THE CRITICAL LEVEL OF WATER INFILTRATION MAPPING IN GAJAHMUNGKUR AND CANDISARI SUB-DISTRICTS, SEMARANG CITY

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Abstract *— The high rate of urbanization in the city of Semarang has an impact on sustainable development which continues to be intensified by the government, accompanied by changes in the function of water infiltration areas to become infrastructure areas. This change in land use causes the water infiltration area to decrease. Therefore, research was carried out on the critical level of the water infiltration area in Gajahmungkur and Candisari Districts, Semarang City, to determine the condition of the critical level and the size of each critical level. The research was carried out by collecting primary data through mapping soil types and lithology in the field and secondary data, including land use data and slope, which will be verified later in the area. The data above will then be analyzed using the Analytical Hierarchy Process (AHP) method by weighing each parameter and subparameter. The parameters are soil type, land use, slope, and lithology. These weightings are then overlaid to produce a zoning map of the critical level of the water infiltration area in Gajahmungkur and Candisari Districts, Semarang City. The study area's critical level of water infiltration areas can be divided into good, naturally normal, started to be critical, slightly critical, critical, and very critical..*

Keywords*: Water infiltration, Mapping, Candisari, Gajahmungkur, Semarang*

I. INTRODUCTION

The city of Semarang, the capital of Central Java, has a population of 1,656,564 million people with an area of 373.87 km^2 [1] and to meet the people's needs, the developing infrastructure that can divert the function of water infiltration areas is needed. The development process can turn vegetation areas into built-up areas in the form of buildings which reduce water absorption. Areas with poor water absorption processes will drain surface water runoff directly into rivers and the sea so that groundwater extraction cannot be maximized [2]. This research has purpose to determine the zoning of criticality level of water catchment areas in the study area using the Analytical Hierarchy Process method.

In Gajahmungkur and Candisari Districts, residential land use has an area of 1,314 ha or around 81.9% of the total area [1]. Land use in the form of dominant settlements diminishes the existing vegetation, making it more difficult or even impossible for an area to absorb water into the ground. Therefore, evaluating the criticality level of existing water infiltration areas is necessary. Evaluation is done by grouping a location based on existing conditions, such as good, normal, natural, starting to critical, moderately critical, critical, and very critical. The critical level of the water infiltration area is determined using the AHP method or the analytical hierarchy process by weighting each parameter and subparameter. The parameters are soil type, land use, slope, and lithology.

AHP is a decision-making method that decomposes complex multi-factor or multi-criteria problems into a hierarchy [3][4]. In its use, AHP can provide measurement scales and methods for obtaining priorities which can then consider relative priorities so that the best alternative can be selected [5]. This method starts with formulating the pairwise comparison matrix, defining the value of the pairwise comparisons, and calculating the eigenvector values. It can test the validity by producing a consistency index [3]. Based on the description above, AHP can be an appropriate method in this study. The research location is in Semarang City, Central Java, which includes Gajahmungkur and Candisari Districts (Fig. 1)

A. Regional Geology

Based on the Geological Map of Semarang Magelang Sheet [6] explains that the geology of Semarang City is composed of Quartenary age alluvial deposits that dominate the northern part of Semarang City while in the southern part of Semarang City, it is dominated by volcanic rocks, with the stratigraphic

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sequence in Semarang City from the oldest one are divided into Kerek Formation, Kalibeng Formation, Kaligetas Formation, Damar Formation that dominate the research area, Jongkong Formation, Kaligesing and Gajahmungkur Volcanic Rock Series and Alluvial Deposits.

B. Local Geology

Based on the Geological Map of Magelang – Semarang Sheet [6] the research area is dominated by the Damar Formation with lithology consisting of tuffaceous sandstone, conglomerate and volcanic breccia. The upper part is characterized by clay-sized material to reddish-brown passive clay. Weathering that occurs in the Damar Formation generally consists of clay, yellowish gray, sticky, clayey and very dense, containing many yellow and slightly red spots, containing a lots of rock fragments and volcanics. The sandy material is blackish gray to bluish, sub-rounded to angular grain size, consisting of quartz, feldspar and lithic rock minerals, containing organic elements and leaves, mossy which is interpreted as a sandstone member of the Damar Formation that was probably deposited in a marine environment [7][8].

