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GROUNDWATER VULNERABILITY ZONATION BASED ON GEOGRAPHIC INFORMATION SYSTEM IN GIRITONTRO, WONOGIRI, CENTRAL JAVA

Disaster Mitigation

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Abstract: Karst is an area with a significant potential for groundwater resources but is very vulnerable to pollution. The very porous nature of limestone makes pollutants easily enter the groundwater zone. The research location is in Giritontro District, Wonogiri, Central Java. The purpose of the study was to determine the level of groundwater vulnerability and to know the groundwater protection zone in the research area. The method uses a Geographic Information System (GIS) by overlaying several APLIS parameters (Altitude/height, Pendiente/ slope, Lithology, Infiltration, and Soil type). The results showed three levels of groundwater vulnerability low (20 – 40%), moderate (40 – 60%), and high (60 – 80%). The low level is 7,19 km^2 (5,31% of the study area), consisting of loose sand-gravel; the moderate level area is 12,49 km^2 (9,19% study area) with limestone layered lithology, and the high groundwater vulnerability level occupies the broadest scope of 115,73 km^2 (85,5% research area) with coral reef limestone. The groundwater protection zone is located at a high level of groundwater vulnerability because included it in the Class 1 Karst Area; activities that can cause groundwater pollution are not allowed in that area.

Keywords: groundwater vulnerability; GIS; APLIS

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1. Introduction

Karst is an area with significant potential for groundwater resources but is very vulnerable to pollution. The very porous nature of limestone makes pollutants easily enter the groundwater zone. It will be challenging to restore pollution quality because it is in the soil or rocks below the surface. Knowing the level of groundwater vulnerability is necessary to determine the protection zone free from pollutants.

The research location is Giritontro District, Wonogiri, Central Java, part of the Gunung Sewu. Gunung Sewu Karst area is one of the unique karst areas in Indonesia because conditions above the surface are generally dry and critical. In contrast, below the ground surface, there are abundant water resources. Activities such as mining in the karst hills can eliminate water absorption zones, disrupting water infiltration into underground rivers, drought, dead springs, and potential flooding in the rainy season. Chemical fertilizers and pesticides also harm groundwater quality because these chemicals will be carried by rainwater and enter caves in the karst area [1].

Minister of Energy and Mineral Resources No. 1456 K/20/MEM/2000 concerning the management of karst areas is a legal rule in Indonesia that karst area zonation is mandatory. The function of karst area management is to optimize the use of karst areas to support sustainable development and consider environmental aspects. Zonation karst areas in this research are by mapping groundwater vulnerability using the Geographic Information System (APLIS) [2]. APLIS are altitude, pendiente/slope, lithology, infiltration, and soil type. The purpose of the study was to determine the level of groundwater vulnerability and to know the groundwater protection zone in the research area.

2. Literature Review

2.1. Definition of Karst

Groundwater is water that is in the saturated zone below the ground surface. The presence of secondary porosity strongly influences groundwater in karst areas, infiltration through the inter-grain cavity, and dominantly through joints, cracks, and rock crevices that occur due to dissolution.

Ford and William (1989) in Widiastuti, state that karst is a field with distinctive hydrological and landform characteristics, formed from a combination of soluble rocks and well-developed secondary porosity [3]. In general, karst is a landscape that develops in carbonate rocks, where a very high dissolution process influences its formation compared to other rocks. The dissolving process is called the karstification process. The limestone dissolution process begins with the dissolution of CO_2 in water to form H_2CO^3. The unstable H_2CO^3 solution will decompose into H^- and HCO_3^{2-}. The H- ion decomposes $CaCO_3$ into Ca^{2+} and HCO_3^{2-}.

Worosuprojo et al. (1997), explained that karst areas could form under several conditions [4]. They are :

a. Soluble rock. Fractures will form in solid rock and thick dissolved rock.
b. Rainfall high. Rain is a solvent medium in the karstification process: the higher rainfall, the more intensive the dissolution process in the karst area.
c. The carbonate rocks are raised at a height so that circulation or drainage vertically / horizontally develops. The higher the uplift of carbonate rocks, the more intensive the karstification process occurs in the area.

Karst morphology is a combination of negative and positive landforms. Negative landforms are below the average surface area due to the dissolution process or debris consisting of Dolina, ponor, uvala, and polje. Dolina is a funnel-shaped hole in limestone with a diameter of several meters to one kilometer and a depth of several meters to hundreds of meters. The uvala is a sizeable closed pit formed by joining several dolina and polje is a comprehensive and elongated closed hole in the karst topography with a flat bottom and steep walls. Positive landforms include kygelkarst, turmkarst, and cave ornaments. Kygelkarst is karst formed by several conical hills sometimes separated by a cockpit. These cockpits are interconnected and occur in a line that follows a solid pattern (diaclase), often referred to as a karst cone. Turmkarst consists of hills with steep or vertical slopes that rise independently between alluvial plains. In addition, below the surface, there are often underground rivers, caves, stalactites, and stalagmites).

2.2. Karst Area Hydrology

The hydrological cycle is the circulation of water on earth, both in the atmosphere, on the earth's surface, and below the earth's surface. The focus of karst hydrology is not on surface water but water stored in drainage systems below the karst surface.

