Groundwater vulnerability in karst area Pucung Village, Eromoko, Wonogiri District

U Syahidin¹*, Komariah² and S H Murti³

¹ Master Program of Environmental Science, Post Graduate School, Sebelas Maret University, Indonesia
² Soil Science Study Program, Faculty of Agriculture, Sebelas Maret University Surakarta, Indonesia
³ Geography Study Program, Faculty of Geography, Gadjah Mada University Yogyakarta, Indonesia

*Corresponden author: umarsyahidin@gmail.com

Abstract. Climate change has a negative impact on the reduction of groundwater resource potential in the Gunungsewu Karst Area, in terms of quantity, quality and continuity. This impact is felt by the people of Pucung Village who use water found in underground rivers and springs to meet their daily domestic water needs. The potential of water resources in the area is very vulnerable to a decrease in quality and quantity related to changes in the carrying capacity and capacity of the karst area as a result of climate change. This study aims to assess the groundwater vulnerability zone and the condition of the water catchment area in the karts area of Pucung Village, Eromoko District, Wonogiri Regency, Indonesia. The research method used is the EPIK method which is applied to the Geographical Information System (GIS). Research variables include (a) Epikarst; (b) Protective Cover; (c) infiltration conditions, and (d) karst network. The four variables obtained from the interpretation of remote sensing images, topographical maps, geological maps and field surveys were analyzed using scoring techniques. The results showed (1) 875.15 hectare or 88% of the area in Pucung Village is in a zone that is very vulnerable and susceptible to contamination of Groundwater; (2) agricultural activities in the water catchment area have the potential to contaminate of groundwater in the study area.

1. Introduction

Climate change can have an indirect impact on the reduction of a potential natural resource. Karst area is one of the earth's surface landscapes that have the potential vulnerability to water resources. According to Bakalowicz, groundwater resources in karst aquifers are vulnerable to contamination, overexploitation, and climate change [1]. Ford and Williams argue that 10% of the world's land surface area contains karst aquifers underneath, and about 20-25% of the world's population depends on the supply of water from karst aquifers directly or indirectly [2]. Leibundgut explained that the level of vulnerability to groundwater pollution in the Karst area is higher than in other areas, whether it comes from springs, underground rivers or logva [3]. One of the impacts of climate change on the vulnerability of karst areas, global water resources are threatened due to climate change caused by soil erosion sedimentation associated with human activities [4]. Hydrology in the karst area itself is very vulnerable to external influences, this is because the karst area has the most complex system among the various lands on the earth's surface which can cause a lot of uncertainty and model errors, both in studying and predicting hydrological behavior [1].
To determine the vulnerability of water resources, several methods of vulnerability assessment based on index measurement have been developed. The several well-known and developed methods specifically for karst aquifer environments, are such as the EPIK [5], the PI method by Goldscheider et al. (2000); and COP by Vías et al. (2006); and CORE by Pavlis and Cummins in 2014 is a vulnerability method developed to simulate susceptibility to groundwater pollution based on karst-specific aquifer characteristics [6] Entering 2010 in responding to the issue of climate change, the method of assessing vulnerability is again under development. One such new method is the GIS-based CC-PESTO [7] Of the several vulnerability methods, the application of the EPIK method is indeed more effective. This is because the EPIK method does not consider time-duration parameters, such as rainfall and recharge. This is because the EPIK method does not consider time-duration parameters, such as rainfall and recharge [8] and it also does not consider water depth parameters and catchment area boundaries through the water flow network approach [9]. The EPIK method is carried out through the use of the Geographic Information System (GIS) with the application of weighting values in determining which zones have very vulnerable, medium, and low classes so that they can provide information about the protected areas of the Karst area [5] Pucung Village has water sources in the form of springs and an underground river. This water source has been used to meet the daily domestic water needs of the population. However, the availability of existing water resources has the potential to decrease the quantity and quality of water. This is because the Pucung Village area is in the Gunung Sewu Karst Area. Given the characteristics of karst areas that are very vulnerable to groundwater pollution, it is necessary to make efforts to protect them from pollution. One of these efforts can be done by providing information and assessing environmental conditions so that this study aims to determine the groundwater vulnerability zone and determine the condition of the spring catchment area.