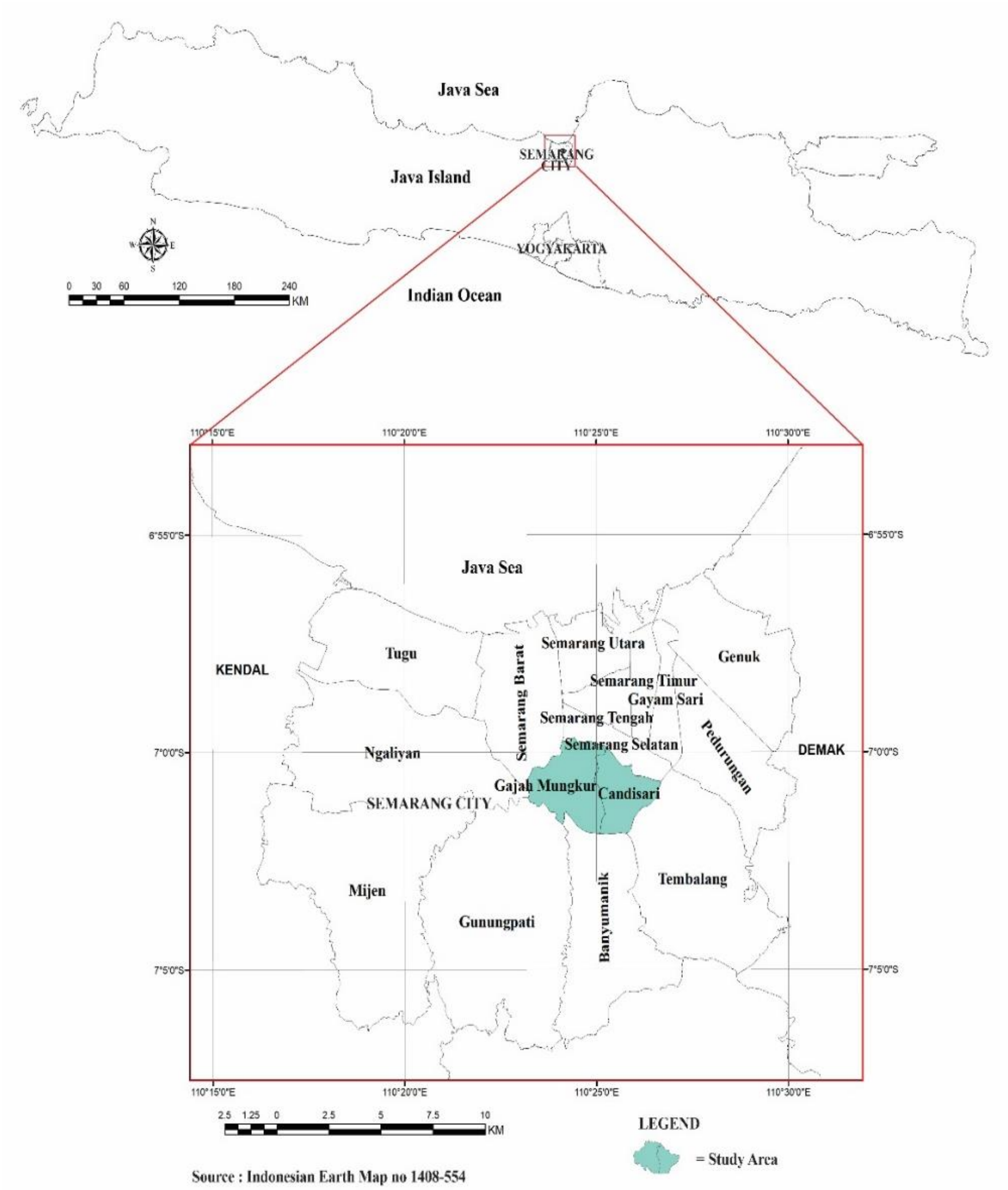

Figure 1. Research area (https://gadm.org/)

II. METHODS

The method that will be carried out in this study includes preliminary stages, data collection, laboratory analysis, and data analysis as shown in Figure 2.

