Groundwater vulnerability study using SINTACS method in Banguntapan district, Bantul Regency

Kartika Ayu Wandari[1], *Ignasius* Loyola Setyawan Purnama[1,*], and *Vincentia* Anindha Primacintya[2]

[1]Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia
[2]Accounting Programme, Master of Science and Doctoral, Faculty of Economics and Business, Universitas Gadjah Mada, Indonesia

Abstract. As one of the districts in Bantul Regency which borders directly with the City of Yogyakarta, the District of Banguntapan has the potential to be an area affected by city development. This is what drives population growth in this district, so that the waste it generates also increases. The purpose of this study is to determine the level of groundwater vulnerability to pollution by using the SINTACS method and analyzing the dominant factors that influence it. Calculation and analysis results show that the variation of groundwater vulnerability index values in the study area ranged from 182.8 to 200.3, with 10 locations classified as high vulnerability and 2 locations classified as rather high vulnerability. Because it is located in a similar geological condition, namely the Aquifer Unit of Merapi Volcanic Fluvio Plain where most of the constituent material of this aquifer is sand and a little clay as inserts, the difference in groundwater vulnerability to pollution in the study area is only determined by the difference in groundwater depth.

1 Introduction

In general, urban areas have a large population, which encourages the need for large clean water as well. The large population will affect the sustainability of groundwater use. In order not to cause adverse impacts, groundwater utilization needs to pay attention to the environmental balance in order to be sustainable.

According to [1], in addition to increasing groundwater exploitation, population growth will also increase the amount of household and industrial waste that is known to have caused significant changes in groundwater quality. The decline in groundwater quality in an area indicates that groundwater pollution and land use are sources of contaminant release that have the opportunity to reduce groundwater quality through the infiltration process [2], while according to [3], sources of groundwater pollutants can be either point or non-points originating from domestic, agricultural, industrial, mining and tourism waste

One of the many approaches taken to maintain the sustainability of good water quality and quantity is to study groundwater vulnerability to pollution [4]. Potential groundwater pollution is influenced by the hydrogeological characteristics of an area. Hydrogeological characteristics are composed of several main geological and hydrological parameters as a system that allows the movement of water in the rock layer [5]. Different hydrogeological characteristics influence groundwater vulnerability to potential pollution. Groundwater vulnerability assessment on pollution is important to know the level of vulnerability and as a frame of reference in groundwater planning, development and management.

Basically, groundwater vulnerability is divided into two namely intrinsic and specific groundwater vulnerability. Intrinsic groundwater vulnerability refers to groundwater vulnerability to contaminants generated by human activities by taking into account geological, hydrological, and hydrogeological characteristics, while specific vulnerability refers to groundwater susceptibility to certain contaminants by considering the nature of contaminants and their relationship to various intrinsic vulnerability factors [6].

As one of the districts in Bantul Regency which borders directly with the City of Yogyakarta, the District of Banguntapan has the potential to be an area affected by city development. This is what drives population growth in the Banguntapan District. The increase in population is also driven by the development of tertiary education, such as STIKES Surya Global, STIE IEU, STTL, STTKD, STIMIK Amikom, BSI Health Polytechnic, Piri Technical Academy, and AMA Dharmala [7]. As a result, the need for land also increased. Increased land requirements cause land conversion, which affects groundwater related to changes in the hydrological response and its impact on groundwater quality.

Noting the existing problems and the increasing influence of human activities in this district, a groundwater vulnerability assessment is needed. The results of the study will be able to show priority areas for groundwater monitoring and protection [8]. The method used in this study is the SINTACS method. This method is one of the Point Count System Model (PCSM) index methods that uses a score system and weighting physical parameters to assess groundwater

* Corresponding author: Setyapurna@geo.ugm.ac.id

vulnerability to pollution [9]. This method was chosen because it is more representative for groundwater vulnerability assessment and mapping on a small to medium scale.

2 Method of research

To analyze groundwater vulnerability to pollution in the study area, the SINTACS method is based on a numerical system of weights and ratings [10]. Weights are determined based on the significance of the effect of parameters on groundwater pollution, while the rating is determined based on the significance of the influence of the variables in each parameter on groundwater pollution. Ratings of each SINTACS parameter and variables in each parameter are shown in Tables 1, 2 and 3.

