Soil Infiltration Mapping in the Eastern Part of Mijen Sub-District, Semarang City, Indonesia

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Abstract. The increase in population every year will encourage changes in land use from previously green open land to an infrastructure. Changes in land use can alter the condition of existing water infiltration areas. Those changes can cause the land to become impermeable and can increase the potential for surface runoff which can cause floods and landslides. Therefore, a research was carried out on the criticality level of water infiltration areas in the eastern part of Mijen Sub-district, Semarang City with the goal of knowing the criticality level of the water infiltration area and its distribution. This research was conducted by collecting primary data in the form of lithology and soil type by mapping and sampling directly in the field, as well as secondary data in the form of land use and slope which were then verified in the field and analyzed using ArcGIS software. The data collected then analyzed using the Analytical Hierarchy Process (AHP) method by weighing each parameter and subparameter. The parameter used are soil type, land use, slope, and lithology, each of which is divided into several subparameter that will reflect land characteristics. Then the final score for each land characteristic can be calculated from the results of the final weighting of parameters and subparameters. From the final score obtained, all data is then overlaid and classified into several criticality level of water infiltration area to obtain a map of the criticality level of the water infiltration areas. The research area's criticality level of the water infiltration area can be devided into six condition with it's distribution, that is good (23,8%), naturally normal (19%), started to be critical (37,4%), slightly critical (6,6%), critical (8,5%), and very critical (4,6%). From the results of this research, it is hoped that it can be a base data and recommendations for maintaining and restoring the criticality of water infiltration areas in the eastern part of Mijen Sub-district.

1 Introduction

Mijen Sub-district is one of the sub-districts in Semarang City which in 2021 was recorded to have a population of 83,321 people with an area of 56.52 km^2 [1]. Every year, there will be an increase in population which results in many changes in land use from originally green open land to settlements area. Changes in land use into settlements can cause the land to become impermeable, so that the water that is on the soil surface cannot absorb properly into the soil and will cause an increase in the volume of surface runoff [2].

Over time, changes in land use that continue to occur can affect the condition of existing water infiltration areas. Reduced water infiltration areas will have an impact on increasing water discharge in rivers and can be one of the causes of flooding [3]. Therefore, it is necessary to map the criticality level of water infiltration areas in the eastern part of Mijen Sub-district, Semarang City to find out the distribution of criticality level of water infiltration areas and minimize the adverse effects that resulted from reduced water infiltration areas. In determining the criticality level of water infiltration areas, the AHP (Analytical Hierarchy Process) method is used by weighting each parameter and subparameter. The parameters used in this study are soil type, land use, slope, and lithology. The criticality level of the water infiltration area is then grouped into 6 conditions, namely good, naturally normal, started to be critical, slightly critical, critical, and very critical [4] and then a map of the criticality level of water infiltration areas with a scale of 1:50.000 is produced.

AHP is a supporting method in decision making where this method will decompose complex multi-factor or multi-criteria problems into a hierarchy [5]. This method can solve complex and unstructured problems into several components in a hierarchical arrangement, by providing a subjective value regarding the relative importance of each variable, and determining which variable has the highest priority to influence the results in that situation [6]. Therefore, based on the explanation above, the AHP method is a suitable method for this research. The initial step in the AHP method is to create a pairwise comparison matrix between parameters, then the pairwise comparison matrix is normalized and weights are calculated. After that, the value of eigenvector can be calculated and value of the CR (Consistency Ratio) can be calculated to test the consistency of the calculations that have been done. The research location is in the eastern part of Mijen Sub-district, Semarang City, which includes Pesantren Village, Kedungpane Village, Jatibarang Village, Mijen

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Village, Purwosari Village, Polaman Village, and Karangmalang Village as shown in Figure 1.