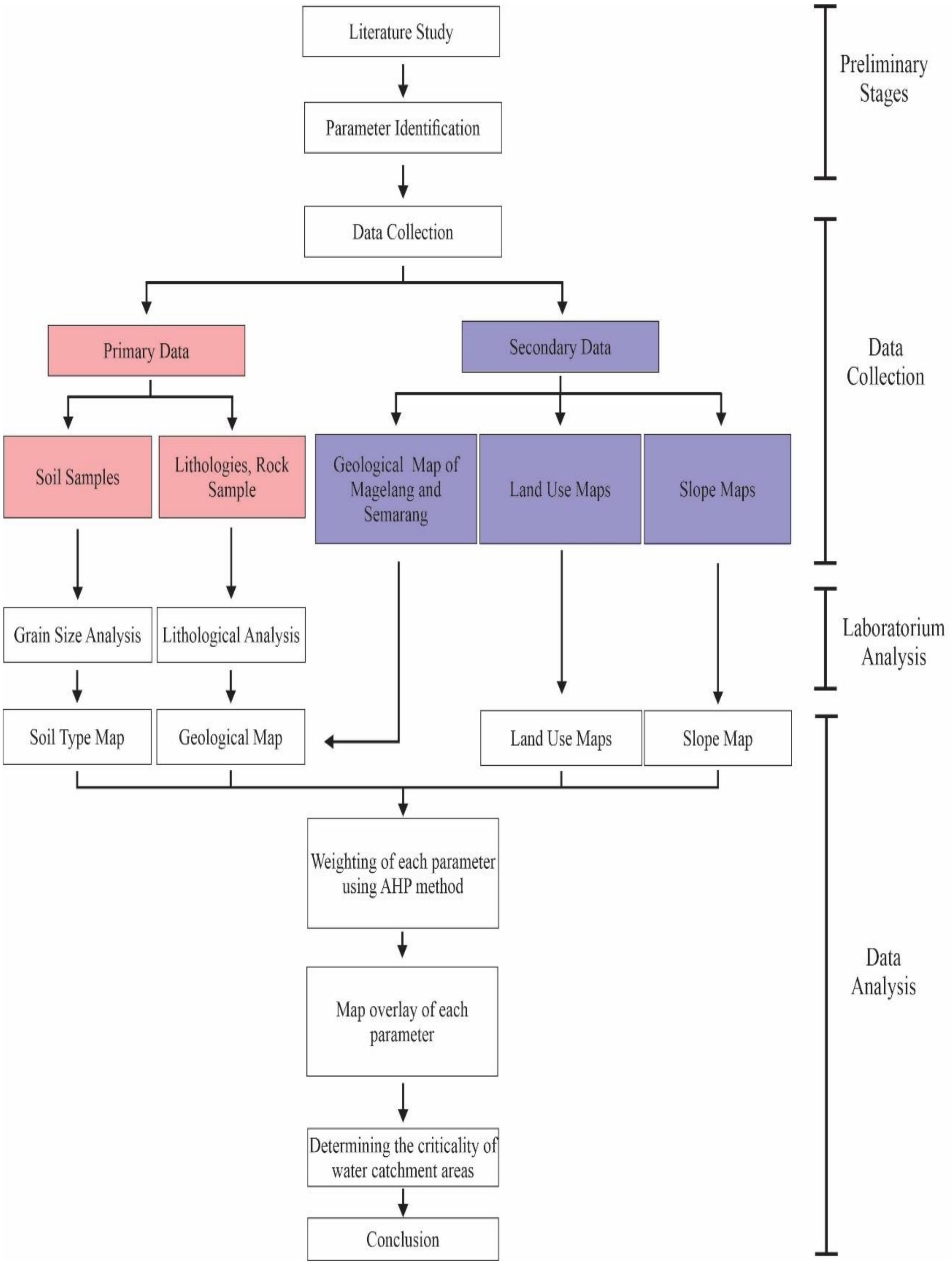

Figure 2. Research method diagram [11]

A. Preliminary stages

This research begins with a preliminary stage in library research through collecting related references. Based on existing references, it can then be used to identify parameters that will be further studied and evaluated regarding the critical level of water infiltration areas using the priority scale of several existing parameters.

B. Data collection

Data collection can be done directly in the field and through secondary data. Data taken directly in the field includes soil and rock samples, while the secondary data used is in the form of regional geological maps, land use maps, and slope maps processed through ArcMap software.

C. Laboratory analysis

Laboratory analysis was carried out as a grain size test using soil samples taken in the field to determine the distribution of soil types in the study area.

D. Data analysis

Based on the parameters obtained in soil type, land use, slope, and lithology, data analysis can be done using the AHP method, starting with preparing a pairwise comparison matrix. Compilation of comparisons based on the author's subjective judgment referring to previous research. The comparison is expressed with a value of 1-9. The reciprocal law applies, where if parameter a is considered four times more important than parameter b, then parameter b becomes ¼ more important than parameter a. After the pairwise comparison matrices are compiled, it can be normalized the weights of each parameter and then can find the eigenvector values. Finally, a consistency test can be carried out through a value that refers to the CR (Consistency Ratio). The CR value is obtained by comparing the consistency index and random indices. The weighting can be declared valid if the resulting CR value is <0.1. To find CI and RI values, you can use equations 1 & 2 as follows [3]:

$$CI = (\lambda max - n)/(n - 1) \quad (1)$$
$$CR = CI/RI \quad (2)$$

The value of λ max is the sum of the product of the priority vector for each row by the sum of each column, where n is the number of matrix orders. At the same time, the RI value can be determined through a table based on [3].

Table 1. RI value [3]

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RI	0	0	0,58	0,89	1,12	1,24	1,32	1,41

III. RESULTS AND DISCUSSION

Through the AHP calculations that have been described previously, the inter-parameter weighting results are obtained as shown in the Table 2.

Table 2. AHP calculation on each parameter [11]

	1	**2**	**3**	**4**	**Weight**
Soil type	1	2	3	5	0,467
Land use	1/2	1	3	4	0,315
Slope	1/3	1/3	1	2	0,139
Lithology	1/5	1/4	1/2	1	0,079
		λmax			4,0748
		CI *(consistency index)*			0,0249
		CR *(consistency ratio)*			0,0277

A. Soil type

Soil-type data was obtained through the results of grain size analysis tests using a sieve shaker using a modified USCS classification [9] without carrying out soil plasticity tests. The division of soil types is based on the percentage of fine fraction because all soil samples have >50% coarse grain size [10] which is divided into 3 types, such as <5% fines, 5-12% fines and > 12% fines, as shown in Figure 3. Based on the results obtained, the authors classify soil types into two soil types, which are coarse-grained soil with a small fine fraction (<5% fines) and coarse-grained soil with a medium fine fraction (5-12% fines) with a distribution as shown in Figure 4.

Figure 1. Difference between coarse grained soil with small fine fraction (left) and coarse grained soil with medium fine fraction (right) [11]

