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GEOLOGI DAN ZONASI KERENTANAN GERAKAN TANAH MENGGUNAKAN *ANALYTICAL HIERARCHY PROCESS* DAERAH KEBANARAN DAN SEKITARNYA, KECAMATAN MANDIRAJA, KABUPATEN BANJARNEGARA, JAWA TENGAH

GEOLOGY AND VULNERABILITY OF LANDSLIDE ZONING USING ANALYTICAL HIERARCHY PROCESS METHOD IN KEBANARAN AND SURROUNDING AREA, MANDIRAJA SUB-DISTRICT, BANJARNEGARA REGENCY, CENTRAL JAVA

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Abstrak— Daerah Kebanaran dan Sekitarnya, Kecamatan Mandiraja, Kabupaten Banjarnegara, Jawa Tengah merupakan daerah yang berlokasi di tepi Sungai Serayu dan berbatasan dengan jalur pegunungan selatan. Daerah penelitian juga merupakan daerah yang memungkinkan terjadinya gerakan tanah, hal ini diakibatkan adanya beberapa faktor alamiah dan faktor aktivitas manusia yang menyebabkan gerakan tanah. Dilakukannya penelitian ini yaitu untuk menjelaskan hubungan kondisi geologis terhadap faktor kerentanan gerakan tanah di daerah penelitian. Metode yang digunakan adalah metode *Analytical Hierarchy Process* (AHP). Metode ini mencocokkan beberapa parameter yang dianggap sebagai faktor terjadinya gerakan tanah dan diberikan nilai berdasarkan kriteria pembobotan. Berdasarkan hasil penelitian, terdapat beberapa parameter, seperti faktor alam, geologi, dan aktivitas lainnya yang mempengaruhi gerakan tanah di daerah penelitian yang diantaranya adalah intensitas curah hujan, litologi, kerapatan sungai, strukur geologi, tata guna lahan, serta kemiringan lereng. Parameter – parameter tersebut kemudian diberikan penilaian dan pembobotan sebagai untuk mendapatkan nilai akhir dalam menentukan zona kerentanan gerakan tanah. Hasil dari perhitungan tersebut menghasilkan 4 tingkat gerakan tanah yaitu zona kerentanan gerakan tanah rendah, zona kerentanan gerakan tanah sedang, zona kerentanan gerakan tanah tinggi, dan zona kerentanan gerakan tanah sangat tinggi..

Kata kunci **—** gerakan tanah, parameter gerakan tanah, *Analytical Hierarchy Process* (AHP), geologi

Abstract— *Kebanaran and its surrounding area, Mandiraja Subdistrict, Banjarnegara Regency, Central Java, located on the side of Serayu River and bordered by the line of Southern Mountanious Range. Research sites have the vulnerabilities of landslides occurence due to some factors, natural occurences and human activities. Natural occurences that might be the cause of landslide are rain intensities, slopes, and geological elements. The purpose of this research is to explain the correlation about geological conditions and the possibilities of landslide. The method that used in this research is Analytical Hierarchy Process (AHP). This method comparing some paramaters that used and considered as the main cause of landslide. Based on the research, parameters that used in this research are Rainfall Intensities, Lithologies, Stream Densities, Geological Structures, Landuses, and Slopes. Those parameters then will be given scores to determining zone of landslide possibilities. From the calculations and analysis, there are 4 type of landslide zone, low intensities, medium intensities, high intensities, and very high intensities*.

Keywords— *landslides, landslides parameters, Analytical Hierarchy Process (AHP), geology*

I. INTRODUCTION

Landslides refer to the movement of slope-forming materials such as rocks, soil, or mixed materials that fall and shift away from the slope [1]. Geologically, this phenomenon involves the detachment of rocks or masses of soil, influenced by both natural and anthropogenic factors.

Administratively, the study area is located in Kebanaran and its surroundings, within Mandiraja Sub-district, Banjarnegara Regency, Central Java Province. The area encompasses several villages, including Kebanaran, Kaliwungu, and Simbang.