2. Method
The method used in this research is the survey method. The research analysis was carried out using geographic information system (GIS) analysis. The determination of the groundwater vulnerability zone is done using the EPIK method. The variables in this study include: (a) epikarst; (b) protective cover; (c) Infiltration conditions; and (d) Karst network. The four variables are obtained from the interpretation of remote sensing images, maps of the earth, geological maps and field surveys, then analyzed using scoring techniques.

Referring to the assessment of the vulnerability of groundwater in karst areas by Doerfliger [10] each EPIK parameter, namely epikarst, protective cover, infiltration conditions and karst network are given weight values of 1, 2, and 3 are then divided into various a class that is assigned a rating between 1 and 4. Where an equation is defined as follows:

\[ (Fp) = 3E + 1P + 3I + 2K \]  

where:
Fp : protection factor
E : epikarst
P : protective cover
I : infiltration
K : karst network

3. Results and discussion
3.1 Karst surface shape (Epikarst)
According to Williams (2008) Epikarst is a zone located at the top of the aeration zone in carbonate rocks with a thickness of up to 30 meters, the process is dominated by the transmission of water seeping downwards which provides recharging to the saturated or phreatic zone [11]. The epikarst in the study area is divided into 3 classes, namely E1, E2 and E3 it is shown in Table 1. The area of the epikarst
distribution, the class E1 has an area of 642.2 ha or 46%. The area has morphological formations such as caves, ponor (swallow hole), and karren which cover the surface of karst hills.

Table 1. Area of the epikarst.

| Class | Information                                      | Area (Ha) | %  |
|-------|-------------------------------------------------|-----------|----|
| E1    | morphological formations such as doline, cave, karren | 642.2688  | 46%|
| E2    | morphological polje, and uvala                  | 480.1668  | 35%|
| E3    | non karst                                       | 267.5206  | 19%|
| Total |                                                 | 1389.956  | 100%|

Areas in class E2 have morphological formations in the form of polje and uvala. The formation of karst morphology can be seen in Figure 1. In the rainy season the Polje formation is a karst Logva filled with water, but in the dry season zone E2 is dry and is used by the community for agricultural land, while class E3 is a rock transition area between the Wonisari and Semilir formations. The distribution of the karst surface in the study area can be seen in Figure 2. Epikarst distribution.

Figure 1. Formation of polje morphology. a. Polje conditions in the dry season, b. Polje conditions in the rainy season)

Figure 2. Epikarst distribution.
3.2. Protective cover

The vulnerability assessment to protective cover parameters is a zone assessment based on soil thickness. Soil thickness is closely related to the length of time the water lasts, because the thinner the soil, the greater its vulnerability [10]. Based on the availability of soil type data obtained, the area of soil thickness class in the study area can be seen in Table 2. In Table 2 shows Class P1 dominates in the study area with an area of 100.4 ha, where the average distribution of soil thickness attached to the karst rock layer is between 0-20 cm. Then the P4 class is 20% or 279.4 ha, most of which are non-karst areas with low permeability and a soil thickness of more than 1 meter.

| Class | Area (Ha) | %     |
|-------|-----------|-------|
| P1    | 100.4     | 73%   |
| P2    | 77.35     | 6%    |
| P3    | 10.35     | 1%    |
| P4    | 279.4     | 20%   |
| sum   | 1371.1    | 100%  |

Note: P1: Soil thickness between 0-30 cm which rests directly above rock formations which have fast permeability properties; P2 and P3: Soil thickness > 30-100 cm; and P4 Soil thickness > 8 m and are in rock formations with low permeability

![Zona P1](image1.png) ![Zona P4](image2.png)

Figure 3. Soil thickness conditions.

