Mapping the critical level of water infiltration areas in the western of Mijen sub-district, Semarang City, Central Java

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Abstract. Semarang City as the capital of Central Java Province is the main destination for urbanization in the Central Java region, which causes population density in Semarang City to increase, resulting in the development of land functions that can interfere with water infiltration areas. The western sub-district of Mijen, Semarang City, which is located on the border of Semarang City with Kendal Regency, and Semarang Regency, has also become a place for land use development due to the dense urban area. From these problems, research was conducted on the criticality of water infiltration areas in the western part of Mijen Subdistrict in order to be taken into consideration by the government to make policies. This research uses primary data in the form of soil and lithology mapping, and secondary data in the form of land use and slope, which are then verified in the field. The data were analyzed using the AHP (Analytical Hierarchy Process) method by creating a pairwise comparison matrix on each parameter, and subparameter, which was then overlay. The western part of Mijen Sub-district has a good level of criticality of water infiltration areas located in parts of Wonoplumbon Village, Ngadirgo Village, Tambangan Village, and a small part of Cangkiran Village. Naturally normal conditions and starting to be critical are relatively evenly distributed throughout the research area. Slightly critical, critical, to very critical conditions are located in the center of Wonoplumbom Village, north of Ngadirgo Village, and south of Cangkiran Village, and Bubakan Village.

1 Introduction

Semarang City is the capital of Central Java Province which was recorded in 2021 as having a population of 1,656,564 people with an area of 373.78 km^2 [1]. Semarang City is the main destination for urbanization from people in the Central Java region, causing the population density in Semarang City to increase, which has shown by changing the function of agricultural land and unused land into residential areas. The increasing population density every year causes problems in Semarang City such as water crisis that occurs during the dry season due to groundwater conditions that are difficult to renew. Water crisis often occurs during the dry season, as the groundwater in some areas of Semarang City is limited and difficult to renew [2].

The western part of Mijen sub-district (Figure 1) is one of the areas where land use is currently growing. The land in this area was originally dominated by production forests including teak forests, rubber forests, and sengon forests. Due to the increase in population that caused the city center area to be unable to accommodate the growth, the western Mijen Sub-district, which is directly located near Kendal Regency and Semarang Regency, became an alternative for people to build settlements. The production forest in the western part of Mijen Sub-district has been changed into settlements and fields. This land use change causes changes to the soil type, as well as the lithology in the surrounding area, which will then affect the water infiltration area which tends to be critical.

From those problems, it is necessary to reduce the impact of less-than-optimal water infiltration areas, which is by evaluating water infiltration areas into the categories of good water infiltration areas, naturally normal, starting to critical, slightly critical, critical, and very critical [2]. In determining the evaluation of water catchment areas in the western part of Mijen Subdistrict, Semarang City, the AHP (Analytical Hierarchy Process) method which was then made into a map with a scale of 1:50.000.

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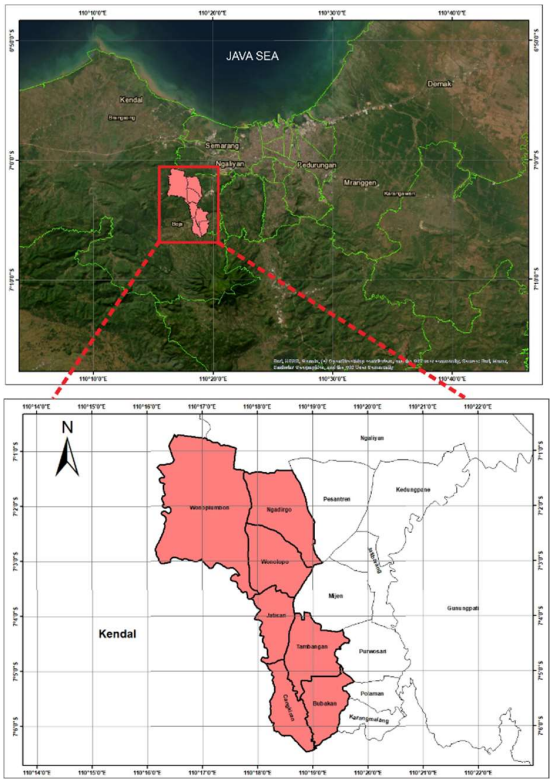

Fig 1. Research Area (Source : ArcGis World Imagery 2022 ; https://gadm.org/)

2 Research Methods

The research method in this study includes the following stages: preliminary stage, data collection, laboratory analysis, and data analysis.