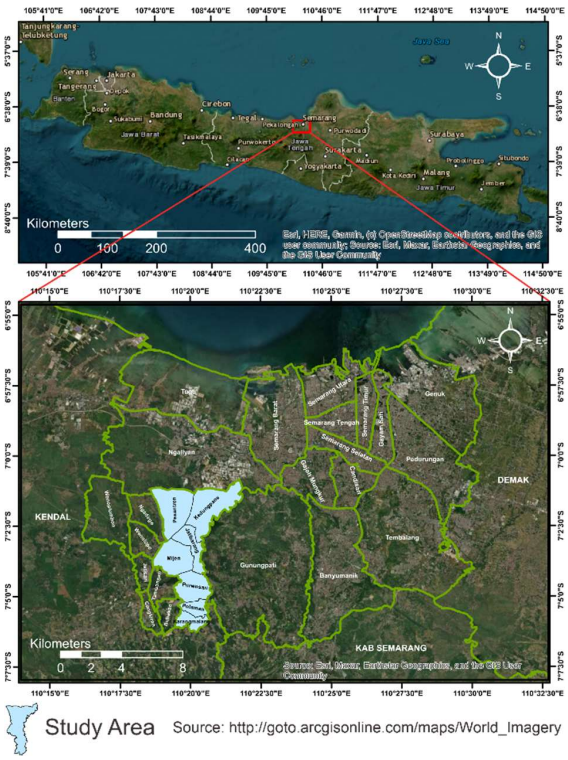

Fig. 1. Research Area (ArcGIS World Imagery, 2022)

2 Research methods

In this study, the methods that is used are the preliminary stage, data collection, laboratory analysis, and data analysis.

2.1 Preliminary stages

The preliminary stage includes a literature study related to the research topic which is then used to identify the parameters to be further studied and evaluated regarding the critical level of the water infiltration area by using a priority scale of several parameters and subparameters. The parameters will be sorted from the most important to the least important.

2.2 Data collection

In this study, data collection was carried out through field data collection and through secondary data collection. Soil type and lithology data are data taken directly in the field, while for data collected through secondary data, that is land use maps and slope maps which are then processed using ArcGIS software.

2.3 Laboratory analysis

The laboratory analysis carried out in this study was the grain size analysis of the soil using soil samples that had been taken in the field. The analysis was carried out to determine the type of soil and its distribution in the study area.

2.4 Data analysis

Data analysis in this study was carried out using the AHP method using parameters of soil type, land use, slope, and lithology. The AHP method begins by arranging a pairwise comparison matrix between parameters by giving a comparison value between parameters based on the author's subjective assessment based on previous research. The comparison value between the given parameters is expressed in values of 1 – 9, where the reciprocal law applies. Then the pairwise comparison matrix is normalized and the weight of each parameter is calculated. After that, the maximum eigenvector value (λmax) can be calculated by multiplying the sum of matrix of each parameter with the parameter weight, then the CI (Consistency Index) value can be calculated using equation (1), where "n" is the number of parameters used. Finally, the CR value (Consistency Ratio) is calculated to determine the validity level of the calculations that have been made. The calculation is valid if the CR value is <0.1. If the CR value does not meet CR <0.1 then the calculation needs to be redone. The CR value can be calculated by dividing the CI value by the RI (Random Indices) value as shown in equation (2).

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

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

The RI value is obtained based on the value by [7], which can be seen in the following Table 1.

Table 1. RI value [7]

n	1	2	3	4	5	6	7	8	9
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45

3 Data representation

Based on the AHP calculations described earlier, the weighting between parameters and the weights of each parameter can be seen in the following Table 2.