The geological composition of Kebanaran and its surrounding areas primarily consists of rocks from the Waturanda Formation [2] and the Terrace Deposits Formation [3]. Field observations indicate that the surface materials have undergone significant weathering and the slopes range from gentle to steep. These conditions heighten the potential for landslides, particularly during the rainy season, thereby posing a threat to the safety of local residents. The morphology of the Kebanaran area is characterized by two main types of landforms: hilly terrain in the southern region and flat lowlands in the northern region. These two zones are demarcated by the Kali Sapi River, which flows from east to west. The southern hilly region, in particular, is more prone to landslides. This study aims to reduce disaster risk by developing a landslide susceptibility zoning map. This zoning serves to minimize the potential impacts and provide a reference for disaster preparedness among residents living in the area. The methodology employed in this study involves spatial analysis using Geographic Information Systems (GIS), where each parameter is assigned a weight using the Analytical Hierarchy Process (AHP) method.

II. LITERATURE REVIEW

The Analytical Hierarchy Process (AHP) is a decision-making method that takes into account various factors such as perception, preference, and intuition. It is particularly useful for addressing complex problems through a hierarchical system. In the context of landslide susceptibility zoning, the AHP method allows for the integration of essential base parameters, including rainfall maps, slope gradient maps, land use maps, soil permeability maps, and geological maps [4]. These datasets are processed and combined into a single set of influencing parameters, which are then overlaid using Geographic Information System (GIS)-based layers [5].

AHP also incorporates a consistency check to ensure the reliability of the pairwise comparison matrix. The consistency index (CI) and consistency ratio (CR) are calculated as follows:

$$CI = \frac{\{\lambda max - n\}}{n - 1}$$

$$CR = \frac{CI}{RI}$$

Where:

CI	= Consistency Index
λ maks	= Maxmimal eigenvalue
n	= Jumlah parameter
RI	= Ratio index
CR	= Consistency ratio

The consistency index must be less than 0.10. If it exceeds this threshold, the decision criteria (i.e., pairwise comparisons) must be revised, and the relative importance of each parameter reconsidered. If the consistency ratio is acceptable, the parameter weights may be used for further analysis [4].

III. RESEARCH METHODS

This study consists of several key stages, as outlined below:

A. *Preparation Stage*

This stage involves preparatory activities necessary for conducting the research, including a review of literature related to the geological characteristics of the study area and the methodology to be applied. In addition, secondary data—such as rainfall data and Digital Elevation Model (DEM) data—were collected. These data serve to provide a general overview of the study area.

B. *Data Collection Stage*

This stage involves geological mapping in the field. Field data collection aims to obtain direct geological information and to observe conditions that may trigger landslides. The expected outputs from this stage include traverse maps, lithological data, structural geology data, geomorphological data, samples for petrographic and micropaleontological analysis, and data on the distribution of landslide susceptibility.

C. *Data Analysis and Processing Stage*

After the field data collection, further analysis is conducted, including laboratory-based petrographic and micropaleontological analysis, as well as desktop analysis to examine the geological structures in the study area. These analyses are essential for processing geological data and serve as the basis for producing geological maps of the area. The processed data yield outputs such as geological maps, geomorphological maps, stratigraphic columns, and the geological history of the region. Following the geological data analysis, further analysis is conducted using the Analytical Hierarchy Process (AHP) method based on multiple parameters, including rainfall data, slope gradients, lithology, river density, geological structures, and land use. Each parameter is weighted accordingly, and the resulting scores are used to determine the landslide susceptibility zoning in the study area.

IV. RESULTS AND DISCUSSION

A. General Geology

1) Geomorphology of the Study Area

In general, the morphology of the study area comprises hilly terrain in the southern part and lowland plains in the north. These two landforms are separated by the Kali Sapi River, which flows from west to east. According to landform classification [6], the geomorphological units of the study area can be categorized into five units, as depicted in the Geomorphology Map (Figure 1):