In the karst area, the carbonate rock has many cavities. The rock is easily soluble in water, so the surface drainage system is not developed and is dominated by the subsurface drainage system. Groundwater recharge is rainwater that enters the aquifer system for a certain period, but groundwater recharge can also come from surface water [5]. A groundwater recharge area (water catchment area) is an area that can absorb moisture and can drain it up to the water saturation zone. Groundwater recharge comes from above the basin's surface or from the basin itself. The recharge components included in the recharge potential from the basin's surface are recharge from residential areas, irrigation areas, and surface water. Recharge from within the basin is in the form of transfers between aquifers. The hydrological condition of the Gunung Sewu karst area is not different from the karst area. Secondary porosity due to tunnel enlargement and dissolution process characterizes karst area aquifers [6].

Haryono (1999) suggested that the porosity of the epikarstic zone of Mount Sewu varies in several regions. Chalky limestone has lower secondary porosity than hard reef limestone [7]. Generally, water that flows into underground rivers comes from meteoric water and percolation water. Meteoric water is water that enters the ground through the mouth of the cave, and percolation water is water that enters through fractures. The two will meet one in an underground river flow. Soil texture and permeability affect the percolation of water infiltration into the soil.

2.3. Karst Area Management

Decree Minister of Energy and Mineral Resources Number 1456 K/20/MEM/2000 discusses the management of karst areas [8]. The zonation of the karst area will produce a regional classification map in 3 regions, namely the class I, II, and III karst areas. The following is an explanation of the classification criteria according to the Decree of the Minister of Energy and Mineral Resources Number 1456 K/20/MEM/ 2000:

1. Class I Karst Area; Class I karst areas include karst areas that have one of the following functions:

a) Areas that function as permanent water storage areas in the form of aquifers, underground rivers, lakes, or underground lakes;
b) Areas that have active underground caves and rivers that form a network either horizontally or vertically;
c) Areas that have caves with active speleotherms (cave ornaments) or historical relics so that they have the potential to be developed as tourist attractions; or
d) Areas with unique flora and fauna fulfill the meaning and function of social, economic, cultural, and scientific development.

2. Class II Karst Area is a karst area that does not have class I karst criteria but has one of the following criteria:
a) Areas that function as groundwater recharge in the form of rainwater catchment areas that affect the rise and fall of the underground water level of the karst area so that, in general, it still supports the hydrological function of the karst area.
b) An area that functions as a network of underground passages formed by rivers and caves that have dried up and a permanent residence for fauna, all of which can provide economic value and benefits.

3. Class III Karst Area is a separate area that does not include the criteria for Class II and III Karst areas.

One of the essential steps for zoning karst areas is mapping groundwater recharge and mapping groundwater vulnerability. Regions that are potential areas for groundwater recharge in karst areas must be protected, and the quantity and quality of water resources in the karst area in areas with a high level of groundwater vulnerability.

2.4. Groundwater Vulnerability

Groundwater vulnerability is the level of resistance of groundwater to contaminants from the surface and below the surface. Groundwater vulnerability is high if natural factors provide little protection as groundwater shields from contaminating activities on the ground surface. Groundwater vulnerability is low if natural elements provide relatively good defense as a groundwater shield from contamination [9].

Zones of very high and high groundwater vulnerability must maintain the authenticity of the landscape and its ecosystem while using shallow zones as cultivation areas such as mining, fisheries, settlements, industry, or if there is land. A lot of sediment can be used for agricultural land [10].

3. Material & Methodology

The research method consists of three stages: an introduction, field observation, and data processing using *ArcMap 10.7.1 software* and *Global Mapper 21.1*. The preliminary stages include the preparation of the 2001 Indonesian Topographical Map and literature studies from journals and previous data to determine the classification and weighting of the methods used. Locations of field observations include making lithological maps and maps of soil types. The data processing stage provides data analysis for making elevation maps, slope maps, and infiltration zone maps. The five APLIS variables were classified and weighted, respectively. After that, an overlay using the formula from Andreo et al. (2004) [5] will produce a Groundwater Vulnerability Zoning Map (Figure 1).

Elevation and slope maps from the Digital Map of the Indonesian Earth Form, Parangupito Sheet 1407-641, Kalak Sheet 1407-642, Pracimantoro Sheet 1407-643, and Giriwoyo Sheet 1407-644 published by BAKOSURTANAL with a scale of 1: 25,000. The Surakarta Geological Map 408-3 and Giritontro 1407-6, Java scale 1:100,000 by Surono et al. (1992) [11] produce a lithological map derivation one and data collection at the research site. The infiltration zone map and soil map resulted from a soil map published by PUSLITTANAK Bandung in 1994 with a scale of 1:50,000 [12], field observations, and previous research. Then the soil data is converted into the FAO classification.

This research uses Geographic Information Systems (GIS), precisely the APLIS method, which refers to the classification of Andreo et al. (2008) [5]. APLIS comes from the Spanish language: *altitude, pendiente/slope*, *lithology, infiltration,* and *soil type.* Each variable is classed and scored according to the level of its influence on the amount of groundwater recharge. Then it will reflect the level of groundwater vulnerability in an area. The value of each APLIS variable has an interval of 1 – 10, where a score of 1 is the minor effect, while a score of 10 is the most significant influence.

