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RESEARCH ARTICLE

Analysis of Subsidence Hazards in Pandan Cave Area, Giri Mulyo Village, Marga Sekampung District, East Lampung using Analytical Hierarchy Process

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Abstract

Pandan Cave is a basalt lava cave which is a unique geological tourism area located in Giri Mulyo Village, Marga Sekampung District, East Lampung Regency, Lampung Province. This cave was formed when the lava flow cooled at the top because it was in contact with the cold atmosphere, while at the bottom it was still flowing. This uniqueness caused Pandan Cave to become one of the tourist attractions that was once crowded with tourists. However, the condition of this cave is still very natural which can lead to the risk of geological disasters such as subsidence which can endanger tourists, so it is necessary to research to minimize the occurrence of geological disasters in the area. This research was conducted by observing aerial photographs, collecting data directly in the field, and then processing it with the Analytical Hierarchy Process (AHP). Parameters used in this AHP method include lithology, vegetation, weathering, rock mass class, and cave roof thickness. The existence of subsidence in the study area is influenced by weathering (34%), vegetation (31%), thickness of the cave roof layer (16%), lithology (10%), and rock mass class (9%). Based on the overlay results for each parameter that has been weighted, the Pandan Cave tourism area is divided into three subsidence hazard zone classifications, that is low hazard zone with value of 0.28-0.44, medium hazard zone with range of 0.44-0.60, and high hazard zone with range of 0.60-0.75. Through the Analytical Hierarchy Process (AHP) method and overlay of each parameter used, the distribution of subsidence hazard zones in the study area was obtained. The low threat zone of 27.57 ha is about 57.07% of the total research area, the medium threat zone is 15.86 ha or about 32.83% of the total research area, and the high threat zone is 4.88 ha or about 10. 10% of the total research area.

Keywords: Pandan Cave, basalt lava cave, geological tourism, lava flow, Analytical Hierarchy Process, geological disasters, subsidence

1. Introduction

Indonesia is one of the largest countries that has active volcanoes due to its location in the Sundaland block (Metcalfe, 2017). To put it more specific, this volcanic activity is caused by the subduction zone produced by the activity of the Indian, Australian, Pacific, and Philippine oceanic plates beneath Southeast Asia (Abdurrachman et al., 2018). This volcanic activity also resulting a lava cave in Lampung province, also known as Pandan Cave. Pandan Cave is a lava cave that is a unique geological tourist area located in Giri Mulyo Village, Marga Sekampung District, East Lampung Regency, Lampung Province. These lava caves are composed of Basalt Sukadana that cover 30.69% of the Sukadana Subdistrict (Ermana et al., 2022). This extent of the lava flow is influenced by the rate of effusion from the vent and independent from its previous eruptions (Theinat et al., 2019). This area has several cave entrances with different uniqueness with a width of ± 4 meters, an average height of 2.5 meters, and a length of caves that are known to reach 200 meters (Natalia Sirait et al., 2023). This area is above the Sukadana Basalt rocks (Qbs) which are composed of vesicular basalt rocks and scoria (Mangga et al., 1993). The geological features of lava caves are common and result from effusive processes along weak bands extending across the surface (Cruden and Weinberg, 2018). This process's similarities to Hawaii lava caves caused Pandan Cave has become one of the tourist attractions that tourists once visited. However, the condition of this cave is still very natural and there are no scientific studies or efforts to anticipate disasters in the area.