Table 2. AHP calculation for each parameter

	Soil type	Land use	Slope	Lithology	Weighting
Soil type	1	2/1	2/1	4/1	0,4244
Land use	1/2	1	3/1	3/1	0,3141
Slope	1/2	1/3	1	2/1	0,1667
Lithology	1/4	1/3	1/2	1	0,0947
λmax					4,1379
CI (Consistency Index)					0,0460
CR (Consistency Ratio)					0,0511

3.1 Soil type

Soil type data was obtained based on the results of the grain size analysis test using a sieve and sieve shaker. The grouping of soil types refers to the USCS classification [8] which has been modified without conducting the soil

plasticity tests. From the results of soil grain size analysis, it was found that all samples had a coarse grain size > 50% [8] so that the grouping of soil types was based only on the percentage of fine fraction which could be grouped into 3 types, namely fines <5%, fines 5 – 12 %, and fines >12%. Based on this grouping and the results of the analysis, the soil type in the study area can be grouped into 2 types of soil, that is coarse-grained soil with a small fine fraction (fines <5%) and coarse-grained soils with medium fine fraction (5 – 12% fines). Soil type map with a scale of 1:50.000 was produced which can be seen in Figure 2.

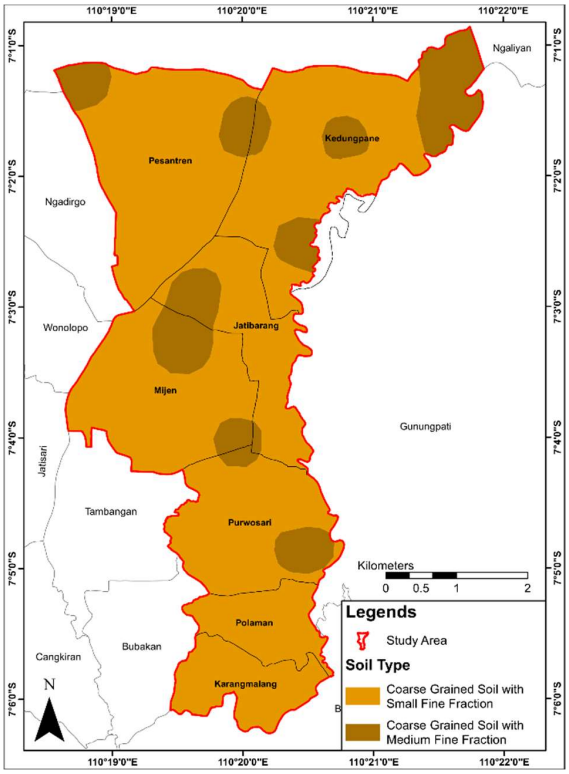

Fig. 2. Map of soil type in the research area [9]

3.2 Land use

Land use data was obtained from secondary data based on [10] which has a scale of 1:100.000, then verified in the field and re-plotted on ArcGIS software to determine the suitability of land use in the field and then a land use map can be produced with a scale of 1:50.000. The distribution of land uses in this study uses the classification from [11], which then results in land uses in the research area, that is production forests, settlements, fields and meadows, ricefields, and shrubs, with its distribution which can be seen in Figure 3.

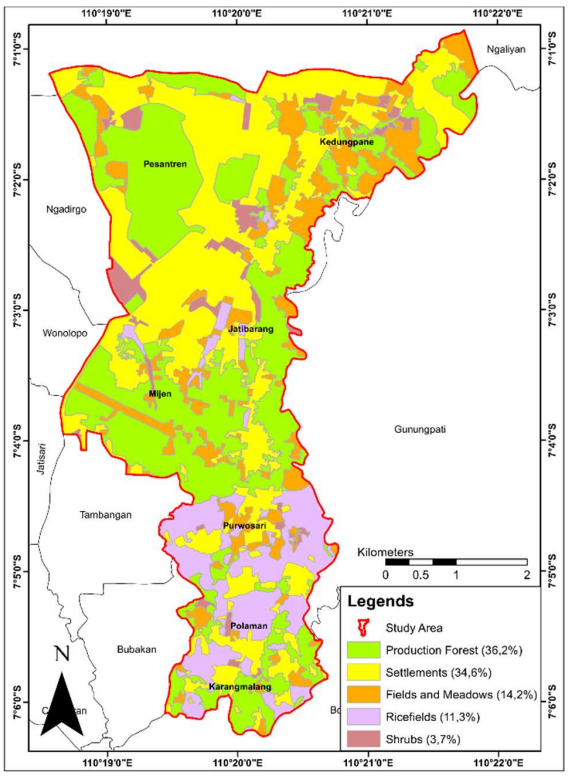

Fig. 3. Map of land use in the research area [9]