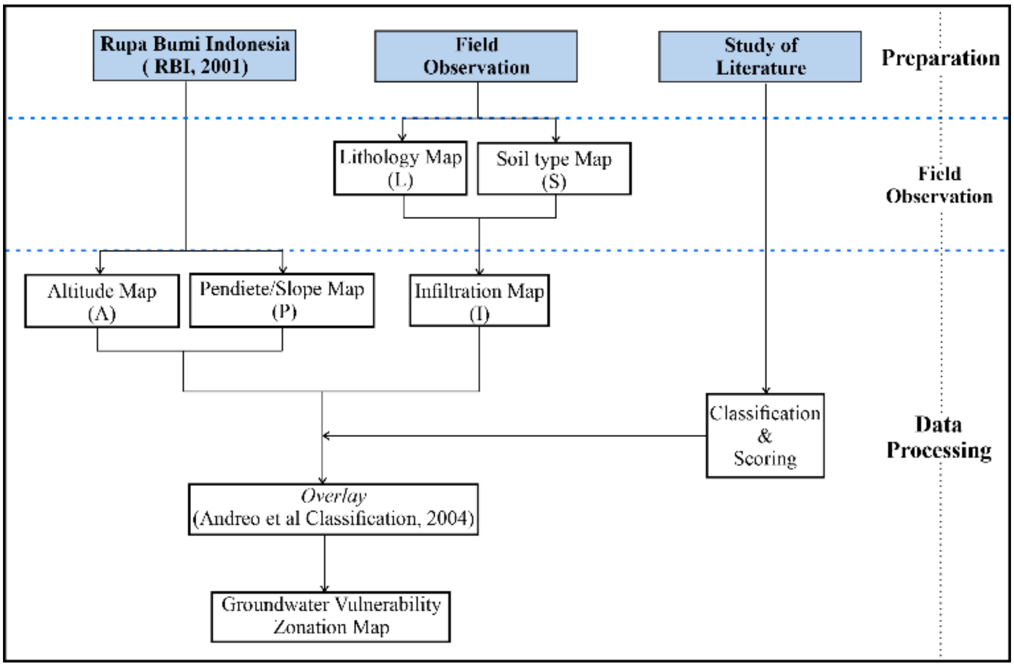

Figure 1. Research Flowchart

Classification and weighting of each variable according to the type of Andreo et al. (2008) [13] as follows:

a. Altitude (A)

The 2001 Earth Visual Map of Indonesia produced an elevation map, and then Andreo et al [5] was used as a classification and a variable height/Altitude score (Table 1). The altitude variable indicates the sheer presence of an object seen through a predetermined point. The unit of height is masl.

Table 1. Altitude Classification and Score [5]

No.	Altitude (masl)	Score
1.	≤ 300	1
2.	> 300 – 600	2
3.	> 600 – 900	3
4.	> 900 - 1200	4
5.	> 1200 - 1500	5
6.	> 1500 - 1800	6
7.	> 1800 - 2100	7
8.	> 2100 - 2400	8
9.	>2400 – 2700	9
10.	> 2700	10

b. Pendiente/Slope (P)

The slope variable determines the effect of the erosion rate and surface water flow size, the slope map from the Digital Map of Indonesia in 2001. Then the classification and score of the slope variable were based on the type of Andreo et al. [5] (Table 2).

Table 2. Slope Classification and Score [5]

No.	Slope		Score
	(%)	(◦)	
1.	3	1,35	10
2.	>3 - 8	1,35 - 3,6	9
3.	>8 - 16	3,6 – 7,2	8
4.	>16 - 21	7,2 – 9,45	7
5.	>21 - 31	9,45 – 13,95	5
6.	>31 - 46	13.95 – 20,7	4

7.	>46 - 76	20.7 – 34,2	3
8.	>76 - 100	34.2 - 45	2
9.	>100	>45 (minimum and unchanged affix)	1

c. Classification of Lithology/Lithology (L)

To determine the characteristics of megascopic rocks using lithological parameters. Field data will produce a lithological map. After that, Andreo et al. [5] (Table 3) underlie the classification and scores of lithological variables.

Table 3. Lithology Classification and Scores [5]

No.	**Lithology/Rock**	**Score**
1.	Limestone and dolomite karstified	9 -10
2.	Marble with fracture, limestone and dolomite moderately karstified	7 - 8
3.	Limestone and dolomite fractured	5 - 6
4.	Coluvial sand and gravel	4
5.	Marl, breccia and conglomerate	3
6.	Plutonic and metamorphic rocks	2
7.	Skis, slate and clay	1

d. Infiltration (I)

The infiltration zone is related to the water flow process by infiltration or seepage. Lithology correlated with recharge maps, then classification and scores of infiltration zone variables were made by Andreo et al. [5] (Table 4).

Table 4. Infiltration Classification and Score [5]

Lithology	**Score**
Main Infiltration Zone	10
Other Infiltration Zones	1

e. Soil Types (S)

Published references and field data will produce an FAO land classification soil map. The following (Table 5) is a classification and score of soil type variables based on Andreo et al. [5].