With this uniqueness, the Pandan Caves area has a big potential to become one of the geoheritage in Indonesia. But, in the one of assessment parameters of geoheritage, we need to consider the obstacle parameter (Badan Geologi, 2017). One of the obstacles referred to is natural hazard potential, specifically subsidence in the Pandan Cave area. Subsidence is the downward movement of the ground surface (Ritzema, 1994; Sahu and Lokhande, 2015). The type of subsidence in this area is sinkhole subsidence because subsidence occurs due to space below the surface (Sahu and Lokhande, 2015). This is indicated by the discovery of subsidence traces as deep as 1-3 meters with a width of 2-4 meters. The entrance to the lava cave occurs at a place where the roof has collapsed (Palmer, 2007). Since we are dealing with young lava caves, there is no tectonic structure in this area. However, the primary structure needs to be considered as discontinuity as one of the factors that makes the caves unstable. That is because during the evolution of magma, primary structures like columnar joints are usually present during the eruption of lava to the surface (Jerram et al., 2018). Therefore, it is necessary to carry out scientific studies in this area to determine the safeness of the Pandan Cave area and its surroundings as a tourist area.

Based on Ritzema (1994), the speed and level of subsidence are influenced by lithology, climate, degree of weathering, compression/compaction, shrinkage, groundwater conditions, and tectonic movements. The Pandan Cave area is composed of volcanic igneous rock with plantation land use, so the parameters used in this study need to be adjusted to field conditions. The parameters used in this study were lithology, cave roof layer thickness, vegetation, rock mass class, and weathering. These were obtained through direct data collection in the field and aerial photographs. This research was conducted to minimize the occurrence of geological disasters that could affect tourists and residents.

2. Methodology

To get a clear vision of the whole area, we conducted retrieval of data using drones from a height of 100 meters. The drone takes aerial photos which are processed and combined. Then observations were made through aerial photographs to obtain the type of plant roots in the study area. This will help to understand how root type might affect the rock surrounding the research area. This aerial photograph also becomes a reference to determine the location of sample collection and field test. The sample collection is used for measuring the rate of weathering using the loss of ignition test and rock mass rating as a field test to understand the quality of rock in the study area. Besides that, lithology type and its thickness are also measured as additional data to identify hazard potential. One of the best approach to find the solution from many consider parameters is using overlay analysis in GIS (Nadi and Murad, 2017). One These data were then evaluated using the Analytical Hierarchy Process (AHP) method to determine the effect and weight of the values of each parameter used. Flow chart of this research can be seen on Fig 1.

The Analytical Hierarchy Process (AHP) is a system that is considered the most inclusive for making decisions using several criteria in Geographic Information System (Taherdoost, 2017). According to Saaty (2008), the Analytical Hierarchy Process is an organized decision-making method by comparing the priority scales of each parameter used. Besides that, AHP also gives objective consideration between parameters to ensure the credibility of the result (Taki and Maatouk, 2018). The importance level of each parameter was determined based on Table 1. Since this is considered a general method that can be used in many fields, this method is also used in many geoscience research to identify geological hazards that are controlled by several parameters. Ahp method was succeded used in landslide research in many places around the world (Asmare, 2023; El Jazouli et al., 2019; Kumar and Anbalagan, 2016; Liu et al., 2024; Panchal and Shrivastava, 2022). Although not many subsidence studies around the world use AHP, several studies used this method to identify subsidence (Rezaei et al., 2022; Zhang et al., 2023). In Lampung itself, there are several landslide studies with the AHP approach that succeded in showing the vulnerability area of landslide (Agustina et al., 2023; Indahsari et al., 2022). Altough AHP method have been used in several cases of landslide study in Lampung, there has been no subsidence study in Lampung using this method so far. However, in several areas in Indonesia, this method is widely used for subsidence studies (Mohamad Deros et al., 2022; Satriawan et al., 2018).