3.3 Slope

Slope data was obtained from secondary data based on DEMNAS which has a scale of 1:100.000, which was then analyzed with the slope process using ArcGIS software to obtain the value of the slope and then a slope map with a scale of 1:50.000 was produced. The classification of the slope values used in this study is based on [11], which is divided into flat (0 – 8%), sloping (8 – 15%), wavy (15 – 25%), steep (25 – 40%), and very steep (> 40%) with its distribution which can be seen in Figure 4.

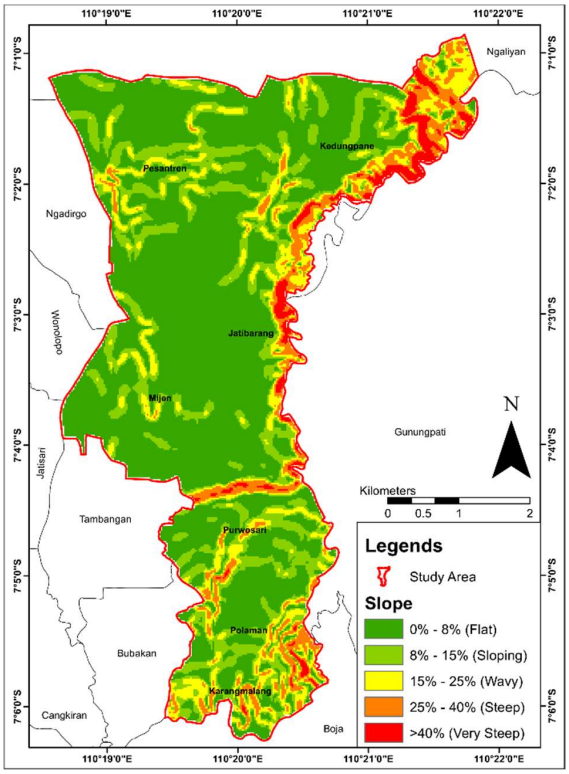

Fig. 4. Map of slope in the research area [9]

3.4 Lithology

Lithology data was obtained through geological mapping in the field with the Geological Map of Magelang and Semarang Sheet [12] as a secondary map. Based on geological mapping in the field and results of correlation with the Geological Maps of Magelang and Semarang Sheet [12], the lithology units in the study area from the oldest to the youngest are volcanic breccia units, breccia-inserted sandstone unit, and andesite lava unit and then a lithological map with a scale of 1:50.000 was produced, whose lithological distribution can be seen in Figure 5.

3.5 Analytical hierarchy process approach

In the AHP method, scoring is determined after data collection and analysis by weighting each parameter and sub-parameter. Each parameter and subparameter will have a different weighting. The weighting for each subparameter can be seen in Table 3.

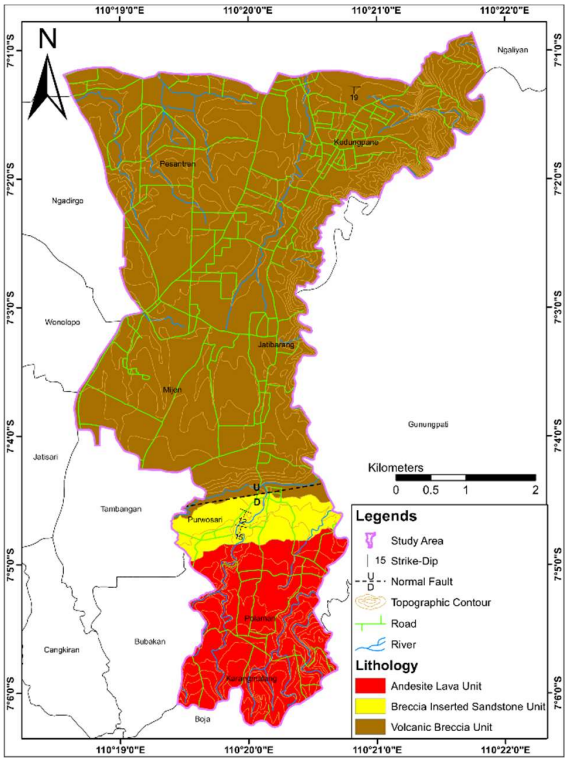

Fig. 5. Map of lithology in the research area [9]