In soil types, classes are grouped based on general thickness characteristics and main texture. Soils such as leptosols generally have little soil cover and very coarse texture, so the score is ten or maximum, while thick and loamy soils, such as vertisols, have a score of 1 or minimum.

Table 5. Soil type Classification and Score [5]

No.	**Type of soil**	**Score**
1.	Leptosols	10
2.	Arenosols and Xerosols	9
3.	Calcareous Regosols and Fluvisols	8
4.	Eutric Regosols dan Solonhacks	7
5.	Cambisols	6
6.	Eutric Cambisols	5
7.	Histosols, dan Luvisols	4
8.	Chromic Luvisols	3
9.	Planosols	2
10.	Vertisols	1

After that, the five APLIS variables that already have their respective values and weights, are *overlaid* using a Geographic Information System (GIS) with the equation:

$$\mathbf{V = (A + P + 3L + 2I + S)/0,9} \quad (1)$$

Information :

V = Groundwater vulnerability (%) L = Lithology
A = Altitude I = Infiltration
P = Pendiente/Slope S = Soil type

In calculating the affixed value, the affix symbol is R (*Recharge*). In the vulnerability measurement, V replaces F, which indicates the value of vulnerability (*Vulnerability)*. The value of V is the sum of the APLIS variable scores divided by 0,9. The value of 0,9 is the assumption of the average annual rainfall that has the opportunity to become groundwater recharge ranging from 8.8% to 88.8% (secondary porosity in karst areas) so it is very high (Table 6).

Table 6. Classification of Affinity Value and Vulnerability [5]

No.	**Addition Value (%)**	**Class**
1.	20	Very low
2.	20 – 40	Low
3.	40 – 60	Currently
4.	60 – 80	Tall
5.	80 – 100	Very high

The higher the groundwater recharge value (R), the higher the groundwater vulnerability (V), and if the groundwater recharge value (R) is low, the groundwater vulnerability (V) will also be common.

4. Result and Discussion

4.1. A (Altitude)

Analysis of Indonesia's Digital Earth Map yields altitude on Paranggupito Sheet 1407-641, Kalak Sheet 1407-642, Pracimantoro Sheet 1407-643, and Giriwoyo Sheet 1407-644 with a scale of 1:25,000. Based on APLIS, the class scores 0-600 masl in the classification of the research area. The higher the regions, the better the infiltration process (maximum score).

Based on the elevation map, the lowest area is Pulanganom Village and partially Giritontro Village, with the lowest altitude, around 160 meters above sea level. A region with a height of >300 masl in the study area is well-karstified karst hills with the highest size ranging from 470 masl (Figure 2). Areas with an altitude of <300 masl are partial to the Baturetno Basin (Table 7).

Table 7. Area and altitude parameter scores

Altitude (msal)	**Score**	**Wide**	
		(%)	**(km^2)**
300	1	35	47,376
>300 – 600	2	65	87,984

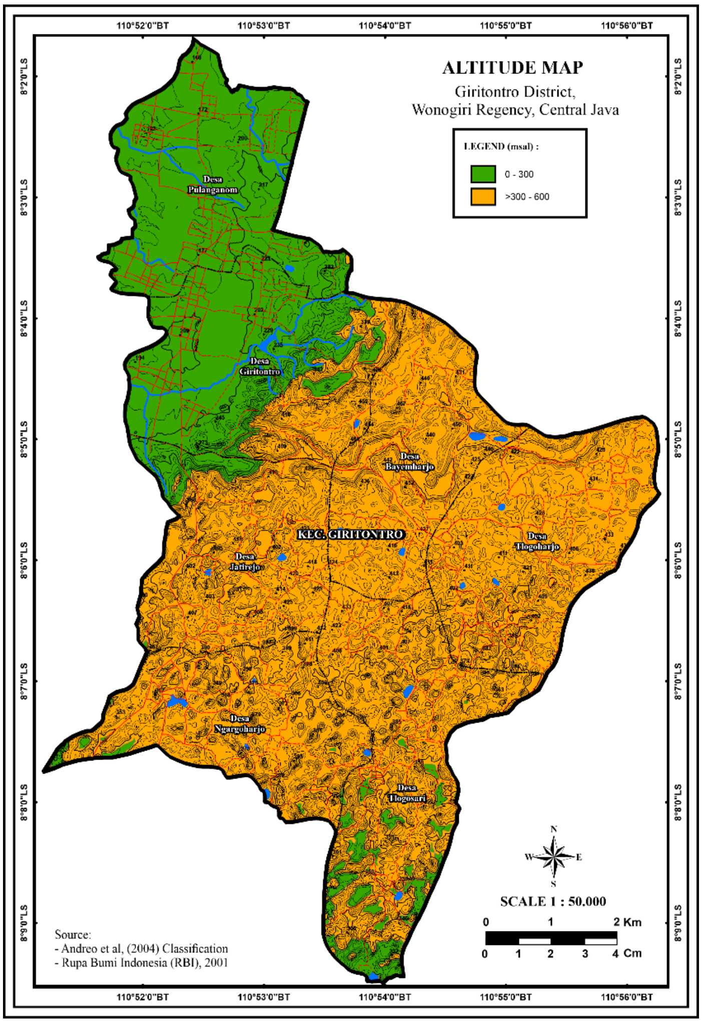

Figure 2. Altitude Map

4.2. P (*Pendiente*/Slope)

The results of the 1:50,000 contour map analysis produce a slope map (Figure 3). The slope of the study area varies from 0-76%. Slopes 0-8% and the hilly regions>8% characterize the plains and hills in the study site Plains and hills are groupings based on the slope in the study area (Table 8).