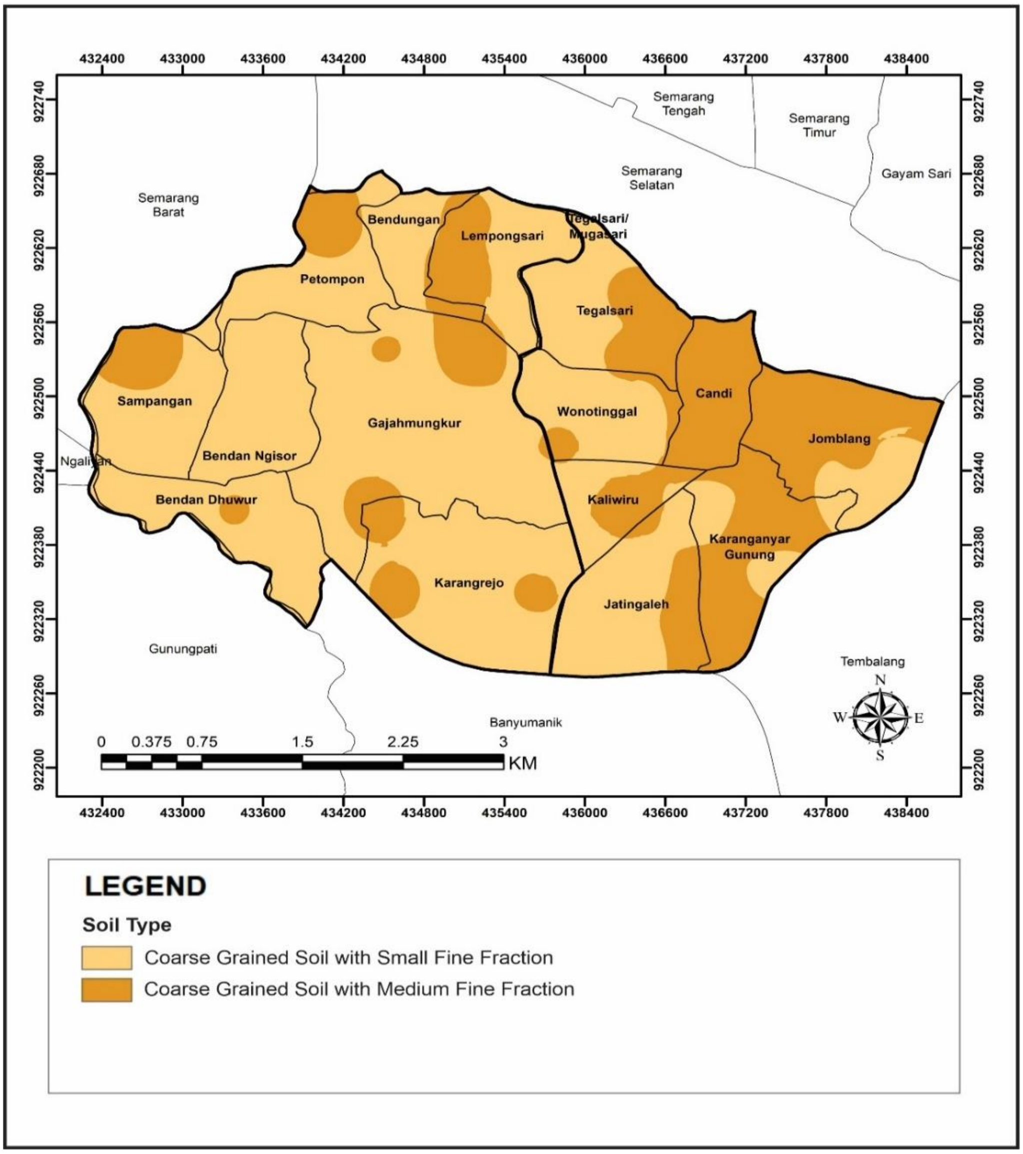

Figure 2. Soil type map in research area [11]

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Land use

Land use data was obtained through secondary data based on [11], which was then verified in the field. The classification used in the division of land use classes refers to [12] so that land use is divided into settlements, meadows, fields, and shrubs with a distribution shown in Figure 5.