2.1 Preliminary stage

At this stage, a desk study is carried out by collecting several references rto elated to the research. From the references that have been collected, the identification of parameters to be examined and evaluated against the parameters that will be used in determining the level of critical level of water infiltration areas by comparing the priority scale starting from the most important to the less important.

2.2 Data collection

The data collection consisted of primary data and secondary data. Primary data was collected directly in the field includes soil sample, and lithology, and secondary data that resulted from from the desk study are land use maps, and slope maps.

2.3 Laboratory analysis

The laboratory analysis carried out is the grain size analysis test to determine the grain size distribution of soil samples. Soil samples taken from the field are then sieved using a sieve shaker arranged with mesh sizes 10, 50, 100, 140, and 200, where the largest mesh size is in the uppermost position. The mesh arrangement is then placed on the sieving machine, so that the sample can adjust the grain size in each of the arranged mesh. After sieving, the percentage (%) of soil that successfully passed the 200 mesh size was calculated.

2.4 Data analysis

After processing data from the parameters of soil type, land use, slope, and lithology, then the AHP method carried out to obtain the final weight of each parameter in percentage form. the first step is to create a pairwise comparison matrix of each parameter. The results of the pairwise comparison are normalized, and calculate the eigen vector value. After getting the value of the eigenvector, the next step is to calculate consistency index (CI). After getting the value of the eigenvector, the next step is to calculate CI. If the CI value has been obtained, the consistency ratio (CR) value can be calculated. CI and CR values are obtained using equations 1 and 2. The results of the calculation of parameter values in the AHP method can be accepted or said to be consistent if the Consistency Ratio (CR) value is <0.1.

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

$$CR = CI/RI \quad (2)$$

Pairwise matrix comparison of soil type, land use, slope, and lithology parameters can be seen in Table 1.

Table 1. Pairwise matrix comparion on each parameter

Parameters	Soil type	Land use	Slope	Lithology	Weight
Soil type	1,0	2,0	2,0	3,0	0,41
Land use	0,50	1,0	2,0	3,0	0,29
Slope	0,50	0,50	1,0	2,0	0,19
Lithology	0,33	0,33	0,50	1,0	0,11

3 Data Representation

3.1 Soil type

Soil type data is obtained by taking soil samples on the surface directly in the field which is then carried out a grain size analysis test using a sieve shaker. The USCS classification [3] divides the number of fine fractions into three, namely a small fine fraction (<5%), a medium fine fraction (5-12%), and a large fine fraction (>12%). Based on the sieving results, the author divides the soil type in the research area into two soil type units, namely coarse-grained soil units with a small fine fraction (passing through mesh 200 <5%), and coarse-grained soil units with a medium fine fraction (passing through mesh 200 5-12%). The distribution of soil type ini research area shown in Figure 2 with a scale of map 1:50.000.

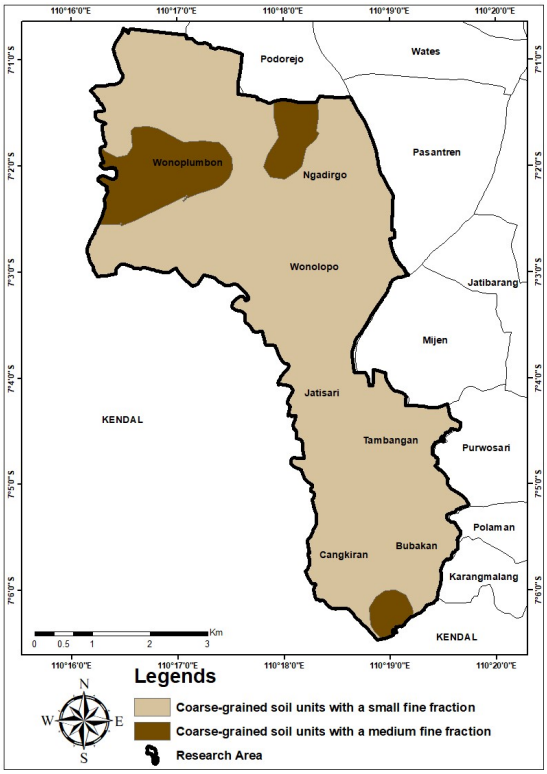

Fig 2. Soil type map [4]