Slope class 3 is 3,21% of the study area or about 4,34 km^2. Slope class >3-8% is the largest area in the study area, 41,95 km^2 or 30,99% of the total research area. Slope class >8-16% is 4,81% of the study area or about 6,51 km^2. Slope class >16-21% is 4,75% of the study area or about 6,43 km^2. Slope class >21-31% is 21,88% of the study area or about 29,62 km^2. Slope class >31-46% is 25,06% of the study area or about 33,92 km^2. While the slope class >46-76% is 9,30% of the research area or about 12,59 km^2. Areas with plain slopes have a larger infiltration zone than hilly areas because water will move more slowly so that more water can seep into groundwater. Meanwhile, in areas with higher slopes, water will tend to flow towards a lower place than into the ground.

Table 8. Area and slope parameter score

Slope (%)	Score	Wide	
		(%)	(km ^{2})
3	10	3,21	4,34
>3-8	9	30,99	41,95
> 8 – 16	8	4,81	6,51
> 16 – 21	7	4,75	6,43
> 21 – 31	5	21,88	29,62
> 31 – 46	4	25,06	33,92
> 46 – 76	3	9,3	12,59

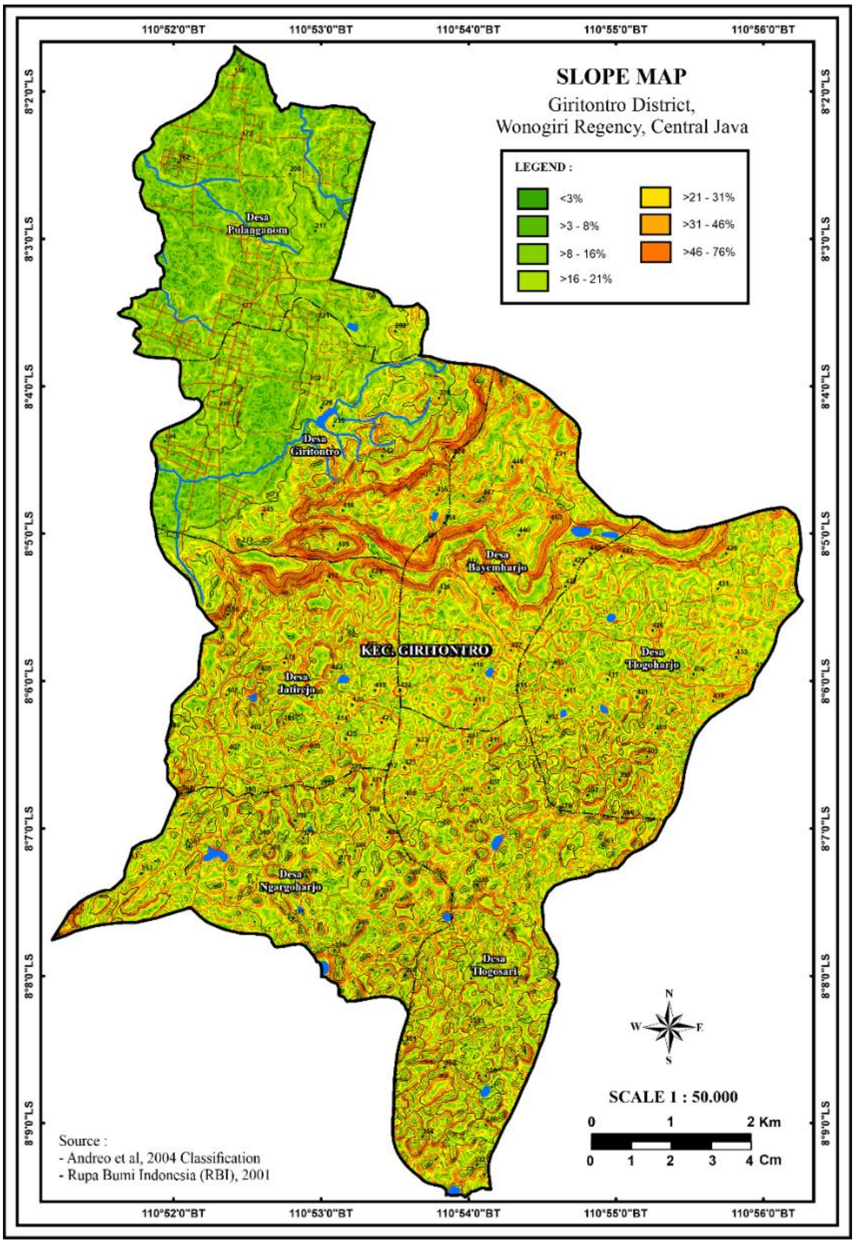

Figure 3. Slope map

4.3. Lithology

The Wonosari-Punung Formation (Tmwl) in the form of reef limestone, layered limestone is the lithology in the study area and sand-gravel-sized loose material deposits from the Baturetno Formation (Qb) (Figure 4). Reef limestones in the study area are well karstified—characteristics of karst landforms starting to form show karstification symptoms (Table 9). On the surface (exokarst) are conical hills, Dolina, lakes, and permanent springs, while at the bottom (endokarst) there are caves connected to underground river flows. The nature of the ingress of surface runoff and the development of very fine layers.