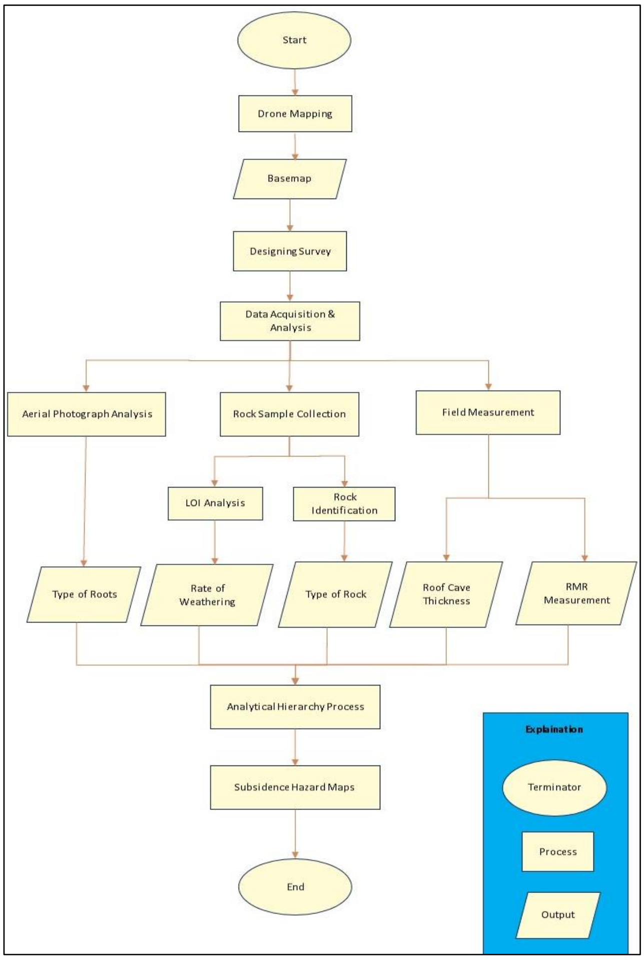

Fig. 1 Research Flow chart

Unlike landslides, subsidence has many different parameters depending on the subsidence type and natural characteristics of a particular area. So, there is no guidance to determine which parameter is relevant to the study. Therefore, the determination of parameters is based on observation in the field. Based on this observation, the parameters used to control subsidence that were used in the AHP method were lithology, cave roof thickness, vegetation, rock mass class, and weathering.

Table 1. The fundamental scale of absolute numbers (Saaty, 2008).

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

The AHP method uses a paired comparison matrix and forms a reciprocal matrix to turn qualitative data into quantitative (Budianta, 2021). After determining the intensity of interest and the weighting of the value of each parameter, then the zoning of the subsidence hazard area is carried out using the overlay method for each parameter. The weight of each parameter is based on the conclusion from the discussion between the relevant researcher, village official, and experts from BPDASHL

3. Result and Discussion

Determination of the subsidence hazard area is carried out by determining the intensity of importance and weight of the values of each parameter used. Weathering has a greater influence than the lithology, vegetation, rock mass class, and thickness of the cave roof layer. Vegetation and the thickness of the cave roof layers are more influential than the lithology and rock mass class. Lithology has the smallest influence on each parameter used. A Comparison of the importance and intensity of each parameter can be seen in Table 2. From this comparison, the consistency ratio (CR) value is -0,8. This value is lesser than the threshold value (0,1) which means that the comparison is consistent. After determining the comparison value of each parameter, the column is summed and then used as a divider in the normalization process. Normalization is done by dividing the value of the intensity of interest in each column by the total value of each column.

Table 2. Comparison of interest Intensity between parameters

Parameter	Lithology	Vegetation	Weathering	Rock Mass Class	Cave Roof Thickness
Lithology	1	0,5	0,2	1	0,5
Vegetation	2	1	1	3	3
Weathering	5	1	1	3	2
Rock Mass Class	1	0,33	0,33	1	0,5
Cave Roof Thickness	2	0,33	0.5	2	1
Total	11,00	3,16	3,03	10,00	7,00

Based on the results of normalization (Table 3), it can be concluded that the weight of each parameter that affects subsidence potential from largest to the smallest are weathering (34%), vegetation (31%), the thickness of the cave roof layer (16%), rock mass class (10%), and lithology (9%). Determination of the intensity of importance and normalization is also carried out for each classification on each of the parameters used.