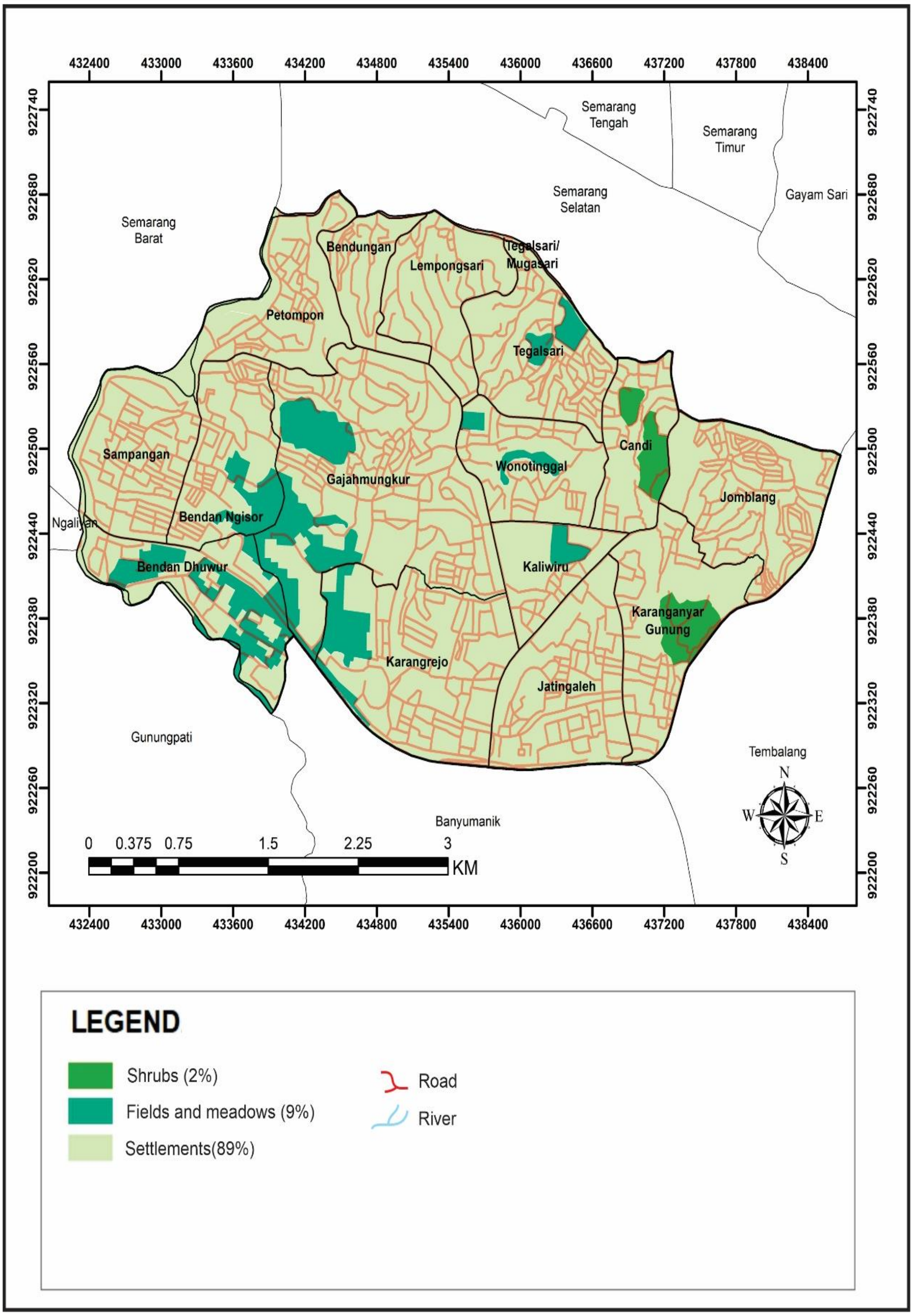

Figure 3. Land use map in research area [11]

B. Slope

Slope data was obtained through topographic data analysis, which was processed using ArcGIS software based on secondary data from DEMNAS. The Slope process then carries out the result to obtain the value of the slope. The classification used for the slope data is based on [12] which consists of flat (0-8%), sloping (9-15%), wavy (16-25%), steep (26-40%) and very steep (>40%) with the distribution as shown in Figure 6.

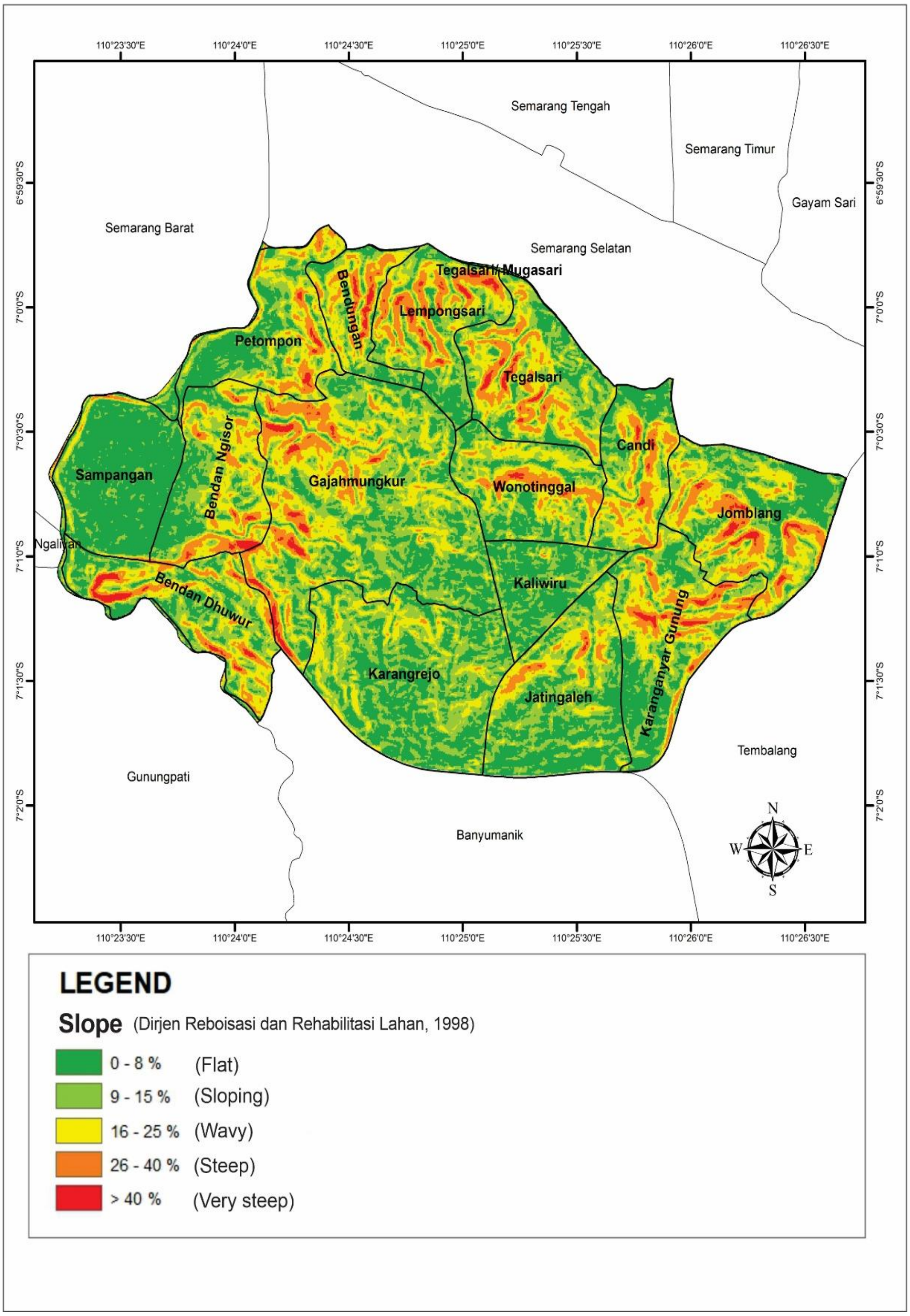

Figure 4. Slope classification in research area [11]