Table 3. Calculation for each subparameters

		1	2	3	4	5	Weight
	Soil type						
1	CgrSFfr	1	2				0,667
2	CgrMFfr	1/2	1				0,333
	CR (Consistency Ratio)						0,0
	Land use						
1	Production forest	1	2	3	4	4	0,413
2	Shrubs	1/2	1	2	3	3	0,257
3	Fields and meadows	1/3	1/2	1	2	2	0,154
4	Settlements	1/4	1/3	1/2	1	1	0,088
5	Ricefields	1/4	1/3	1/2	1	1	0,088
	CR (Consistency Ratio)						0,0110
	Slope						
1	0-8%	1	2	3	4	5	0,416
2	8-15%	1/2	1	2	3	4	0,262
3	15-25%	1/3	1/2	1	2	3	0,161
4	25-40%	1/4	1/3	1/2	1	2	0,099
5	>40%	1/5	1/4	1/3	1/2	1	0,062
	CR (Consistency Ratio)						0,0202
	Lithology						
1	BiS	1	2	3			0,539
2	VB	1/2	1	2			0,297
3	ALv	1/3	1/2	1			0,164
	CR (Consistency Ratio)						0,0096

The final score can then be calculated by multiplying the final score for each parameter with the final score for each subparameter. The final score is then used to divide the critical condition of the water infiltration area in the study area. The final score can be seen in Table 4.

Table 4. Final scoring value

No	Parameters	Parameter weight	Sub-parameters	Subparameter weight	Final score
1	Soil type	0.4244	Coarse-grained soil with a small fine fraction	0.667	0.283
			Coarse-grained soil with the medium fine fraction	0.333	0.141
2	Land use	0.3141	Production Forest	0.413	0.130
			Shrubs	0.257	0.081
			Fields and Meadows	0.154	0.048
			Settlements	0.088	0.028
			Ricefields	0.088	0.028
3	Slope	0.1667	0-8%	0.416	0.069
			8-15%	0.262	0.044
			15-25%	0.161	0.027
			25-40%	0.099	0.016
			>40%	0.062	0.010
4	Lithology	0.0947	Breccia-inserted sandstone	0.539	0.051
			Volcanic breccia	0.297	0.028
			Andesite lava	0.164	0.016

After the final score is obtained, then the overlay process is carried out using ArcGIS software. The values that have been obtained from the overlay process can then be grouped into six classes of water infiltration conditions [4] using the interval class formula from [13] shown in equation (3), where the variable "I" is the class interval value, variable "c" is the highest value, "b" is the lowest value, and "k" is the number of class intervals.

$$I = (c - b)/k \tag{3}$$

Then the range of values for each condition of the water infiltration area is obtained which can be seen in Table 5. From Table 5, a map of the criticality level of the water infiltration area in the eastern part of Mijen Sub-district, Semarang City with a scale of 1:50.000 can be produced which can be seen in Figure 6.