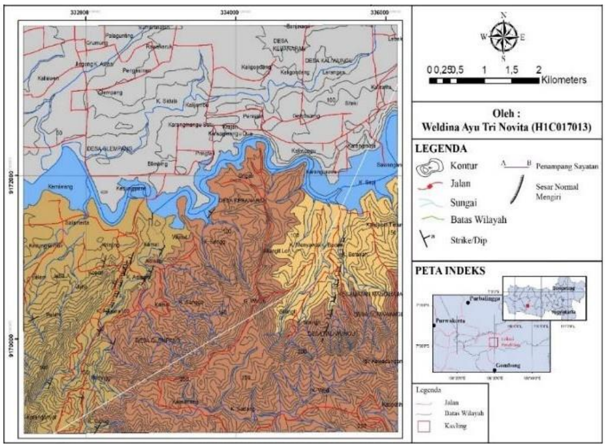

Figure- 1. Geomorphology Map of the Study Area

a. Kebanaran Fault Hill Unit (Figure 1). This unit covers approximately 25% of the study area and is represented in light brown on the geomorphology map. It is characterized by layers of rock that have undergone faulting after their formation.
b. Kaliwungu Fault Hill Unit. Occupying around 10% of the study area and marked in beige, this unit is similarly characterized by faulted rock layers following lithological development.
c. Kebanaran River Floodplain Unit. This unit accounts for about 15% of the study area and is marked in blue. It stretches along the Kali Sapi River and is formed by alluvial deposits along the riverbanks.
d. Kebanaran Alluvial Plain Unit. This unit occupies approximately 20% of the study area and is indicated in grey. It represents flatland formed by erosional processes acting on pre-existing lithology or by material carried and deposited by river flow.
e. Wuluh Pyroclastic Flow Ridge Unit (Figure 1). Covering around 30% of the study area and represented in brown, this unit consists of elevated landforms formed by tectonic uplift and composed of pyroclastic flow deposits.

2) Stratigraphy of the Study Area

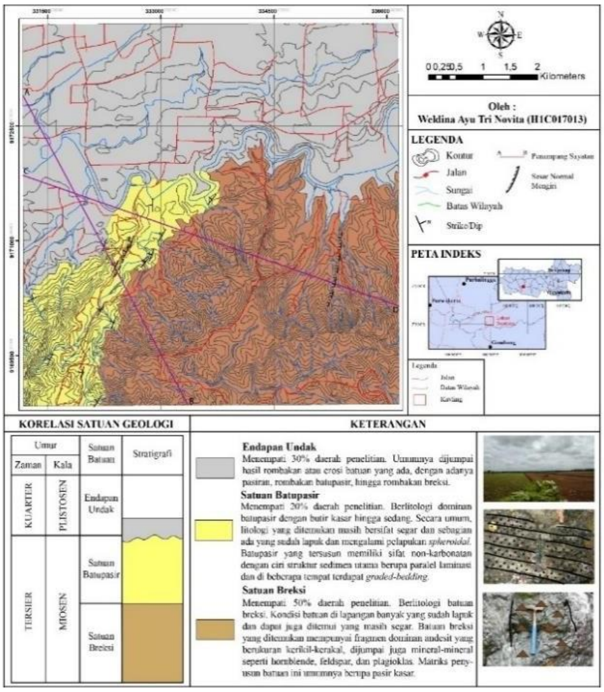

Figure- 2. Geological Map of the Study Area

Based on the research findings, the Kebanaran area and its surroundings consist of three main rock units: breccia, sandstone, and alluvial deposits. The distribution of these units is shown on the Geological Map (Figure 2). A vertical representation of the regional stratigraphy, based on geological mapping and thickness estimates, is illustrated in Figure 3.

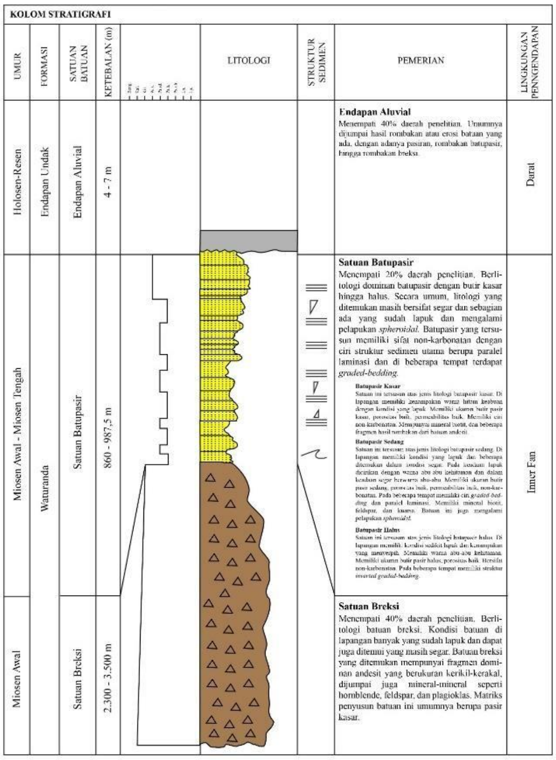

Figure- 3. Stratigraphic Column of the Study Area

a. Brecca Unit

The breccia unit occupies approximately 40% of the study area, with the dominant lithology consisting of breccia. The rocks in this unit are found in both weathered and fresh conditions. The breccia fragments are composed of andesitic igneous rocks with gravel-sized clasts, embedded in a coarse-grained sandstone matrix.