Table 3. The percentage value of influence of parameters on subsidence

Parameter	Percentage (weight) of Influence
Lithology	9 %
Vegetation	31 %
Weathering	34 %
Rock Mass Class	10 %
Cave Roof Thickness	16 %
Total	100 %

3.1 Lithology

Field mapping was carried out in the study area to determine the lithology and vegetation types in the study area. Based on this mapping, the type of lithology in the study area is basalt rocks. In the study area, there is only one type of lithology, therefore in giving weights using the Analytical Hierarchy Process (AHP), the lithology parameter in the study area is given a value of one because the area consists of the same lithology and it has the same effect on subsidence in the study area.

3.2 Vegetation

The area around Pandan Cave is a plantation area for the local community with various types of plants. In the research area, an analysis of the distribution of plant species was carried out using aerial photographs and field data validation. Vegetation parameters in this study were divided into two based on the type of plant roots, namely fibrous roots and tap roots. This determination has an important effect on research because different types of roots will affect the speed of physical weathering of a rocks. Tap roots will penetrate deeper into the layers of soil and rock so that they can accelerate weathering more than fibrous roots. The results of the analysis using aerial photographs and field observations produced a zoning map for vegetation types (Fig. 2).

In the study area, the dominant fibrous-rooted vegetation was banana, corn, and coconut, while the taproot vegetation was dominated by cassava, tajar, and papaya plants. Based on the map, a weighting stage was carried out for each type of plant root at the research location. The taproot type has a higher weight compared to the fibrous root type because the taproot has a higher role in rock weathering.

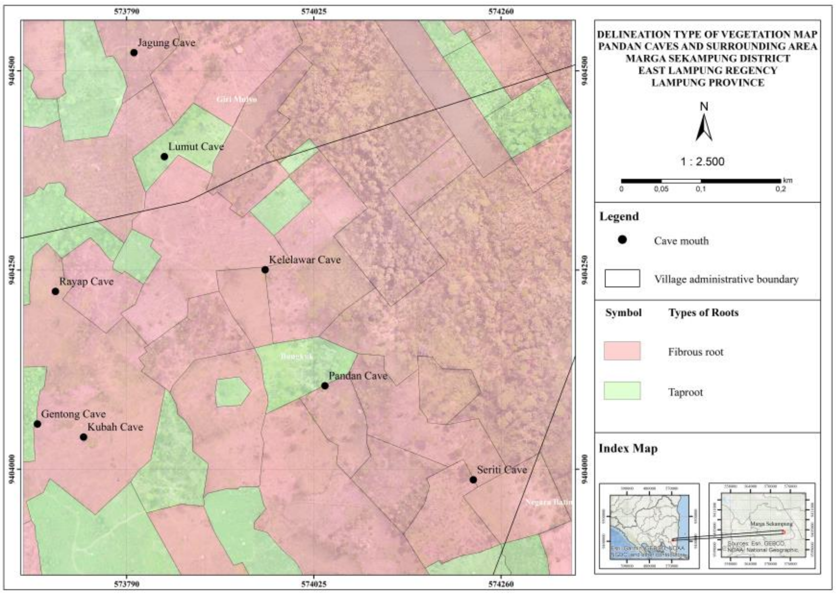

Fig. 2. Delineation Type of Vegetation.

3.3 Weathering

The weathering parameters in this study were divided into two based on the level of weathering, namely weathered marked in red and non-weathered marked with green (Fig. 2). Determination of the level of weathering in the study area using the Loss On Ignition (LOI) method. The Loss On Ignition value is a value that represents the level of weathering of rocks so in this study it is very influential as a subsidence-controlling factor. Based on the LOI values of the seven sampling points in the Pandan Cave area, it is known that the LOI values for each sampling point vary. Three cave points have experienced weathering and four cave points are still fresh. Areas with high LOI values indicate weathered rocks that have a risk of subsidence in the area. Giving weight to high LOI values has a higher weighting value compared to low LOI values. High LOI values are in areas with taproot vegetation, while low LOI values are in areas with fibrous root dominance. This shows the influence of the type of plant roots on weathering.