Table 5. Criticality condition classification and its value

Values	Condition classification
0,47775 – 0,53306	Good
0,42243 – 0,47774	Naturally normal
0,36711 – 0,42242	Started to be critical
0,31178 – 0,36710	Slightly critical
0,25646 – 0,31177	Critical
0,20113 – 0,25645	Very Critical

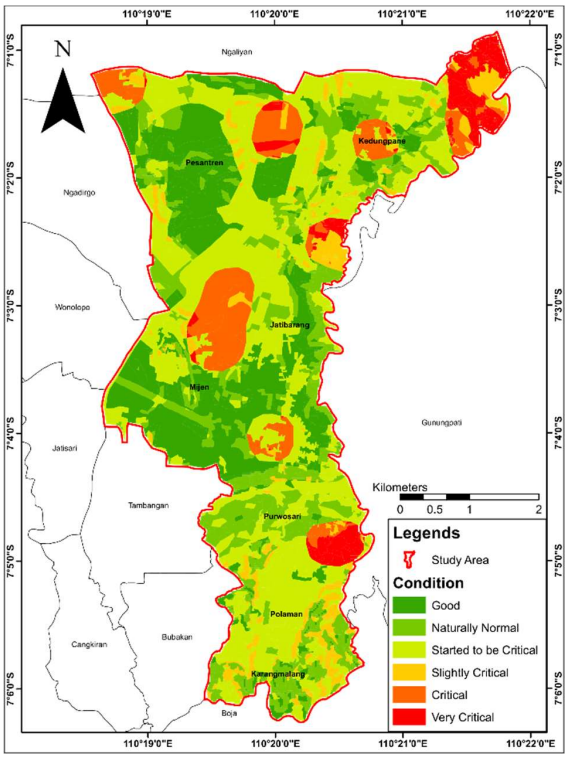

Fig. 6. Map of the criticality level of water infiltration areas in the research area [9]

4 Discussion

4.1 Good condition

Good condition dominated in the central and northern parts of the study area, which include Village of Mijen, Jatibarang, Pesantren, and a small part in Village of Kedungpane, Purwosari, and Polaman. This condition has a distribution of 23,8% of the total area of the study area, where this condition is the second largest after started to be critical condition. After going through the overlay process, a fairly high range of values was obtained, which ranged from 0,47775 – 0,53306 which was then classified into good condition.

4.2 Naturally normal condition

Naturally normal condition dominated in the central and southern parts of the study area, which include Village of Purwosari, Jatibarang and Karangmalang. Some are located in Village of Polaman, Mijen, Kedungpane, and Pesantren. This condition has a distribution of 19% of the total area of the study area. After going through the overlay process, a relatively high range of values was obtained, which ranged from 0,42243 – 0,47774 which was then classified into naturally normal condition.

4.3 Started to be critical condition

Started to be critical condition dominated the northern and southern parts of the study area, which include Village of Kedungpane, Pesantren, Jatibarang, Purwosari, Polaman, and Karangmalang. The distribution of these conditions is the largest with a percentage of 37,4% of the total area of the study area. After going through the overlay process, a range of values was obtained that ranged from 0,36711 – 0,42242 which was then classified into started to be critical condition.

4.4 Slightly critical condition

Slightly critical condition dominated in the southern and northeastern parts of the study area, which include Village of Kedungpane, Polaman, Karangmalang, as well as a small part in Village of Mijen, Pesantren, and Purwosari. This condition has a distribution with a percentage of 6,6% of the total area of the study area. After going through the overlay process, a range of values was obtained ranging from 0,31178 – 0,36710 which was then classified into slightly critical condition.

4.5 Critical condition

Critical condition dominated in the central and northern parts of the study area, which include Village of Mijen, Jatibarang, Kedungpane, Pesantren, and a small part in Purwosari Village. This condition has a distribution percentage of 8,5% of the total area of the study area. After going through the overlay process, a range of values was obtained ranging from 0,25646 – 0,31177 which was then classified into critical condition.

4.6 Very Critical Condition

Very critical condition dominated in the eastern part of the study area, which includes Village of Kedungpane, Purwosari, and a small part is in the Pesantren Village and Mijen Village. This condition has the smallest distribution percentage among other conditions, that is 4,6% of the total area of the study area. After going through the overlay process, a range of values was obtained ranging from 0,20113 – 0,25645 which was then classified into very critical condition.