C. Lithology

Lithology data is determined based on secondary data references in the form of Regional Geological Maps of Magelang and Semarang Sheet [6]. After going through the verification process in the field, it can be determined that the lithology units found in the study area are divided into three, namely Conglomerate-inserted Tuffaceous Sandstone Unit and the Volcanic Breccia Unit, that comes from Damar Formation, and the Sand – Pebble Unit that comes from Alluvial Deposits with the distribution shown in Figure 7. Tuffaceous sandstone comes in greyish (weathered) and white yellowish (fresh) color, with massive structure, grain supported, poorly sorted and angular – sub rounded roundness. While the conglomerate has white (weathered) and brown (fresh) matrix, with medium-sized grain, fine-sorted and grain supported, with gray (fresh) and brownish (weathered) color, massive-structured, pebble-sized fragments. The volcanic-breccia unit has a gray color, with matrix composed by medium-coarse grained sand, poorly sorted and matrix supported texture [13]. While the fragment is composed of igneous rock with angular – sub rounded sphericity, euhedral – subhedral crystal and porfiro aphanitic texture.

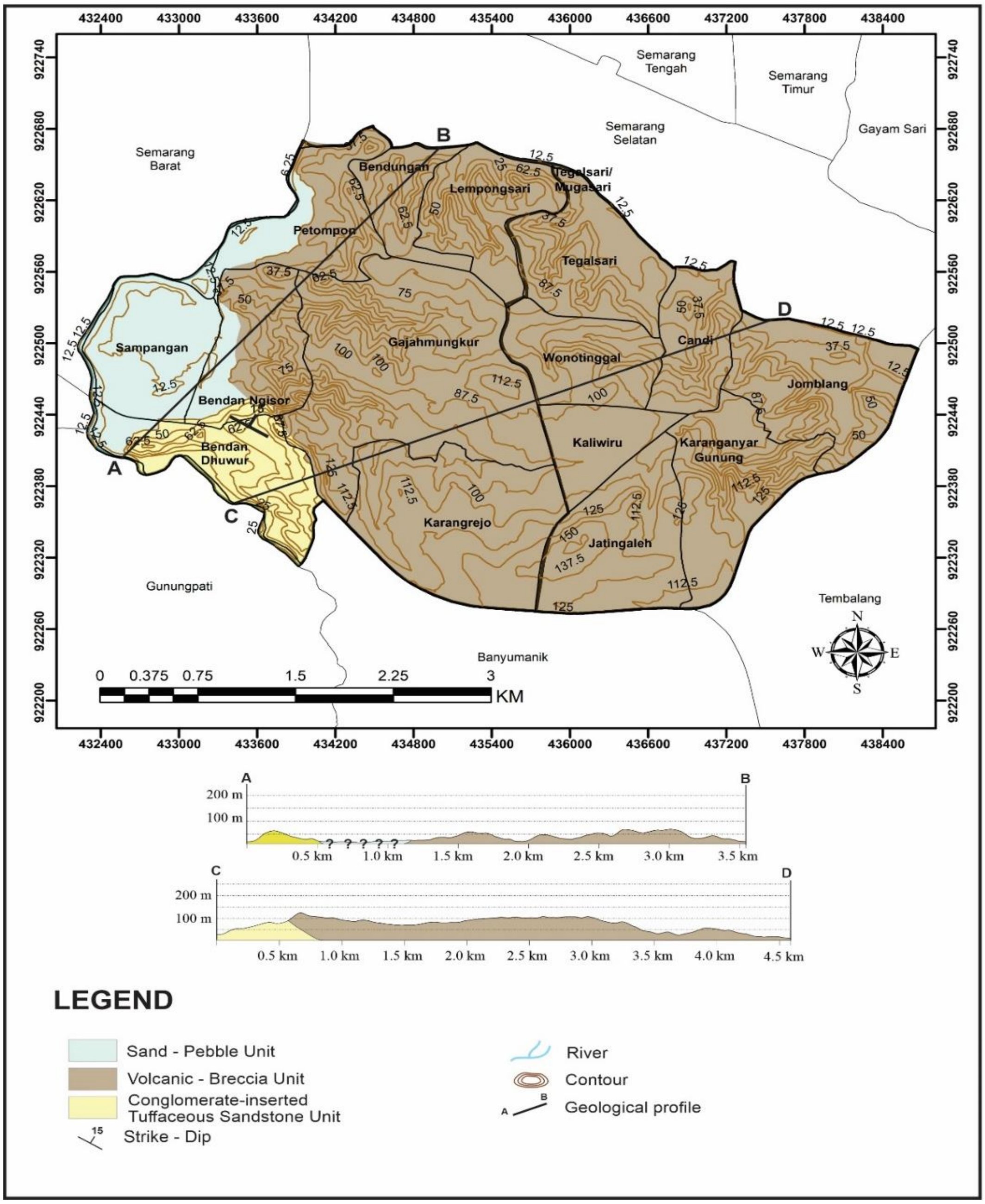

Figure 5. Litological map and geological section in research area [11]

D. Analytical hierarchy process approach

Determining the scoring score in the AHP method is carried out by weighting each parameter and sub-parameter first. After that, it can be multiplied between the parameter scores with each existing subparameter. The weighting on each subparameter is shown in Table 3.