This unit is estimated to be of Early Miocene age and is interpreted to have been deposited in a continental slope environment influenced by turbidity currents. It has a conformable relationship with the overlying sandstone unit.

b. Sandstone Unit

The sandstone unit comprises about 20% of the study area. The lithology ranges from coarse- to fine-grained sandstone, observed in both fresh and weathered conditions. The sandstones are non-carbonate in nature. Texturally, they exhibit fine to coarse sand grain sizes and display sedimentary structures such as parallel lamination, graded bedding, and slumping. Observed minerals include biotite, feldspar, glass shards, and plagioclase.

This unit is estimated to be of Middle Miocene age and was formed in a braided zone of a submarine fan system, where turbidity currents had begun to weaken. It has a conformable contact with the underlying breccia unit but an unconformable contact with the overlying alluvial deposits due to a significant hiatus in deposition.

c. Alluvial Deposits

The alluvial deposits occupy approximately 40% of the study area. These deposits are primarily the result of reworking and erosion of previously formed lithologies, as well as fluvial processes. The deposits mainly consist of sandy sediments and soil derived from erosional processes.

Formed in a terrestrial environment, these deposits are estimated to date from the Holocene to the present. They exhibit an unconformable relationship with the underlying sandstone unit.

3) Geological Structures of the Study Area

The dominant geological structures identified in the study area are faults. These are fractures along which displacement has occurred. Based on field analysis, two fault lines were identified: the left-lateral normal fault of Betakah and the left-lateral normal fault of Krinjing.

4) Geological History of the Study Area

The geological history of the study area begins in the Early Miocene during which the breccia unit was deposited in a continental slope environment influenced by strong turbidity currents. The depositional process is interpreted to have occurred from the slope to the upper fan environment. Volcanic activity during this time contributed volcanic materials to the sediment, which, combined with the strong turbidity currents, led to the formation of the breccia unit.

In the subsequent phase, reduced volcanic activity led to a decreased sediment supply, and the depositional environment shifted to the braided section of a submarine fan. Despite this shift, the currents remained relatively strong, resulting in the deposition of coarse-grained, well-compacted sandstones. The sandstone unit is interpreted to have formed during the Middle Miocene.

Following the deposition of the sandstone unit, a depositional hiatus or "blank zone" occurred, lasting until the Pleistocene. During the Pleistocene, tectonic activity uplifted the study area, transforming its depositional environment into a terrestrial setting. This tectonic uplift also formed geological structures trending southwest–northeast.

The development of the Serayu River subsequently influenced the landscape, integrating the study area into the Serayu river terrace system. Over time, the branching of the river system channeled water to the northern part of the study area. These fluvial processes eroded the pre-existing lithologies, resulting in the deposition of alluvial sediments.

B. Analytical Hierarchy Process (AHP) Method

In this study, a specific analytical approach was applied using the Analytical Hierarchy Process (AHP), a method that involves evaluating and assigning weights to several parameters considered as key factors contributing to landslide occurrences. The parameters used in this study include rainfall intensity, lithology, slope gradient, geological structures, river density, and land use.

1) Rainfall Intensity

Based on interpolation of data from weather stations in Central Java, the average annual rainfall intensity in the study area was determined to be 3,863 mm/year. The classification of rainfall and the assignment of weights to each class were carried out by dividing the rainfall intensity into three categories: Low (< 2000 mm/year), Medium (2000–3000 mm/year), and High (> 3000 mm/year) [7].