5 Conclusion

Based on the results of mapping the criticality level of the water infiltration area in the eastern part of Mijen Sub-district, Semarang City, it can be concluded that the condition of the water catchment area in the eastern part of Mijen Sub-district, Semarang City can be divided into six conditions, that is:

A. Good condition with a distribution percentage of 23,8% which is spread over Mijen Village, Jatibarang Village, Pesantren Village, and a small part in Kedungpane Village, Purwosari Village, and Polaman Village.
B. Naturally normal condition with a distribution percentage of 19% which is spread in Purwosari Village, Jatibarang Village, Karangmalang Village, and some are in Polaman Village, Mijen Village, Kedungpane Village, and Pesantren Village.
C. Started to be critical condition with a distribution percentage of 37,4% spread across Kedungpane Village, Pesantren Village, Jatibarang Village, Purwosari Village, Polaman Village, and Karangmalang Village.
D. Slightly critical condition with a distribution percentage of 6,6% which is spread in Kedungpane Village, Polaman Village, Karangmalang Village, and a small part in Mijen Village, Pesantren Village and Purwosari Village.
E. Critical condition with a distribution percentage of 8,5% which is spread over Mijen Village, Jatibarang Village, Pesantren Village, Kedungpane Village, and a small part of Purwosari Village.
F. Very critical condition with a distribution of 4,6% which is spread in Kedungpane Village, Purwosari Village, and a small part in the Pesantren Village and Mijen Village.

For the future research, the infiltration rate can be measured directly in the field to get more accurate results regarding the correlation between the infiltration rate and the existing soil type.

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References

1. Badan Pusat Statistik Kota Semarang, *Kepadatan Penduduk (Jiwa/km2) 2019 – 2021*, BPS Kota Semarang (2023), accessed from https://semarangkota.bps.go.id/indicator/12/48/1/kepadatan-penduduk.html on February 2023
2. Uca, S. Nyompa, N.C. Rahayu, J. Env. Sci **4**, 33-46 (2021)
3. A.K. Wibowo, C.T. Widodo, S. Darsono, H. Budieny, J. Kary. Tek. Sip **6**, 226 – 235 (2017)
4. S.A. Gunawan, Y. Prasetyo, F.J. Amarrohman, J. Geod. Univ. Diponegoro, **5**, 125 – 135 (2016)
5. M.I. Hadi Saputra, N. Nugraha, J. Ilm. Tek. dan Rek **25**, 199 – 212 (2020)
6. J. Parhusip, J. Tekno. Info **13**, 18 – 29 (2019)
7. T.L. Saaty, Int. J. Serv. Sci **1**, 83 – 98 (2008)
8. A. Casagrande, Trans. of the American Soc. of Civ. Eng **113**, 901 – 930 (1948)
9. E. Dwisaputra, *Pemetaan Tingkat Kekritisan Daerah Resapan Air di Kecamatan Mijen Bagian Timur, Kota Semarang, Provinsi Jawa Tengah dengan menggunakan Metode Analytical Hierarchy Process*, Undergraduate Thesis Departement of Geological Engineering, Universitas Gadjah Mada (2023) (unpublished)
10. Dinas Penataan Ruang Kota Semarang, *Peta Tata Guna Lahan Kota Semarang*, Distaru Kota Semarang (2021), accessed from https://distaru.semarangkota.go.id/semarang/index.php?webgis=tataruang on August 2023
11. Dirjen Reboisasi dan Rehabilitasi Lahan, *Keputusan Direktorat Jendral Reboisasi dan Rehabilitasi Lahan Nomor: 041/KPTS/V/1998*, Jakarta, Departemen Kehutanan (1998)
12. R.E. Thanden, H. Sumadirdja, P.W. Richards, K. Sutisna, T.C. Amin, *Peta Geologi Lembar Magelang dan Semarang, Jawa skala 1:100.000*, Bandung, Pusat Penelitian dan Pengembangan Geologi (1996)
13. I. Umar, Widiatmaka, B. Pramudya, B. Barus, M. Ilm. Globe **19**, 83 – 94 (2017)