Table 3. AHP calculation on each subparameter [11]

	Factors	1	2	3	4	5	Bobot
	Soil type						
1	CgrSFfr	1	2				0.67
2	CgrMFfr	1/2	1				0.33
	CR *(Consistency Ratio)*						0.00
	Land use						
1	Shrubs	1	2	3			0.53
2	Fields and meadow	1/2	1	3			0.33
3	Settlements	1/3	1/3	1			0.14
	CR *(Consistency Ratio)*						0.06
	Slope						
1	0-8%	1	2	3	4	5	0.42
2	9-15%	1/2	1	2	2	3	0.23
3	16-25%	1/3	1/2	1	2	3	0.17
4	26-40%	1/4	1/2	1/2	1	2	0.11
5	>40%	1/5	1/3	1/3	1/2	1	0.07
	CR *(Consistency Ratio)*						0.02
	Lithology						
1	SP	1/3	3	5			0.65
2	CiTS	1/2	1	2			0.23
3	VB	1/5	1/2	1			0.12
	CR *(Consistency Ratio)*						0.01

To produce the final scoring value, it can be found by multiplying the final weight of each parameter by the weight of each subparameter. The final scoring value, which is used as a reference for dividing the criticality classes of groundwater infiltration areas, is shown in Table 4.

Table 4. Final scoring value on each parameter and subparameter [11]

No	**Parameter**	**Parameter weight**	**Subparameter**	**Subparameter weight**	**Score (Parameter weight x Subparameter weight)**
1	Soil type	0.399	Coarse-grained soil with a small fine fraction	0.667	0.266
2			Coarse-grained soil with the medium fine fraction	0.333	0.133
3	Land use	0.339	Shrubs	0.525	0.178
4			Fields and meadows	0.334	0.113
5			Settlements	0.142	0.048
6	Slope	0.165	0 - 8 %	0.423	0.070
7			9 - 15 %	0.233	0.039
8			16 - 25 %	0.167	0.027
9			26 - 40 %	0.109	0.018
10			>40 %	0.067	0.011
11	Lithology	0.097	Sand-pebble	0.648	0.063
12			Volcanic breccia	0.230	0.022
13			Conglomerate-inserted tuffaceous sandstone	0.122	0.012

After obtaining the final scoring value, the ArcMap software can carry out the overlay process. The values obtained can then be divided into six classes using the class interval formula [14], as shown in equation (3). Through class divisions such as Table 5, a map of the criticality of water infiltration areas can be compiled, such as shown in Figure 6.

$$I = \frac{c-b}{k} \tag{3}$$

The variable "I" shows the class interval value, with "c" indicating the highest value, "b" being the lowest value, and "k" indicating the desired number of classes.

Table 5. Criticality classification and its values [11] [15]

Values	Condition criteria
0,162 – 0,180	Good
0,144 – 0,161	Naturally normal
0,127 – 0,143	Started to be critical
0,109 – 0,126	Slightly critical
0,091 – 0,108	Critical
0,073 – 0,090	Very critical

