasinan Village have access to electricity, although not all are registered customers due to uneven access to the electricity grid. Most households have low electricity consumption, with houses lacking satellite dishes and being located far from proper road access. The proximity of a house to a well-maintained road is inversely related to its level of vulnerability. Communities living in landslide-prone areas often suffer from inadequate access to basic services and have a higher dependency on natural resources. These observations align with the findings of Mirdda et al. (2022) and Luo et al. (2021).

The overall accuracy of the environmental vulnerability assessment, as determined by comparing interpretation results with field data for 30 sample houses, is 86.66%. Among these samples, 26 were correctly classified, while 4 were misclassified. The accuracy of the building age parameter is 80%, with some discrepancies arising due to houses with dark brown roofs under 30 years old that had undergone partial renovations, yet retained their original roof tiles. Conversely, some houses over 30 years old had brighter roofs due to roof replacements or their location in open areas that prevent dampness. The accuracy of the electricity consumption parameter is also 86.66%, with some households falling into the low-consumption category despite having satellite dishes, likely due to the household composition, such as elderly occupants who use fewer electronic devices.

In conclusion, the environmental vulnerability assessment of Ngasinan Village based on orthophoto analysis provides a high level of accuracy. The spatial distribution of house vulnerability to landslides (Figure 3) is consistent with

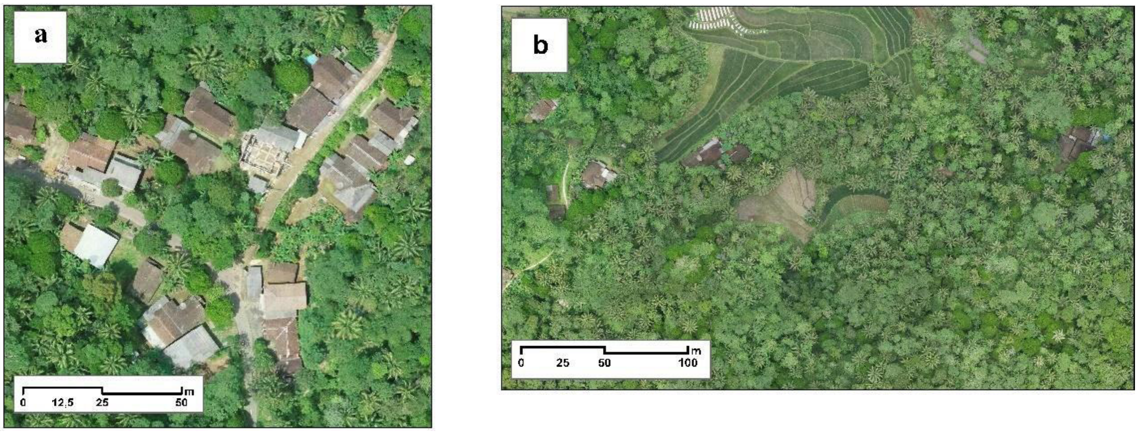

Figure 6. a) House located near a decent road b) House located far from a feasible road