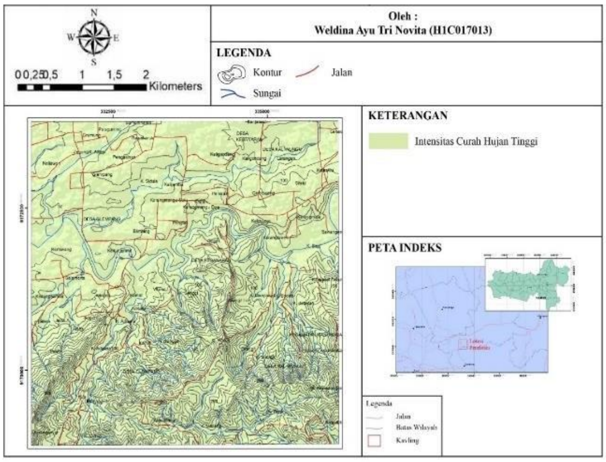

Figure- 4. Rainfall Intensity Parameter Map with Uniform Intensity Levels

2) Lithology of the Study Area

The lithological data for the study area were obtained through direct field mapping and classified based on rock units. Each rock unit was assigned a lithological value according to its characteristics. Harder rock types are more resistant to weathering, whereas relatively softer rocks tend to be more susceptible to landslides due to weathering processes [8].

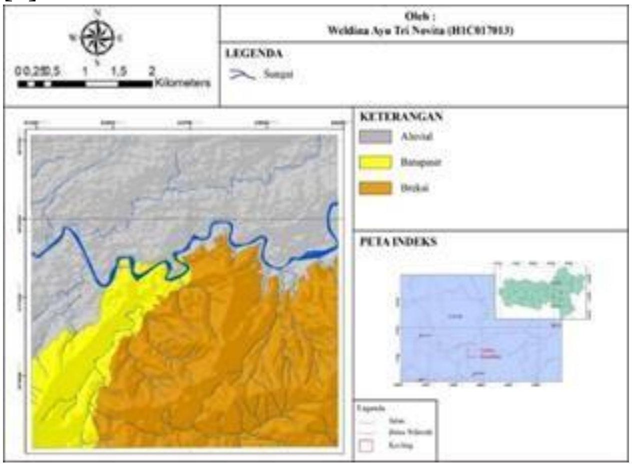

Figure- 5. Lithology Parameter Map

3) Slope Gradient of the Study Area

Based on spatial data, the slope gradient in the study area ranges from 0° to 49.48°. The slope gradient classification used in this study is based on the van Zuidam slope classification system [9].

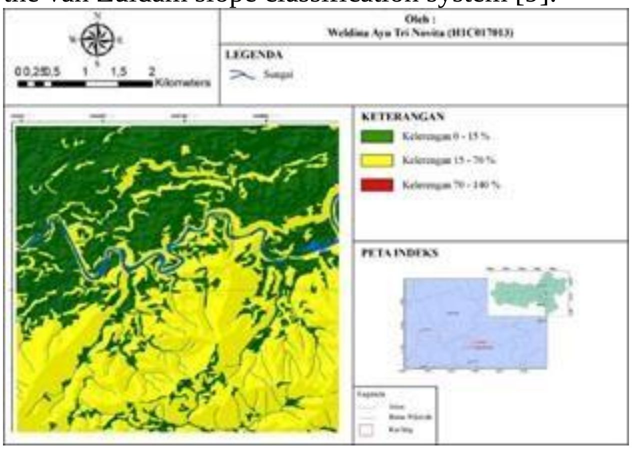

Figure- 6. Slope Gradient Parameter Map

4) Geological Structure Buffering of the Study Area

According to the analysis, two fault lines were identified as controlling structures within the study area. The proximity to these faults significantly influences landslide susceptibility, especially when the faults are active and capable of initiating ground movement [10].

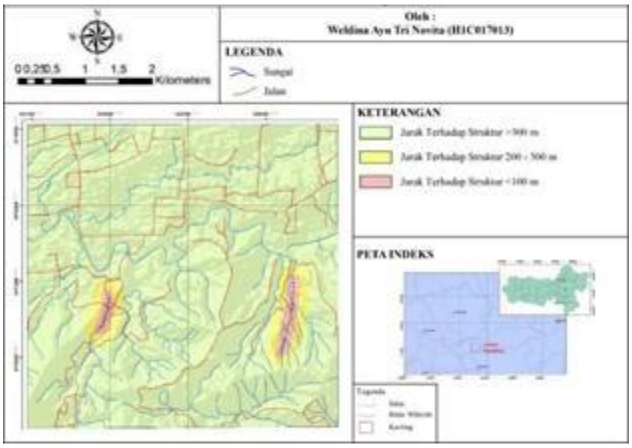

Figure- 7. Geological Structure Buffering Parameter Map

5) River Density of the Study Area

River density is considered an influential factor due to its correlation with geological structures. Areas with high river density tend to experience accelerated weathering, increasing the potential for landslides [11].