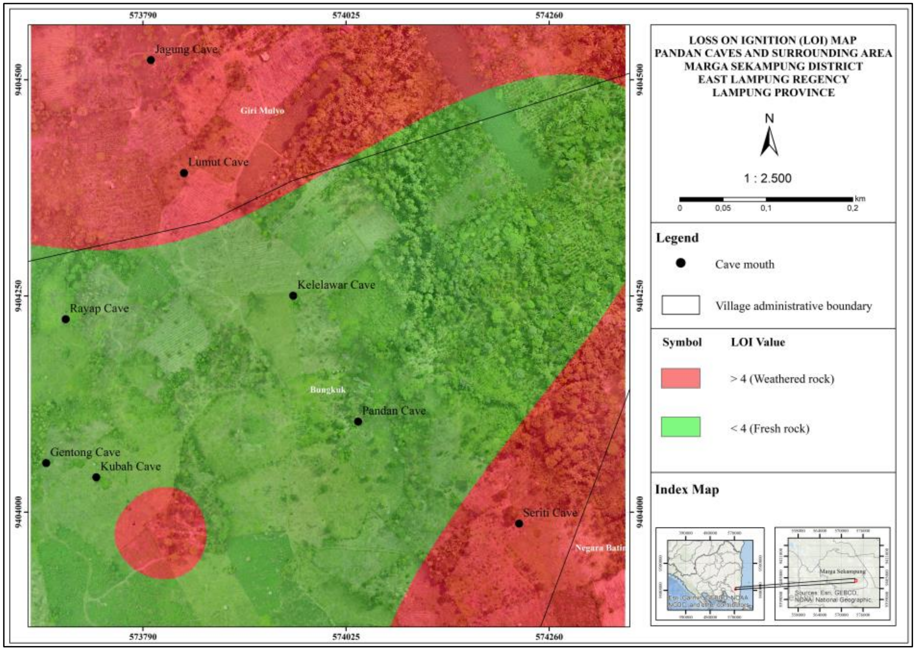

Fig. 1. Map of Loss On Ignition Value Distribution.

3.4 Rock Mass Class

The Pandan Cave tourist area has many cave paths that are connected. Each cave wall has different characteristics, causing each cave wall to have a different strength level. To determine the strength level of the cave in the research area, the stability values of the cave walls were measured. One of the rock mass classification systems used for tunnels or caves is the Rock Mass Rating (RMR) System (Bieniawski, 1989). The strength values of the cave walls from 20 sampling points ranged from 51–78,1. Based on the RMR value, the cave walls in the study area are divided into two classes, namely good rock and fair rock (Fig. 3). The walls of the cave with the good rock class are stronger than the walls of the cave with the fair rock class because they have a higher RMR value, so from the weighting results the weight value for the fair rock class is greater because the rock strength is weaker. The difference in RMR values is influenced by the conditions, geological features, and geometry of the different cave walls.