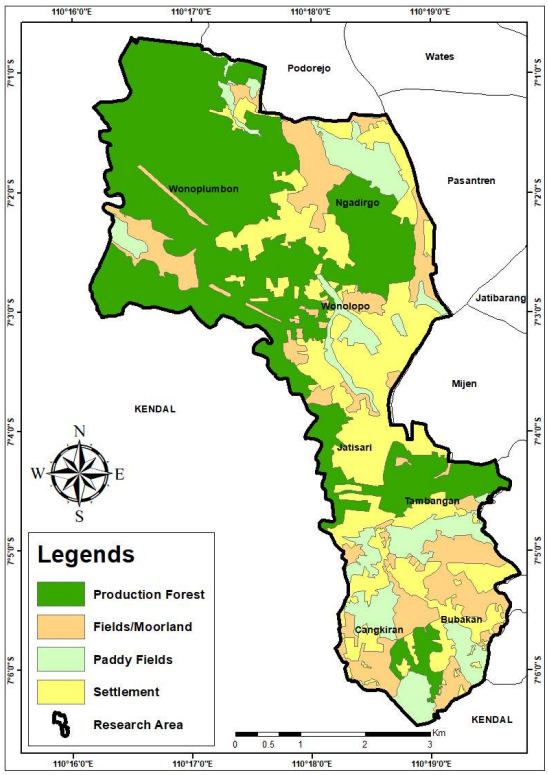

Fig 3. Land use map [4]

3.2 Land use

Land use data was obtained through secondary data made by Dinas Penataan Ruang Kota Semarang [5], which was then verified by making delineations on topographic maps in the field to determine the suitability and changes in land use that have occurred. The land use classification was based on the Directorate General of Reforestation and Land Rehabilitation [2, 6]. The author divides the research area into four types based on this classification, namely, production forest, fields or moor, settlements, and paddy. The distribution of land use in research area shown in Figure 3 with a scale of map 1:50.000.

3.3 Slope

Slope data obtained from secondary data, namely DEMNAS and direct observation in the field for verification. Slope analysis is done by converting DEMNAS data into slope data. Classification of slope based on the Directorate General of Reforestation and Land Rehabilitation [2, 6] into 5 classes, which are flat with a slope percentage of 0-8%, sloping with a slope percentage of 8-15%, wavy with a slope percentage of 15-25%, steep with a slope percentage of 25-40%, and very steep with a slope percentage of >40%. The distribution of slope in research area shown in Figure 4 with a scale of map 1:50.000.

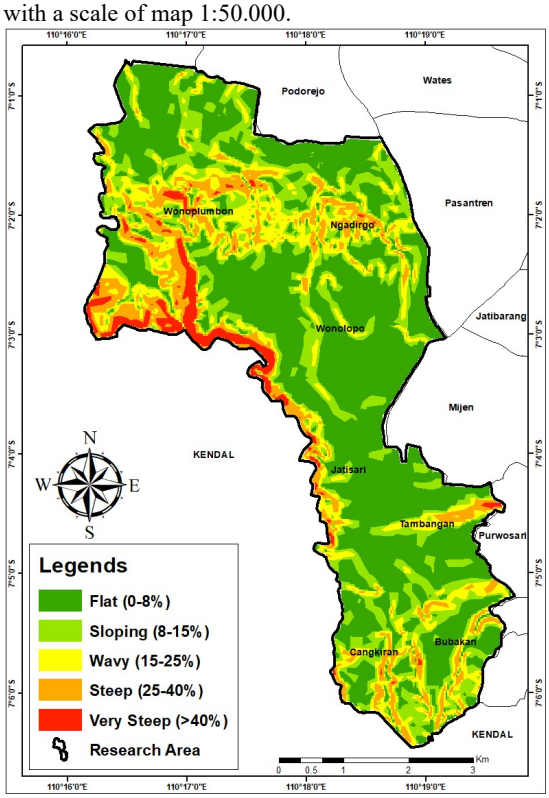

Fig 4. Slope map [4]