Table 1. Rating of Phreatic Depth, Infiltration and Aeration Condition [11–13]

Depth of Phreatic (m)		Infiltration (mm/hour)		Aeration Condition	
Class	Rating	Class	Rating	Tipe of rock	Rating
0.0-2.0	10.0	< 1	1.0	Coarse alluvial sediment	6 – 10
2.0- 2.5	9.0	1-5	2.0	Karst limestone	8 – 10
2.5-3.5	8.5	5-20	3.0	Fractured limestone	4 – 8
3.5- 4.5	8.0	20-65	4.0	Silt dolomit	2 – 5
4.5-5.0	7.5	65-125	5.0	Fine-moderate alluvial sediment	3 – 6
5.0-6.0	7.0	125-250	6.0	Sand	4 – 7
6.0-7.0	6.5	> 250	7.0	Sandstone, conglomerate	5 – 8
7.0-8.0	6.0			Turbiditic sequences	2 – 5
8.0-9.0	5.5			Silt volkanic	5 – 10
9.0-10.0	5.0			Marl, claystone	1 – 3
10.0-13.0	4.5			Clay, silt, peat	1 – 2
13.0-17.0	4.0			Pyroklastic rock	2 – 5
17.0-20.0	3.5			Silt metamorphose	2 - 6
20.0-25.0	3.0				
25.0-30.0	2.5				
30,0-40,0	2.0				
>40,0	1.5				

Table 2. Rating of Soil Textur and Aquifer Media [11–13]

Soil Textur		Aquifer Media	
Textur	Rating	Type of Rock	Rating
Clay	1-1.5	Coarse alluvial sediment	8 – 9
Silty clay	1.5-2.0	Karst limestone	9 – 10
Loamy clay	2.0-3.0	Fractured limestone	6 – 9
Silty loam clay	3.0-4.0	Silt dolomit	4 – 7
Loamy silt	3.5-4.0	Fine-moderate alluvial sediment	6 – 8
Loam	4.0-5.0	Sand	7 – 9
Sandy loam clay	4.5-5.0	Sandstone, conglomerate	4 – 9
Sandy loam	5.5-6.0	Turbiditic sequences	5 – 8
Sandy clay	6.3-7.0	Slit volkanic	8 – 10
Peat	7.5-8.0	Marl, claystone	1 – 3
Sandy silt	8.0-8.5	Clay, silt, peat	1 – 3
Fine sand	9.0-9.5	Pyroklastic rock	4 – 8
Fine gravel	9.5-10.0	Silt metamorphose	2 - 5
Thin soil	10.0		

Table 3. Rating of Hydraulic Conductivity and Gradient of Slope [11–13]

Hydraulic Conductivity (m/sec)		Gradient of Slope (%)	
Value	Rating	Class	Rating
3.9×10^{-6} - $5,5 \times 10^{-6}$	4.5	0-2	9.5
5.5×10^{-6} - $1,0 \times 10^{-5}$	5.0	2-4	8.5
1.0×10^{-5} - $1,8 \times 10^{-5}$	5.5	4-6	7.5
1.8×10^{-5} - $3,0 \times 10^{-5}$	6.0	6-9	6.5
3.0×10^{-5} - $5,0 \times 10^{-5}$	6.5	9-12	5.5
5.0×10^{-5} - $9,0 \times 10^{-5}$	7.0	12-15	4.5
9.0×10^{-5} - $1,5 \times 10^{-4}$	7.5	15-18	3.5
1.5×10^{-4} - $2,0 \times 10^{-4}$	7.75	18-21	2.5

Hydraulic Conductivity (m/sec)		Gradient of Slope (%)	
Value	Rating	Class	Rating
2.0×10^{-4} - $3{,}0 \times 10^{-4}$	8.0	21-25	1.5
3.0×10^{-4} - $4{,}5 \times 10^{-4}$	8.25	25-30	1.0
4.5×10^{-4} - $6{,}0 \times 10^{-4}$	8.,5		
6.0×10^{-4} - $1{,}0 \times 10^{-3}$	8.75		
1.0×10^{-3} - $1{,}5 \times 10^{-3}$	9.0		
1.5×10^{-3} – $2{,}5 \times 10^{-3}$	9.25		
2.5×10^{-3} – $4{,}5 \times 10^{-3}$	9.5		
4.5×10^{-3} – $4{,}0 \times 10^{-2}$	9.75		

After all variable values and parameter weights from each observation point are determined, the SINTACS index can be determined by calculating the values of each indicator and adding them together.

$$I_{SINTACS} = \sum^{7}{}_{i} = Ri \times Wi$$

where $I_{SINTACS}$ is the groundwater vulnerability index, R is the rating for each parameter and W is the weight for each parameter as shown in Table 4.