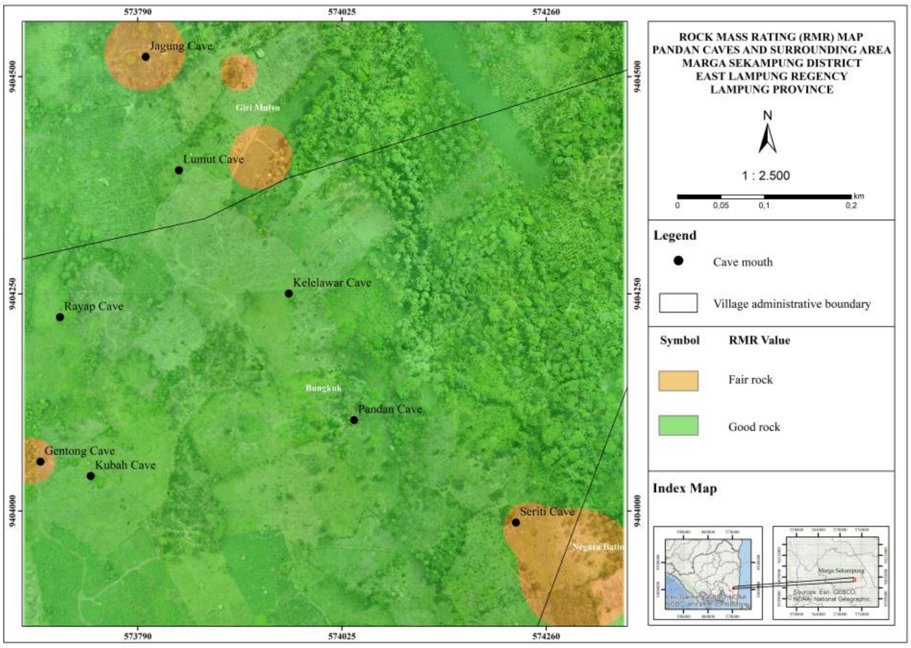

Fig. 2. Map of Rock Mass Rating Value Distribution.

3.5 Cave Roof Thickness

The cave roof thickness data was obtained from the processing of geophysical data using the geoelectrical method and then validation was carried out directly in the field to ensure the distribution of layer thickness in the Pandan Cave area. Obtained 58 points of location of subsidence remains indicating the presence of weak areas in the surrounding rock and the thickness of the layer of the roof of the cave was measured. Based on the measurement results, the thickness of the layer ranged from 30 cm to 280 cm which was classified into three classes (fig. 4), namely 0-100 cm totaling 28 points, 101-200 cm totaling 17 points, and 201-300 cm totaling 13 points. The thickness of the roof's cave influences the threat of subsidence. The thinner of roof layer of the cave, the higher the risk of subsidence, so the thinner the rock layer the higher the weight value.

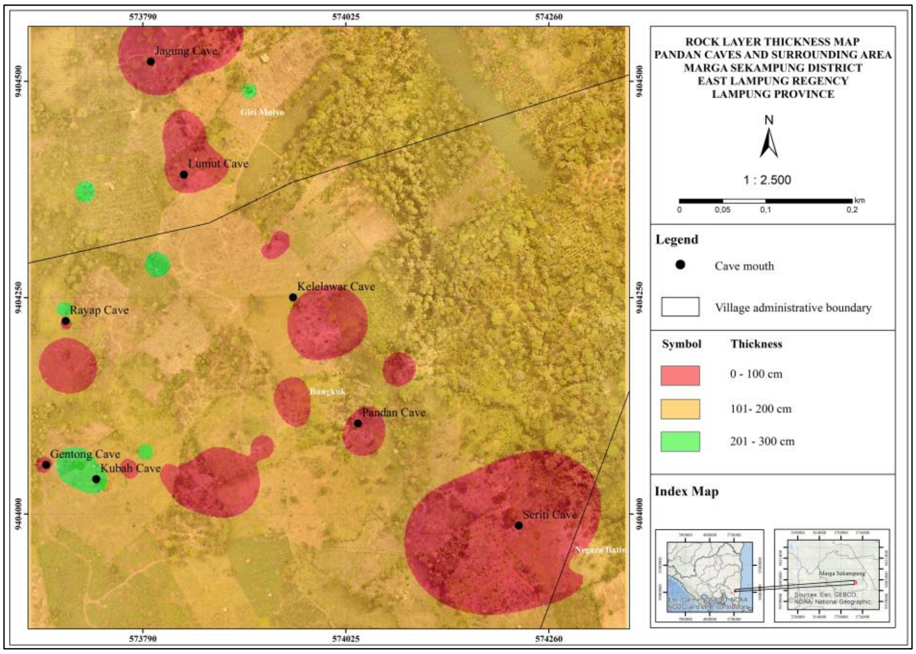

Fig. 3. Map of Rock Layer Thickness of Roof's Cave.