3.4 Lithology

Lithology data was collected by conducting geological mapping in the field with reference to the Regional Geological Map of Magelang and Semarang Sheets [7]. The results of the geological mapping carried out there are two rock units from the oldest, namely the volcanic breccia unit, and the andesite lava unit. Geology map of the results of field mapping in the study area can be seen in Figure 5 with a scale of map 1:50.000.

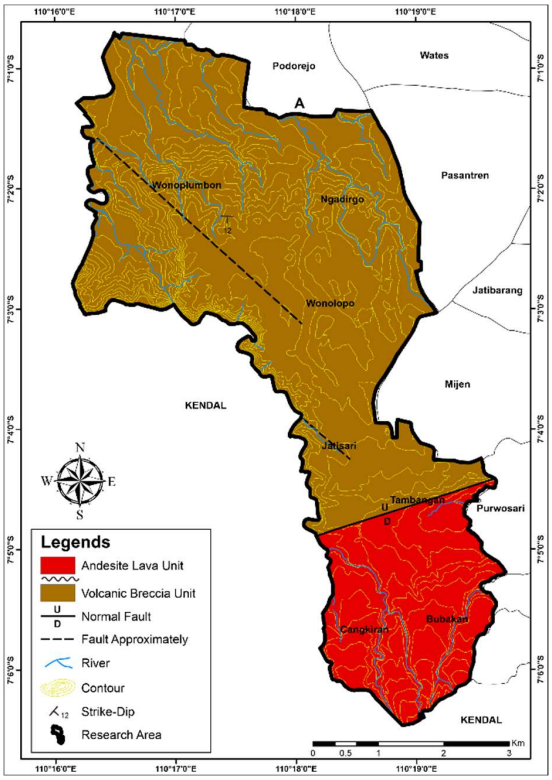

Fig 5. Geological map of the research area [4]

3.5 Analytical hierarchy process approach

AHP determination was carried out after data collection in the field, using the analytical hierarchy process method by Saaty (1980) [8]. The assessment was carried out on parameters, and subparameters, each of which has a different assessment weight. The parameters and sub-parameters are compared with each other, then the comparison results can be used to create a pairwise comparison matrix table.

Table 2. Soil type pairwise comparison matrix table

Parameter	CGSFfr	CGMFfr	Weight
CGSFfr	1	2	0,67
CGMFfr	0,5	1	0,33
Consistency Ratio			0

Table 3. Land use pairwise compatrion matrix table

Parameter	Production Forest	Fields	Paddy	Settlement	Weight
Production Forest	1,00	2,00	3,00	3,00	0,45
Fields	0,50	1,00	2,00	2,00	0,26
Paddy	0,33	0,50	1,00	1,00	0,14
Settlement	0,33	0,50	1,00	1,00	0,14
Consistency Ratio					0,00

Table 4. Slope pairwise comparison matrix table

Parameter	0 - 8%	8 - 15%	15 - 25%	25 - 40%	>40%	Weight
0 - 8%	1,00	2,00	3,00	4,00	5,00	0,42
8 - 15%	0,50	1,00	2,00	3,00	4,00	0,26
15 - 25%	0,33	0,50	1,00	2,00	3,00	0,16
25 - 40%	0,25	0,33	0,50	1,00	2,00	0,10
>40%	0,20	0,25	0,33	0,50	1,00	0,06
Consistency Ratio						0,02

Table 5. Lithology pairwise comparison matrix table

Parameter	Volcanic Breccia	Andesite Lava	Weight
Volcanic Breccia	1,00	2,00	0,67
Andesite Lava	0,50	1,00	0,33
Consistency Ratio			0,00

3.6 Water infiltration area critical level analysis

The analysis of the critical level of water infiltration areas was conducted based on the weighting results of each parameter and subparameter. The purpose of this analysis is to categorize the research area based on the criteria of the condition of the area towards its ability to absorb water. Table 6. is the result of the final scoring between parameters and subparameters.