Figure 4. Distribution of soil thickness

From study area class P1 dominates with an area of 100.4 ha, where the average distribution of soil thickness attached to the karst rock layer is between 0-20 cm. Then the P4 class is 20% or 279.4 ha, most of which are non-karst areas with low permeability and a soil thickness of more than 1 meter. The comparison of soil thickness in zones P1 and P4 in the study area can be seen in Figure 3. Based on Figure 3 the thickness of the soil above the limestone formations in zone P4. However, for the area between the Wonosari and Semilir formations there is class P2 with an area of 10.35 ha and Class P3 with an area of 10.35. ha is located in the southern part of the study area with the depth of the soil layer mixed slightly with karst rock formations that cover the clay and the distribution of soil thickness can be seen in Figure 4.

3.3 Infiltration

According to Doerflinger and Zwahlen the determination of the size of the I value can be done using a spatial approach of the infiltration concentration zone, which is based on a concentrated or diffuse point that has a different susceptibility inference value [10]. This concentrated infiltration zone is related to
geomorphological variables, slope and land use or morphological forms such as the presence of underground rivers and swallow hole. The area of the infiltration zone can be seen in Table 3.

Table 3. Infiltration area

| Class | Information                      | Areas (Ha) | %   |
|-------|----------------------------------|------------|-----|
| I1    | the area of the infiltration concentration | 752.7      | 55% |
| I2    |                                     | 135.8      | 10% |
| I3    |                                     | 118.9      | 9%  |
| I4    | diffuse infiltration               | 353.3      | 26% |
|       |                                   | 1360.7     | 100%|

Note: I2 with a slope of > 25% in the grass area, I3 water catchment area with a slope of <10% in the cultivated area and <25% in the grassy area

The study area has a concentration center in the village with an area of 752.7 ha or 55% of the total area. Zone I1 area is inseparable from the existence of underground rivers and caves that have a water flow system such as Tembus caves, Kucing caves and several caves that have both permanent and seasonal water flow systems, while zone I4 is the second largest with 353.3 ha. The catchment concentration area I4 is in a non-karst area. Zone I2 is the average hilltopography and upper slope and I3 is on the lower slope and the base of the hill where the land use has been through human intervention for both gardens and agriculture. The distribution of the infiltration classes can be seen in Figure 5.

3.4 Karst network

The determination of the karst network is determined by the presence or absence of a network system in the development of the karst [10]. Network development in the research area is found in the water flow system in the form of an underground river in Suruh Cave and several ponors that connect the water to the network system in the karst aquifer. Based on the analysis of the karst network variables, the results of the area of the karst network can be seen in Table 4.

The study area in class K1 has an area of 525.1 ha, and the K1 zone area is a karst area with a well-developed network system, where the central to the southern part of the village area contains ponor and cave systems. While the K2 class area of the karst area is not found in caves with water flow systems or Ponor (swallow hole), so the development of the karst network is very slow and the K3 zone is a non-karst area. The distribution of the karst network in the study area is very well developed, can be seen in
Figure 6. The area in Figure 6 shows that the Karst Network is very well developed from the south to the north and west of the study area.

Table 4. Karst network parameter area.

| Class | Area Ha | %  |
|-------|---------|----|
| K1    | 525.1   | 53%|
| K2    | 165.4   | 17%|
| K3    | 308.2   | 31%|
| Total | 998.7   | 100%|

Note: K1 areas that have a connected water flow system are cm to meters in size, K2 no drainage system or watercourse network which is interconnected or poorly developed, and K3 non karst

![Figure 6. Karst network](image)

3.5 Karst vulnerability zone

Groundwater pollution vulnerability zones are determined based on the weighted results of the EPIK variable, the study shows that 88% of the study area has a high to very high level of vulnerability and can be seen in Table 5. Table 5 shows that very high vulnerability occurs in the northern region and South study location 48% Very high and 40% high respectively, while low vulnerability occurs in the western part near the village border at 12%.