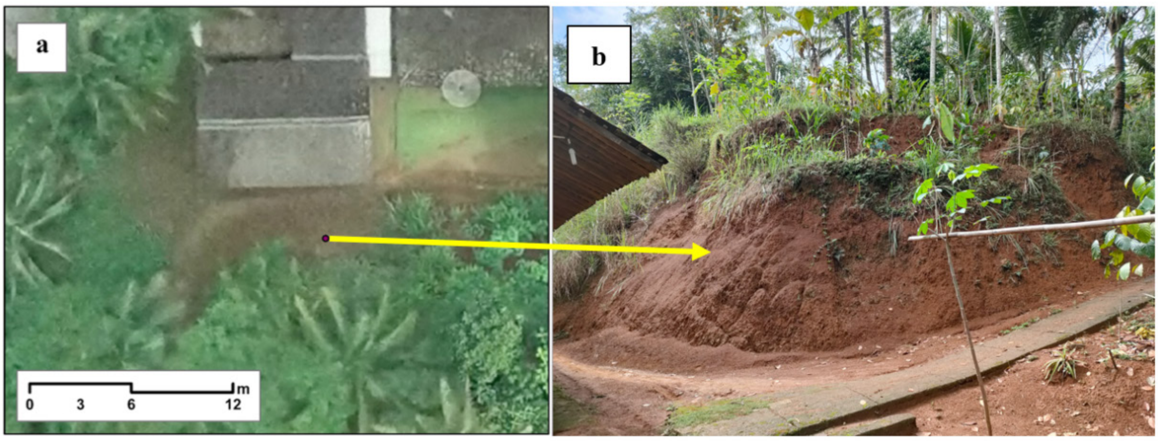

Figure 7.a) Residential landslide seen from orthophoto b) Field photo

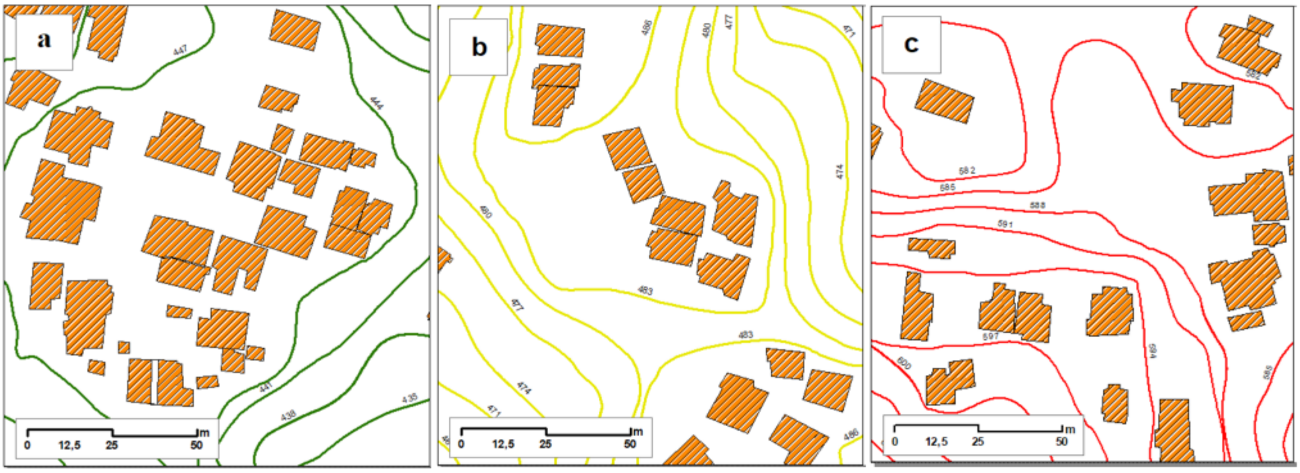

Figure 8. a) Buildings at an altitude below 450 meters above sea level (masl) (b) Buildings at an altitude between 450 and 550 meters above sea level (masl) (c) Buildings at an altitude above 550 meters above sea level (masl)

field conditions. To mitigate environmental vulnerability in Ngasinan Village, it is recommended to enhance building resilience through housing assistance programs, improve road and drainage infrastructure, install retaining walls on slopes adjacent to buildings, and plant vegetation that both controls landslides and offers economic value in open areas and near settlements.

4. Conclusions

This study assessed the environmental vulnerability of Ngasinan Village in Purworejo Regency, focusing on the susceptibility of residential buildings to landslides. The findings reveal that the majority of the village falls into the moderate vulnerability category, with significant portions in the high-vulnerability class. Houses with **limasan** and **gable** roofs, characterized by robust construction, showed lower vulnerability, while those with **srotongan** roofs, made of weaker materials like wood and bamboo, exhibited higher risk. The study also highlighted that homes situated near steep slopes and far from proper road access face increased vulnerability, compounded by socio-economic factors such as low electricity consumption.

The research underscores the importance of improving building structures, infrastructure, and environmental management to mitigate landslide risks. Targeted housing assistance, better road access, and slope stabilization through vegetation planting are recommended strategies to reduce environmental vulnerability. The study's accuracy, validated by field data, supports the reliability of these findings and offers a comprehensive approach to enhancing the resilience of communities in landslide-prone areas.

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