Table 4. Weighting scenarios in SINTACS Method

Weighting Scenarios	S	I	N	T	A	C	S
Normal impact	5	4	5	3	3	3	3
Relevant impact	5	5	4	5	3	2	2
Drainage from surficial network	4	4	4	2	5	5	2
Karstic impact	2	5	1	3	5	5	5
Fissuring impact	3	3	3	4	4	5	4

Source : [14]

Because the study area is a residential and agricultural area, the normal impact scenario is used in this study. Based on this scenario and taking into account weight and rating calculations, groundwater vulnerability in the study area is determined as shown in Table 5.

Table 5. Groundwater vulnerability index

Interval of Vulnerability Index	Vulnerability Level
< 80	Very Low
80 – <105	Low
105 – <140	Moderate
140 – <186	Rather High
186 - 210	High
>210	Very High

Sources : [14, 15]

3 Result and discussion

3.1 Location

This study is located in Banguntapan District which is administratively included in the Bantul Regency area (Figure 1). In general, Banguntapan district is in the eastern Yogyakarta groundwater basin and is included in the geomorphological unit at the Merapi Volcano Foot Plain.

Banguntapan District consists of eight villages namely Tamanan, Jagalan, Singosaren, Wirokerten, Jambidan, Potorono, Baturetno, and Banguntapan. The total area of Banguntapan District reaches 28.48 km^2 or around 5.62 % of the total area of Bantul Regency. The population in the Banguntapan District according to the records of 2018 was 145 956 inhabitants. Banguntapan Village is the village with the largest area and population in Banguntapan Sub-District.

3.2 Determination of groundwater vulnerability

SINTACS stands for parameters that can cause groundwater vulnerability to pollution, namely phreatic level, constant infiltration rate, aeration conditions, soil texture, aquifer media, hydraulic conductivity and slope. The depth of the phreatic level affects groundwater vulnerability because the distance between the surface of the soil and the phreatic level will determine the time taken by the pollutant to groundwater, so that it will determine the time of impregnation of the waste and chemical processes during its absorption. The results of measurements in the field show that the groundwater phreatic level in the study area varied considerably from 1.13 m to 6.40 m, so the rating value ranged from 6.5 to 10 (Table 6).

Table 6. Depth and fluctuations in groundwater level

Location	Depth (m)	Rating
Banjar, Tamanan	1.13	10.0
Glondong, Wirokerten	3.10	8.5
Jambidan Kidul, Jambidan	1.97	10.0
Kretek Lor, Jambidan	2.75	8.5
Singosaren I, Singosaren	3.50	8.0
Sayangan, Jagalan	3.95	8.0
Potorono, Potorono	4.00	8.0
Plakaran, Baturetno	2.00	9.0
Pelem, Baturetno	3.10	8.5
Maguwo, Banguntapan	6.40	6.5
Wonocatur, Banguntapan	5.05	7.0
Plumbon, Banguntapan	4.90	7.5

Infiltration determines the velocity at which contaminants travel to groundwater. If the infiltration rate is low then the ease of contaminants reaching groundwater is also low. Conversely, if the infiltration rate is high, the ease of contaminants reaching groundwater is also high. Because all soil type of the research area is regosol, constant infiltration was determined based on infiltration measurement data that had been done in some regosol soil in Yogyakarta basin before [16, 17]. The results show an average infiltration value of 0.545 cm/minute or 327 mm/hour, so rating values in all observation wells are 7.

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Aeration zone is a hydrogeological system that can function as a barrier to pollutants if the stone texture is impermeable. Therefore, clay is given a low rating because it is impervious to be able to withstand pollutants, while sand is given a high rating because of its porous nature. Field observations show that all research areas are composed of sandy textured material, so the rating value is 5.5.

Soil texture will determine the ease of pollutants in passing through liquids. Sand will be easier to absorb pollutants than clay, so that sand is given a higher rating. The entire study area is composed of clay sand, so the rating value is 6.6.

Aquifer media describe the process that occurs when there is a mixture of pollutants with groundwater. Aquifer media play a role in determining the speed of mixing of pollutants with groundwater. In aquifer media there are also several chemical processes such as dissolution and reaction between pollutants and rocks. It can be said that the aquifer media in the study area is sand so that all the values are 8.

Hydraulic conductivity is a measure of the ability of rocks to pass through liquids. Rock material with high hydraulic conductivity values will be easier to pass through waste, than those with low values. Therefore, sand will have a high rating value compared to other rock types. The study area is composed of sand material, so that all rating values are 7.5.