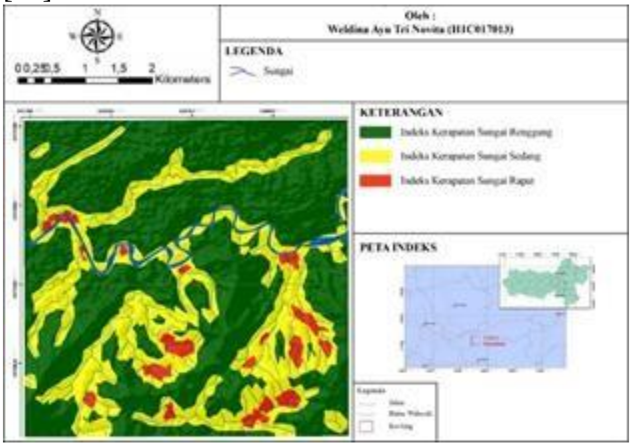

Figure- 8. River Density Parameter Map

6) Land Use of the Study Area

Land use data were derived from the Indonesian Geospatial Agency and modified by the researcher to reflect actual field conditions. Weighting was performed based on land use classifications [12].

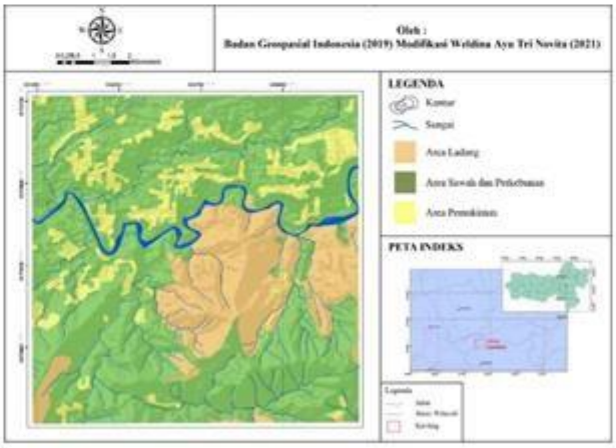

Figure- 9. Land Use Parameter Map

7) Analytical Hierarchy Process

The weighting of each landslide-triggering parameter in the study area followed the AHP method, which involves assigning values to each key parameter based on its relative importance [13]. These values are presented in the form of a pairwise comparison matrix, and parameters with the highest priority scale receive the greatest weight (Table 1).

Table-1. Priority Scale of Parameters Based on Analytical Hierarchy Process

Parameter	ch	l	tgl	bs	kl	ds
ch	1	0,50	0,50	0,33	0,50	0,5
l	2	1	3	1	1	1
tgl	2	0,33	1	2	1	0,5
bs	3	1	0,50	1	0,50	2
kl	2	1	1	2	1	2,00
ds	2	1	2	0,50	1	1
Total	12,00	4,83	8,00	6.83	4,50	7

Note
Ch : Rainfall Intensity
l : Lithology
tgl : Land Use
bisa : Structure Buffering
kl : Slope Gradient
ds : River Density

Table-2. Normalized Pairwise Comparison Matrix of Landslide Parameters

Factor	ch	l	tgl	bs	kl	ds	Total	Weight
ch	0,083	0,103	0,063	0,048	0,111	0,071	0,480	0,080
l	0,167	0,207	0,375	0,146	0,222	0,143	1,260	0,210
tgl	0,167	0,069	0,125	0,293	0,222	0,071	0,947	0,158

bs	0,250	0,207	0,063	0,146	0,111	0,286	1,063	0,177
kl	0,167	0,207	0,125	0,293	0,222	0,286	1,299	0,217
ds	0,167	0,207	0,250	0,073	0,111	0,143	0,951	0,158
Total							6,000	1,000

Table 2 presents the normalized pairwise comparison matrix. From this matrix, the weight of each parameter was derived. These weights are considered valid for use if the consistency ratio (CR) value is less than 0.1 [14]. The CR value is calculated using the following equations:

$$CI = \frac{\{\lambda max - n\}}{n-1}$$

$$CR = \frac{CI}{RI}$$

Where:
CI = Consistency Index
λ max = Maxmimal eigenvalue
n = Number of parameters
RI = Ratio index
CR = Consistency ratio

The maximum eigenvalue can be obtained by multiplying the pairwise comparison matrix (Table 1) by each parameter (Table 2). Based on the calculation using the above formula, the resulting Consistency Index (CI) is 0.106 and the Consistency Ratio (CR) is 0.08572. Therefore, the use of the above weights is considered consistent and acceptable [15].