Table 5. Protection zone area.

| No | Vulnerability Class | Area | Unit | %  |
|----|---------------------|------|------|----|
| 1  | Low                 | 478.1| Ha   | 48%|
| 2  | High                | 397.05| Ha | 40%|
| 3  | Very high           | 121.12| Ha | 12%|

The distribution of groundwater pollution vulnerability in the study area can be seen in Figure 7. Vulnerability Map. Figure 7 indicates the existing water sources in the study area are the Suruh Cave
springs and underground river. Based on the results of the groundwater pollution vulnerability map, the Suruh Cave watershed is classified as very prone and prone. One of the impacts of vulnerability in the water catchment area in the study location is that the quality of underground river water and spring water has poor water quality values.

Figure 7. Vulnerability map

The conditions of the Suruh Cave underground river and the Bayan spring which are used for drinking water have not met the drinking water quality standards, because there are Escherichia coli bacteria that exceed the water quality standard threshold for drinking water [12]. The causes of these bacteria include animal waste, such as the discovery of swallow nests in caves.

Agricultural activities, especially in terms of land management that have an impact on soil erosion, will increase vulnerability to groundwater pollution in karst areas. According to Ravbar and Goldscheider (2007) soil erosion can damage groundwater quality, because soil is an important part of nature’s protective cover. Loss of soil increases the vulnerability of groundwater [2]. Apart from soil erosion, used of fertilizers with high doses and intensities can result in compaction of the topsoil and significant loss of organic matter causing a negative impact from chemical fertilization, where the use of nitrogen fertilizers such as urea results in ammonia evaporation. Especially in tropical areas with high temperatures and low efficiency of N fertilizers, nitrates can be released from N fertilizers, especially during the rainy season and pollute groundwater [13].

Condition of the underground river catchment at Suruh cave can be seen in Figure 8. Figure 8 blue lines identify the presence of an underground river which is displayed on the satellite image map and the blue dot is springs. Suruh Cave is a cave that has springs in the form of an underground river and is in the middle of a karst basin with a tendency of the main flow system to the west [14]. Water catchment area. Around the cave area there is agricultural land where the topographical pattern leads to the cave entrance. When it rains, water can enter directly through topographic surface drainage and carry residual waste from agriculture.

The availability of water in a tropical climate is very dependent on the source of water from rainwater, because there are only two seasons that occur in the study area, namely the rainy season and the dry
season. If the rainwater experiences a decrease in the amount of rainfall due to climate change, the shift in the dry season is longer than usual, this can affect water availability in karst aquifers or artificial rainwater reservoirs. If extreme rainfall comes, it has the potential to cause a flood hazard. Flooding in the karst is caused by an imbalance of water between filling and discharge, this can be attributed to the drainage system into the karst aquifer, which can occur in the recharge, flow, or discharge system, depending on site-specific conditions [15].

![Image](image_url)

**Figure 8.** Map of the condition of the spring area.

### 4. Conclusion

The research area only has two seasons, namely the rainy season and the dry season, the karst area with a tropical rainy climate only relies on rainwater as a source of groundwater reserves. Climate change can cause the amount of rainwater to decrease if there is a seasonal anomaly, where the change in the dry season is longer, so that the amount of groundwater is limited which causes the utilization of water resources to be not optimal. Areas that have a high vulnerability to groundwater pollution can worsen the condition of the availability of these water resources, including in terms of quantity, quality and continuity.

The research area has a very high vulnerability to groundwater pollution, based on the results of the EPIK method the potential for groundwater pollution is included in the category of very vulnerable class to groundwater pollution. Agricultural activities have the potential to pollute groundwater quality, based on the identification of underground watershed conditions, it is known that the underground river Suruh Cave is located in an agricultural area where there is a morphological pattern of drainage that leads to an underground river channel system, where rainwater has the potential to enter through cave passages and can carry various substances and pollutants from agricultural activities. This can affect the value of underground river water quality.
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