The slope gradient plays an important role in the assessment of vulnerability because it will determine the speed of the flow of waste at the ground surface. If the slope is steep, the waste will flow quickly and little will seep into the ground. Conversely, if the slope is flat, the flow velocity at the ground surface will be low and the waste has many opportunities to seep. Therefore, steep places are given a low rating, while ramps are given a high rating. The topography in the study area is flat, so that all rating ratings are 9.5.

3.3 SINTACS index analysis

Because the effect of each of the parameters related to pollution is not the same, the weights are also not the same. For normal impact scenarios, the phreatic surface depth parameters are weighted 5, constant infiltration is weighted 4, the aeration condition is given weight 5, soil texture is given weight 3, aquifer media are given weight 3, hydraulic conductivity is given weight 3 and slope weight is weighted 3.

Furthermore, based on the rating of each parameter and its weight, groundwater vulnerability index can be calculated for each measurement and observation location (Table 7). The results of calculations at 12 measurement and observation locations show variations in groundwater vulnerability index values from 182.8 to 200.3. Judging from the level of vulnerability, 10 locations are classified as high levels of vulnerability and 2 locations are classified as quite high levels of vulnerability (Figure 1).

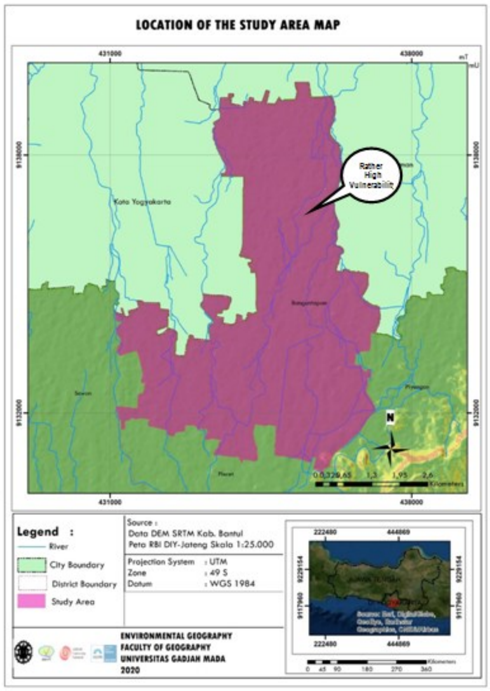

Fig. 1. Study location

From Table 7 and Figure 1, it can be seen that most of the study areas are classified as high levels of vulnerability. The level of vulnerability is rather high only in 2 observation wells in Maguwo and Wonocatur, both of which are in the village of Banguntapan. Noting this, it appears that differences in groundwater vulnerability in the study area are more determined by groundwater depth.

Table 7. Weighted SINTACS parameter values (normal impact)

No	S (weight 5)	I (weight 4)	N (weight 5)	T (weight 3)	A (weight 3)	C (weight 3)	S (weight 3)	Vulnerability Index	Vulnerability Level
1	50	28	27.5	19.8	24	22.5	28.5	200.3	High
2	42.5	28	27.5	19.8	24	22.5	28.5	192.8	High
3	50	28	27.5	19.8	24	22.5	28.5	200.3	High
4	42.5	28	27.5	19.8	24	22.5	28.5	192.8	High
5	40	28	27.5	19.8	24	22.5	28.5	190.3	High
6	40	28	27.5	19.8	24	22.5	28.5	190.3	High
7	40	28	27.5	19.8	24	22.5	28.5	190.3	High
8	45	28	27.5	19.8	24	22.5	28.5	195.3	High
9	42.5	28	27.5	19.5	24	22.5	28.5	192.8	High
10	32,5	28	27.5	19.8	24	22.5	28.5	182.8	Rather high
11	35	28	27.5	19.8	24	22.5	28.5	185.3	Rather high
12	37.5	28	27.5	19.8	24	22.5	28.5	187.8	High

4 Conclusion

The variation of groundwater vulnerability index values in the study area ranged from 182.8 to 200.3, with 10 locations classified as high vulnerability and 2 locations classified as rather high vulnerability.

Because it is located in a similar geological condition that is Aquifer Unit of the Merapi Volcanic Fluvio Plain where most of the constituent material of this aquifer is sand and a little clay as inserts, the difference in groundwater vulnerability to pollution in the study area is only determined by the difference in groundwater depth.

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