8) *Landslide Vulnerability Zoning*

The landslide vulnerability zones in the Kebanaran area and its surroundings were determined through overlay analysis of six parameters: rainfall intensity, lithology, slope gradient, geological structures, river density, and land use. The result identified four levels of landslide vulnerability zones: Low, Moderate, High, and Very High [16].

Table 3. Scores and Weights of Landslide Movement Parameters

Parameter	Sub Parameter	Class Value	Weight	Scoring
Rainfall Intensity (ch)	< 2000 mm/year	1	0,08	0,08
	2000 - 3000 mm/year	2		0,16
	>3000 mm/year	3		0,24
Lithology (l)	Breccia	1	0,21	0,21
	Alluvial	2		0,42
	Sandstone	3		0,64
	Dry Land	1		0,16
	Settlements	2		0,32
Land Use (tgl)	Rice Fields and Plantations	3	0,16	0,48
Structure Buffering (bs)	> 300 m	1	0,18	0,18
	200 -300 m	2		0,36
	< 300 m	3		0,53
Slope Gradient (kl)	0 - 15 %	1	0,22	0,22
	15 - 70 %	2		0,44
	70 - 140 %	3		0,65
River Density (ds)	Sparse	1	0,16	0,16
	Moderate	2		0,32
	Dense	3		0,48

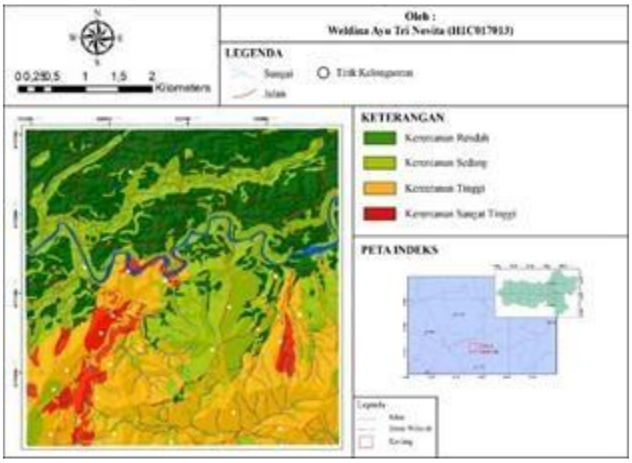

Figure- 10. Landslide Vulnerability Zoning Map of the Research Area

a. Low Vulnerability Zone

This zone covers approximately 20% of the study area. It is generally dominated by alluvial deposits, typically found in areas with flat to very gentle slopes. Land use in this zone includes rice fields and residential areas. It is mainly located in the northern part of the study area.

b. Moderate Vulnerability Zone

This zone covers around 30% of the study area. It typically occurs near riverbanks and in areas with breccia lithology. The slope gradients in this zone are generally gentle to moderately steep. Land use includes dry fields, some residential areas, and parts of rice fields.

c. High Vulnerability Zone

This zone encompasses approximately 35% of the study area. It is mainly found in regions with more pronounced slopes and those approaching structurally influenced zones. Plantations dominate the land use in this zone.

d. Very High Vulnerability Zone

This zone covers about 15% of the study area. It is primarily located in areas with steep slopes and close proximity to zones affected by geological structures. Lithological characteristics significantly influence the vulnerability level in this zone, which is largely occupied by plantations.

CONCLUSION

The geological conditions in the study area generally consist of three geological units: Breccia, Sandstone, and Alluvial Deposits. These units were formed progressively from the Early Miocene to the Holocene period, shaping the present landscape of the study area. Geological structures found in the area are the result of tectonic activities that occurred during the Pleistocene, a period marked by active tectonism on Java Island.

Based on the Analytical Hierarchy Process (AHP) analysis, the landslide vulnerability in the study area is categorized into four levels: low, moderate, high, and very high. Low vulnerability zones are typically located in the northern part of the area. Moderate vulnerability zones are found along riverbanks and in regions with breccia lithology. High vulnerability zones are associated with developed slope gradients and proximity to geological structures. Very high vulnerability zones are situated in areas directly influenced by geological structures. The zoning classification is based on contributing parameters including lithology, rainfall intensity, land use, river density, structural buffer, and slope gradient.

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