3.6 Subsidence Hazard

Determination of the distribution of subsidence hazard zones in the Pandan Cave tourism area was carried out by the overlay method of each parameter used. Based on the overlay results for each parameter that has been weighted, the Pandan Cave tourism area is divided into three subsidence hazard zone classifications (fig. 5), which are low hazard zone with value of 0.28-0.44, medium hazard zone with value of 0.44-0.60, and high hazard zone with range of 0.60-0.75.

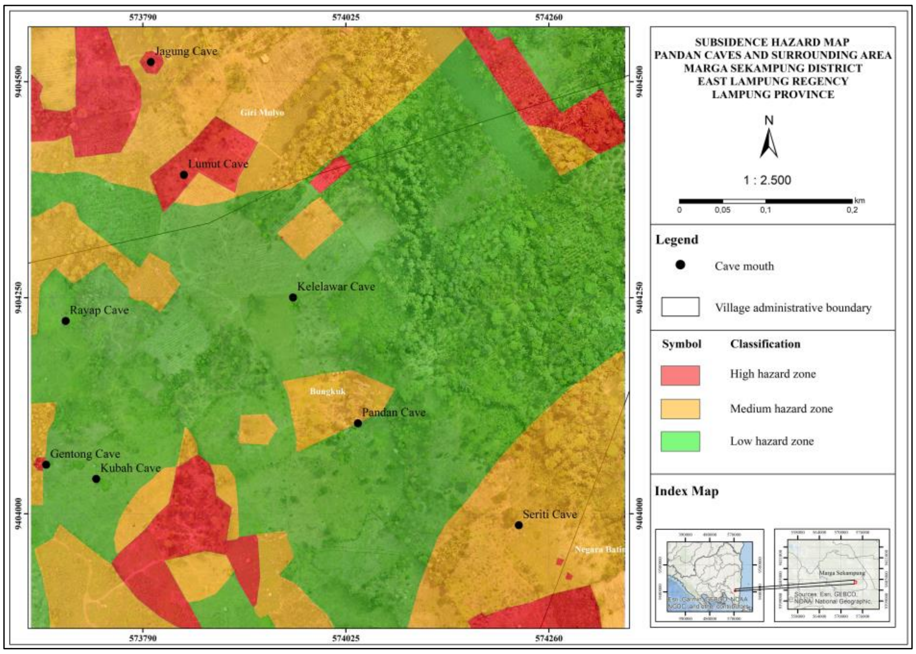

Fig. 4. Map of Subsidence Hazard Area

Based on the subsidence hazard zone map (Fig. 5), the low hazard zone in the research area is 27,57 ha, approximately 57,07% of the total research area. The area included in the moderate hazard zone is 15,86 ha or around 32,83% of the total research area and the area included in the high hazard zone class consists of 4,88 ha or around 10,10% of the total research area. In the research area which is dominated by low-hazard zones, the rock conditions have not experienced weathering with vegetation types dominated by fibrous roots, whereas in the high-hazard zone, weathered rock conditions are dominated by tap roots vegetation

4. Conclusion

The existence of subsidence in the study area is influenced by weathering (34%), vegetation (31%), thickness of the cave roof layer (16%), lithology (10%), and rock mass class (9%). Through the Analytical Hierarchy Process (AHP) method and overlay of each parameter used, the distribution of subsidence hazard zones in the study area was obtained. The low hazard zone of 27.57 ha is about 57.07% of the total research area, the medium hazard zone is 15.86 ha or about 32.83% of the total research area, and the high hazard zone is 4.88 ha or about 10. 10% of the total research area.

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