Table 6. Final scoring between parameters and subparameters

Para-meter	Parameter Weight	Sub-parameter	Sub-parameter Weight	Score (Parameter weight x Sub-parameter weight)
Soil Type	0,41	CGSFfr	0,667	0,273
		CGMFfr	0,333	0,137
Land use	0,29	Production forest	0,455	0,132
		Fields or moor	0,263	0,076
		Settlement	0,141	0,041
		Paddy	0,141	0,041
Slope	0,19	0 - 8%	0,416	0,079
		8 - 15%	0,262	0,05
		15 - 25%	0,161	0,031
		25 - 40%	0,099	0,019
		>40%	0,062	0,012
Litho-logy	0,11	Volcanic Breccia	0,667	0,073
		Andesite Lava	0,333	0,037

To determine the classification of water infiltration condition criteria in the research area, the formula for determining the interval [9], namely by calculating the difference between the highest score and the lowest score, then divided by the number of condition criteria used. In this study, there are six condition criteria, namely good, natural normal, starting to be critical, somewhat critical, critical, and very critical [2]. The calculation of the interval value is obtained using equation 3. The condition criteria for the criticality of water catchment areas in the western part of Mijen Subdistrict, Semarang City can be seen in Table 7. The map of the critical level of water infiltration in research area shown in Figure 6 with a scale of map 1:50.000.

$$I = \frac{c-b}{k} \quad (3)$$

Table 7. Condition criteria and its values interval

Values	Condition Criteria
0,233-0,2871	Very critical
0,2871-0,3412	Critical
0,3412-0,3953	Slightly critical
0,3953-0,4494	Starting to critical
0,4494-0,5035	Naturally normal
0,5035-0,5576	Good

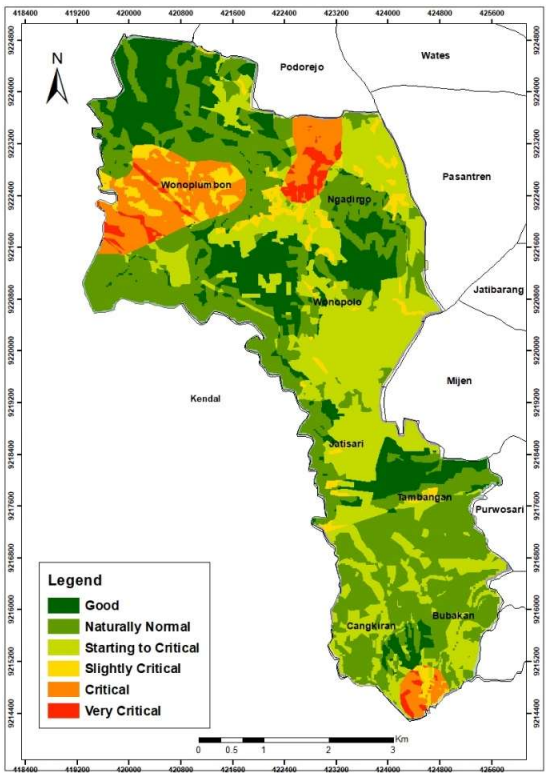

Fig 6. Map of the critical level of water infiltration in research area [4]

4 Discussion

Based on the map of the criticality level of the western part of Mijen Subdistrict, Semarang City using four parameters namely soil type, land use, slope, and lithology, which were then analyzed using the analytical hierarchy process method [8], the research area consists of 6 criteria for the condition of the water catchment criticality level, namely good, naturally normal, starting to be critical, slightly critical, critical, and very critical.

4.1 Good condition

The good condition criteria has a distribution percentage of 18.02% of the total research area. This condition is mostly found in Wonoplumbon Village, Wonolopo Village, Ngadirgo Village, Tambangan Village, and Bubakan Village. The presence of coarse-grained soil types with a small fine fraction, land use in the form of production forests, relatively flat slopes cause this area to have overlay results with a high score between 0.5035-0.5576 and is included in the good condition criteria.