Table 9. Area and score of lithology parameters

Lithology	Score	Wide	
		(%)	(km^2)
Limestone and dolomite well karstified	9 - 10	85,5	115,73
Limestone and dolomite fractured	5 - 6	9,19	12,49
Coluvial sand and gravel	4	5,31	7,19

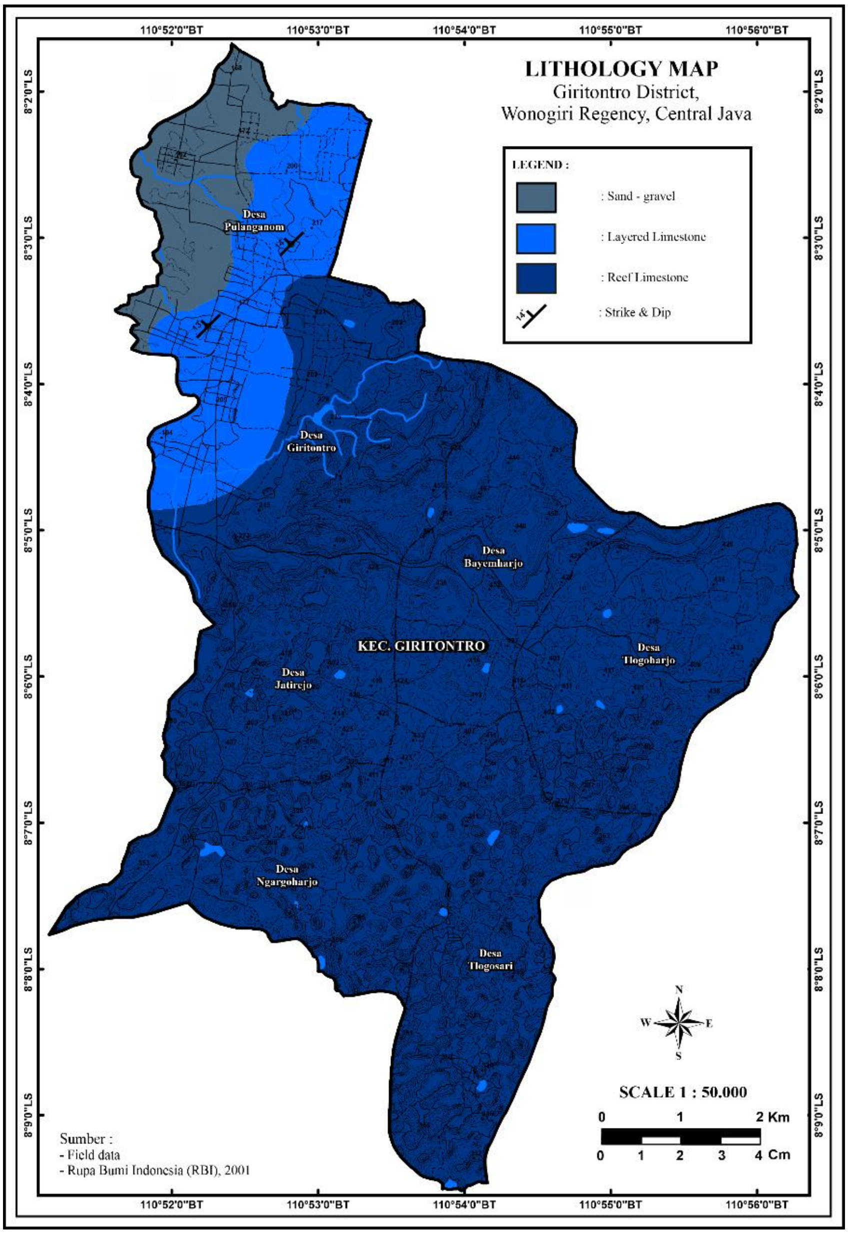

Figure 4. Lithology Map

Reef limestones in the research area are well karstified. On the surface (exokarst) are conical hills, Dolina, lakes, and springs. Caves connected to underground river flows are at the bottom surface (endokarst). According to Kusumayudha (2004), limestone has a calcium carbonate ($CaCO_3$) content of more than 90%. Limestone is challenging to pass water, but the weathering rate is high, so many cracks can cause the porosity level to increase, so that limestone can store and give large amounts of water [14].

In the APLIS method, well-karstified limestone has the highest score of 10. Layered limestone is a classification of cracked limestone with a score of 6 because there are many fractures in the layered limestone area. At the same time, sand-gravel deposits have a score of 4. Reef limestone is 85,5% of the research area or about 115,73 km^2, layered limestone is 9,19% of the study area or about 12,49 km^2, while sand to gravel deposits is 5,31% or around 7,19 km^2 (Table 8).