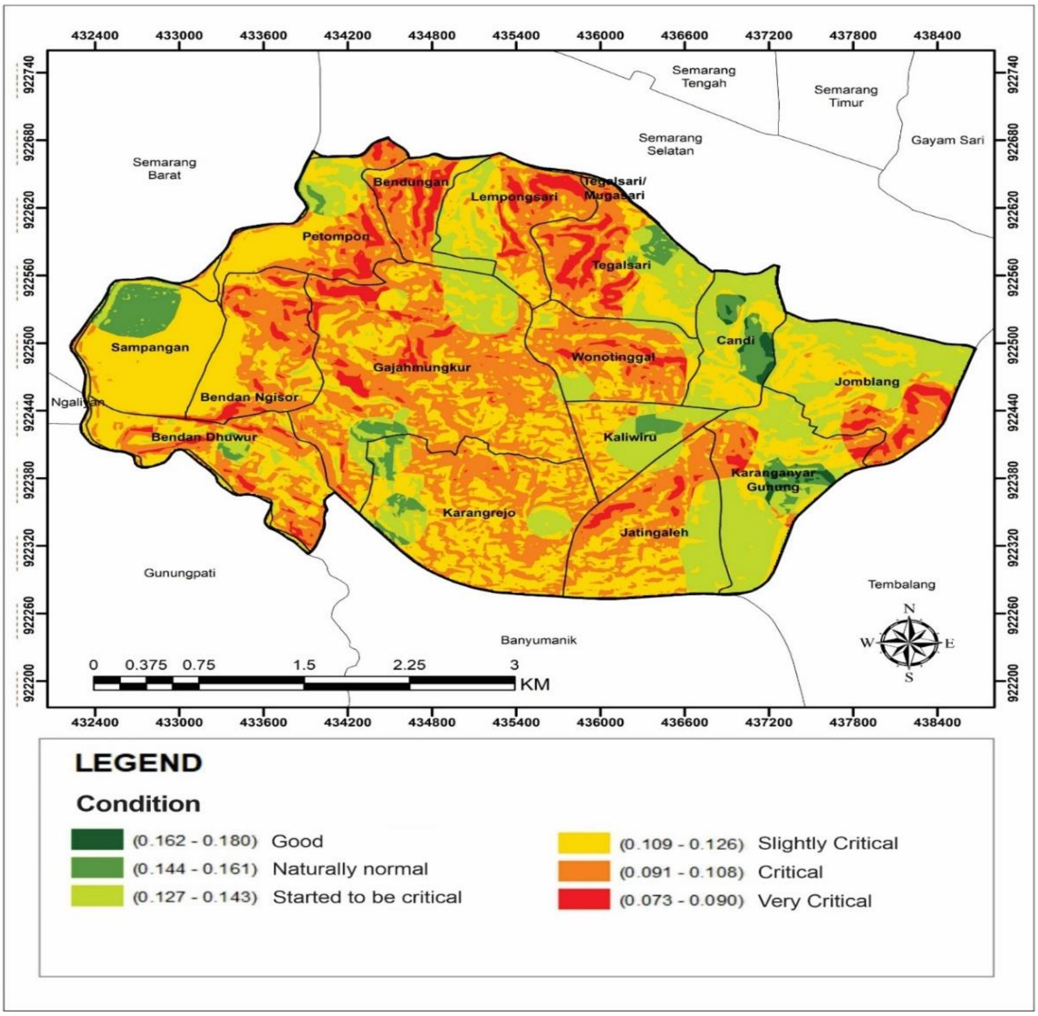

Figure 6. Criticality of water infiltration area map in research area [11]

E. Discussion

1. Good condition

   This condition has the most minor distribution in the study area, equal to 0.9% in Candi Village and Karanganyar Gunung Village. Based on the parameters obtained, after the overlay process is carried out, this area has the highest score ranging from 0.162-0.180, which is included in the criteria of good condition.
2. Naturally normal condition

   Naturally normal conditions have a coverage area of 2.5% in the study area with distribution in Karanganyar Gunung, Candi, Kaliwiru, Tegalsari, Karangrejo, Bendan Duwur, Sampangan and a small part of Petompon and Gajahmungkur Villages. After going through the overlay process, a range of values is obtained between 0.144 - 0.161 to be classified into naturally normal condition criteria.
3. Started to be critical

   In this condition, it has an area percentage of 23.6% which is spread over most of the Karanganyar Gunung, Jomblang, and Candi Villages, as well as a small part of the Jatingaleh, Kaliwiru, Tegalsari, Lepmongsari, Karangrejo, Gajahmungkur, Wonotinggal, Petompon, Sampangan and Bendan Dhuwur Villages. After overlaying, values ranging from 0.127-0.143 were obtained, indicating that this area was included in the criteria for started to be critical conditions.
4. Slightly critical condition

   Slightly critical conditions are spread evenly throughout the study area, with a percentage of 32.7%. After going through the overlay process, the final value obtained in this area is in the range of 0.109 – 0.126, which makes the condition of the criteria for water infiltration areas slightly critical.
5. Critical condition

   Critical conditions have a percentage of 34.6%. It spreads in the central and northern parts, which include most of Gajahmungkur, Bendan Ngisor, Karangrejo, Wonotinggal, Jatingaleh, Bendan Duwur, Bendan Ngisor, Tegalsari, and Bendungan Villages and a small part of Karanganyar Gunung, Jomblang, Petompon Villages and Lempongsari with a percentage of 34.6%. After going through the overlay process, areas with these criteria conditions have a value of 0.073 – 0.090.
6. Very critical condition

   This condition has a coverage area of 5.6% of the study area. The distribution of this condition can be found in a small part of Gajahmungkur, Bendan Ngisor, Bendan Duwur, Petompon, Lempongsari, Tegalsari, Wonotinggal, Jatingaleh, Karanganyar Gunung and Jomblang Villages. After going through the overlay process, areas with these criteria conditions have a value of 0.091 – 0.108.

In this section, the research results are explained and at the same time a comprehensive discussion is provided. The results can be presented in numbers, graphs, tables and others that make the reader understand easily [2][8]. The discussion can be made in several sub-sections.

IV. CONCLUSION

Based on the results of the study, it can be concluded that the water infiltration areas in Gajahmungkur and Candisari Districts, Semarang City, can be divided into six condition criteria, which is :

a. Good criteria, with a percentage of 0.9%, spread over the east sections, especially in Candi Village and Karanganyar Gunung Village.
b. Naturally normal criteria, with a percentage of 2.5% spread in the west, east and south sections of Karanganyar Gunun, Candi, Kaliwir, Tegalsari, Karangrejo, Bendan Duwur, Sampangan Village, and a small part of Petompon and Gajahmungkur Village.
c. Started to be critical criteria, with a percentage of 23.6% spread in the eastern and northern part in most of the Karanganyar Gunung, Jomblang, and Candi Villages, as well as a small part from Jatingaleh, Kaliwiru, Tegalsari, Lempongsari, Karangrejo, Gajahmungkur, Wonotinggal, Petompon, Sampangan and Bendan Dhuwur Village.
d. Slightly critical criteria, with a percentage of 32.7% spread evenly in each sub-district in the study area.
e. Critical criteria, with a percentage of 34.6% spread in the central and eastern parts, especially in most of Gajahmungkur, Bendan Ngisor, Karangrejo, Wonotinggal, Jatingaleh, Bendan Duwur, Bendan

Ngisor, Tegalsari and Bendungan Villages as well as a small part of Karanganyar Gunung Village, Jomblang, Petompon and Lempongsari.

f. Very critical criteria with a percentage of 5.6% which spread in the central and eastern parts, especially in a small part of Gajahmungkur, Bendan Ngisor, Bendan Duwur, Petompon, Lempongsari, Tegalsari, Wonotinggal, Jatingaleh, Karanganyar Gunung and Jomblang Villages.

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