4.2 Naturally normal condition

The naturally normal condition criterion has the highest percentage of distribution, which is 38.54% of the total research area. This condition is found in Wonoplumbon Village, Wonolopo Village, Ngadirgo Village, Tambangan Village, Jatisari Village, Cangkiran Village, and Bubakan Village. The presence of coarse-grained soil types with a small fine fraction, land use in the form of production forests, and fields / moorland, relatively flat to sloping slopes cause this area to have overlay results with a high score between 0.4494-0.5035 and fall into the criteria of naturally normal conditions.

4.3 Starting to critical condition

The starting to critical condition criteria has the second largest percentage distribution after the natural normal condition, which is 28.65% of the total research area. This condition is found in Wonolopo Village, Ngadirgo Village, Jatisari Village, and a small part of Cangkiran Village and Bubakan Village. The presence of coarse-grained soil types with a small fine fraction, land use in the form of settlements, relatively flat to gentle slopes that cause this area to have overlay results with scores between 0.3953-0.4494, and still fall into the criteria for starting to be critical.

4.4 Slightly critical condition

The slightly critical condition criteria has a distribution percentage of 4.87% of the total research area. This condition is found in Wonoplumbon Village, Ngadirgo Village, and a small part of Wonolopo Village. The change in land use from production forest to fields and slopes that tend to be wavy, and the occurrence of coarse-grained soil units with medium fine fractions cause this area to have overlay results with a score between 0.3412-0.3953 and is still included in the criteria for slightly critical conditions.

4.5 Critical condition

The critical condition criteria has a distribution percentage of 8.17% of the total research area. This condition is found in Wonoplumbon Village, Ngadirgo Village, and a small portion in Bubakan Village and Jatisari Village. Land use change from production forest to fields, paddy, settlements and slopes that already tend to be wavy, and the presence of coarse-grained soil units with medium fine fractions, these conditions can cause increased runoff water. This area has overlay results with a score between 0.2871-0.3412 and is still included in the critical condition criteria.

4.6 Very critical condition

The criteria for very critical conditions have the smallest percentage of distribution, namely 1.75% of the total research area. This condition is found in Wonoplumbon Village, Ngadirgo Village, and a small portion in Bubakan Village and Jatisari Village. Land use change from production forest with high vegetation to dry land in the form of fields, settlements, and steep slopes, and the presence of coarse-grained soil units with medium fine fractions, these conditions can cause increased runoff water, so that when the rainy season comes, water will have the potential to flood areas with very critical conditions. This area has an overlay result with a score between 0.233-0.2871 and is still included in the criteria for very critical conditions.

5 Conclusion

Based on the results of research on mapping the level of criticality of water catchment areas in western Mijen Subdistrict, Semarang City, Central Java, it is concluded that the water catchment area in the study area can be divided into six condition criteria, namely:

5.1 Good condition criteria

This criterion has a distribution percentage of 18.02% of the total research area. This condition is found in Wonoplumbon Village, Wonolopo Village, Ngadirgo Village, Tambangan Village, and Bubakan Village.

5.2 Naturally normal criteria

The naturally normal condition criteria has the highest percentage of distribution, which is 38.54% of the total research area. This condition is found in Wonoplumbon Village, Wonolopo Village, Ngadirgo Village, Tambangan Village, Jatisari Village, Cangkiran Village, and Bubakan Village.

5.3 Starting to critical criteria

The started to critical criteria has the second largest percentage distribution after normal natural conditions, which is 28.65% of the total research area. This condition is found in Wonolopo Village, Ngadirgo Village, Jatisari Village, and a small part of Cangkiran Village and Bubakan Village.

5.4 Slightly critical criteria

Slightly critical criteria have a distribution percentage of 4.87% of the total research area. This condition is found in Wonoplumbon Village, Ngadirgo Village, and a small part of Wonolopo Village.

5.5 Critical criteria

The critical condition criteria have a distribution percentage of 8.17% of the total research area. This condition is found in Wonoplumbon Village, Ngadirgo Village, and a small portion in Bubakan Village and Jatisari Village.

5.6 Very critical criteria

The very critical condition criteria have the smallest percentage distribution, which is 1.75% of the total research area. This condition is found in Wonoplumbon Village, Ngadirgo Village, and a small portion in Bubakan Village and Jatisari Village.

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