4.4. Infiltration

The division of the absorption zone in the study area consists of two absorption zones, namely the central absorption zone and other absorption zones. Lithological parameters and infiltration zones are essential to determine groundwater vulnerability zones in karst areas.

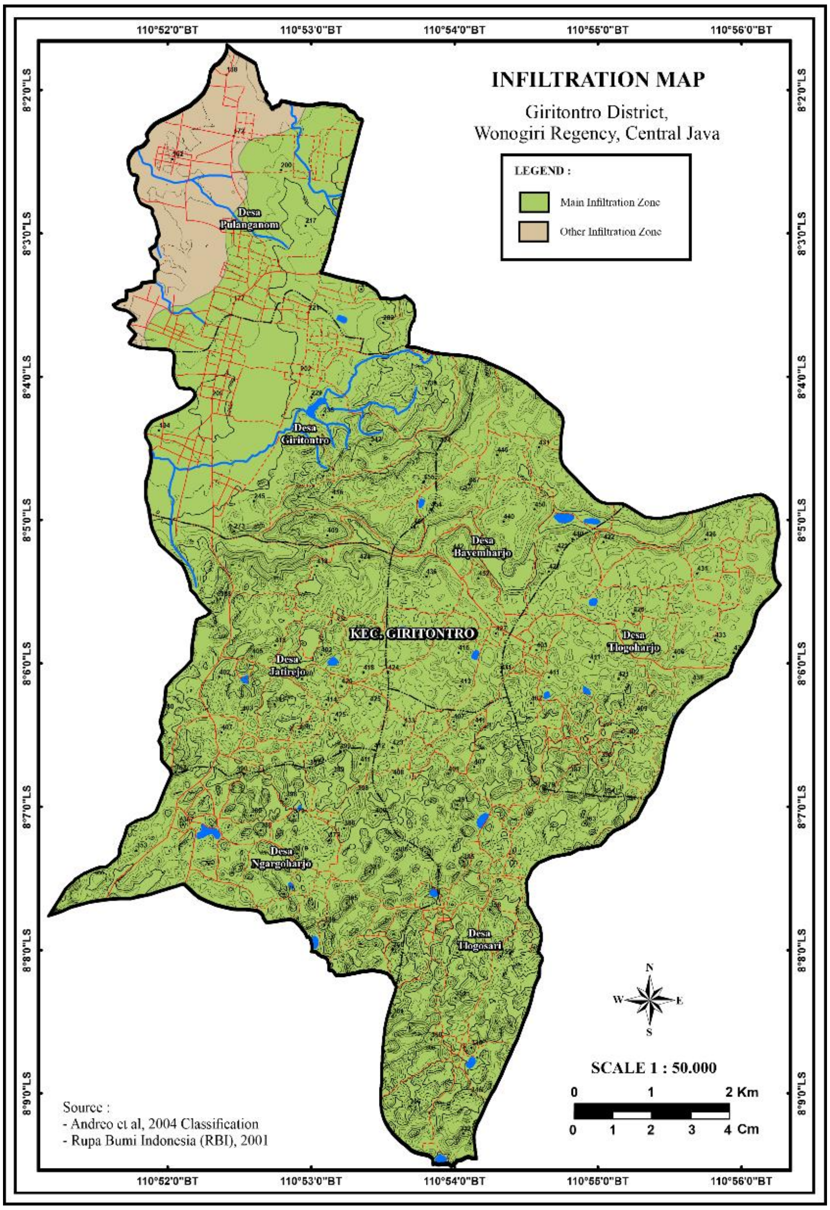

Figure 5. Infiltration Zone Map

Table 10. Infiltration zone parameter area and score

Lithology	Score	Wide	
		(%)	(km ^{2})
Main Infiltration Zone	10	83,2	112,62
Other Infiltration Zones	1	16,8	33,74

The main infiltration zone is the dominant water absorption zone in the karst area. Well-karstified limestone falls into this zone, which can be related to infiltration hydrological processes through joints, fractures, and sinkholes. The other infiltration zones are in lost sand-gravel-sized deposits, to be precise, to the northwest of the research location in Pulanganom Village and partially Giritontro Village (Figure 5). The main infiltration zone is 83,2% or about 112,62 km^2 of the entire study area, while the other infiltration zones are 16.8% or about 33.74 km^2 of the study area (Table 10).

4.5. Soil Type

Soil maps were generated from published references, adapted to the soil in the study area, and then changed in the Food and Agriculture Organization (FAO) soil classification. The division of soil in the study area is vertisol and luvisol. Vertisols were found in the Baturetno Formation area, while the spread of luvisols in the Wonosari-Punung Formation with well-karstified limestone lithology (Figure 6).

Vertisols in the research area are black. In the dry season, the soil will be hard and cracked due to shrinkage, but in the rainy season, it will be sticky because it expands. Luvisols soil is the result of weathering limestone. This soil is red to brown, often found on Dolina bottoms, and has a low fertility level and poor nutrients, so it cannot plan it with plants that require a lot of water but are suitable for palawija, teak, and tobacco. Luvisols soils are 94,48% or around 127,9 km^2 of the total research area, while vertisols soils are 5,52% or about 7,46 km^2 of the study area (Table 11).

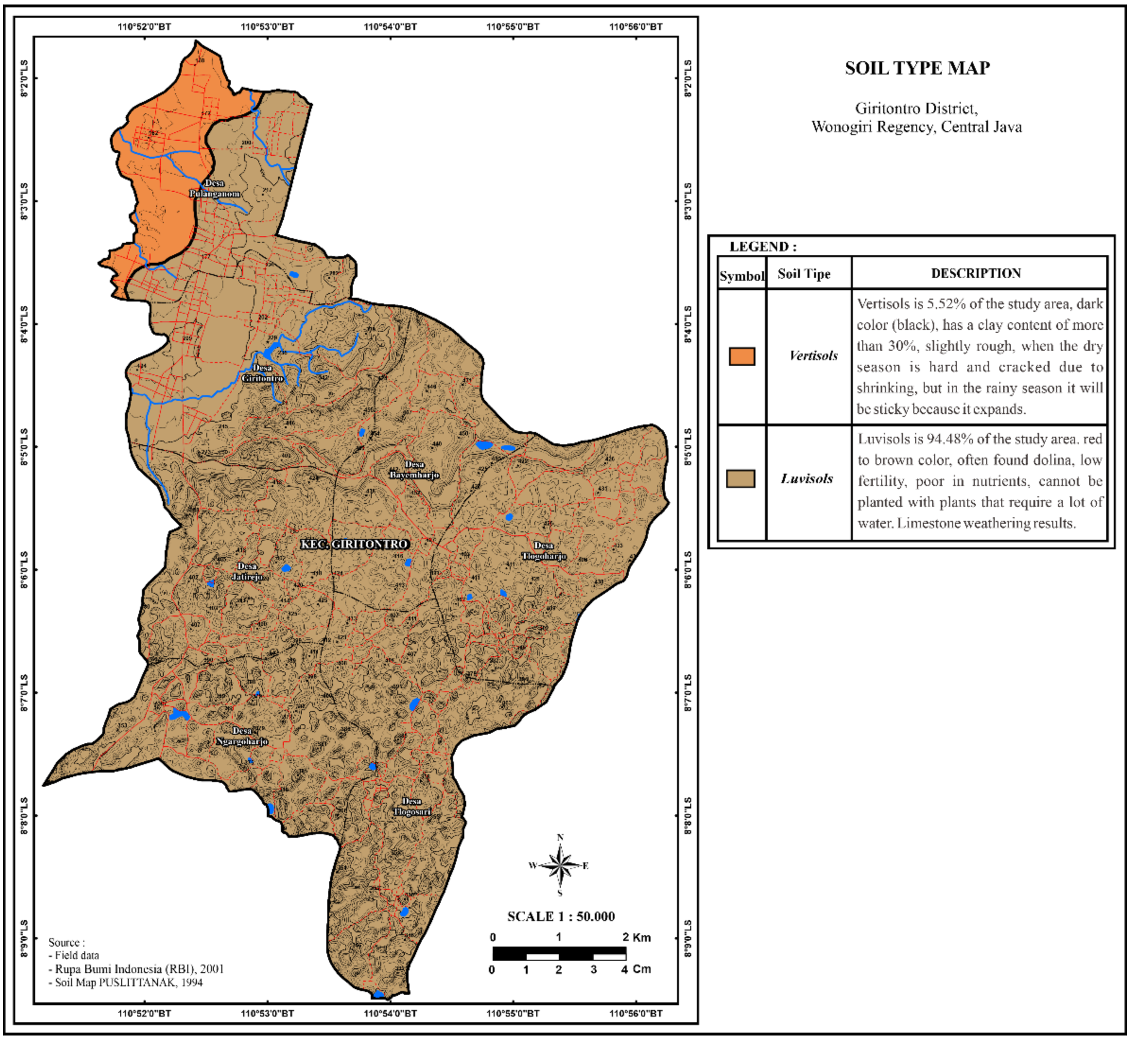

Figure 6. Soil Type Map

Table 11. Soil area and parameter scores

Type of soil	Score	Large	
		(%)	(km^2)
Luvisols	4	94.48	127.9
Vertisols	1	5.52	7.46

4.6. Groundwater Vulnerability Zonatiom

The APLIS method analysis resulted in groundwater vulnerability zoning, namely the overlapping of several parameters, including elevation, slope, lithology, infiltration zone, and soil type. Each APLIS variable's contribution to the groundwater vulnerability level is different. Based on the formula by Andreo et al. (2008)[13], lithology parameters and infiltration zones have high weights. It shows that lithology and infiltration zones dominate in determining groundwater vulnerability zones, while variables with moderate variable contributions are elevation, slope, and type of groundwater soil. Based on the overlay APLIS parameters, groundwater recharge values in the study area from 20 – 80% (low – high). A high level of groundwater recharge also causes a high level of groundwater vulnerability. It indicates that high groundwater recharge in an area makes it easier for contaminants to enter the groundwater system.

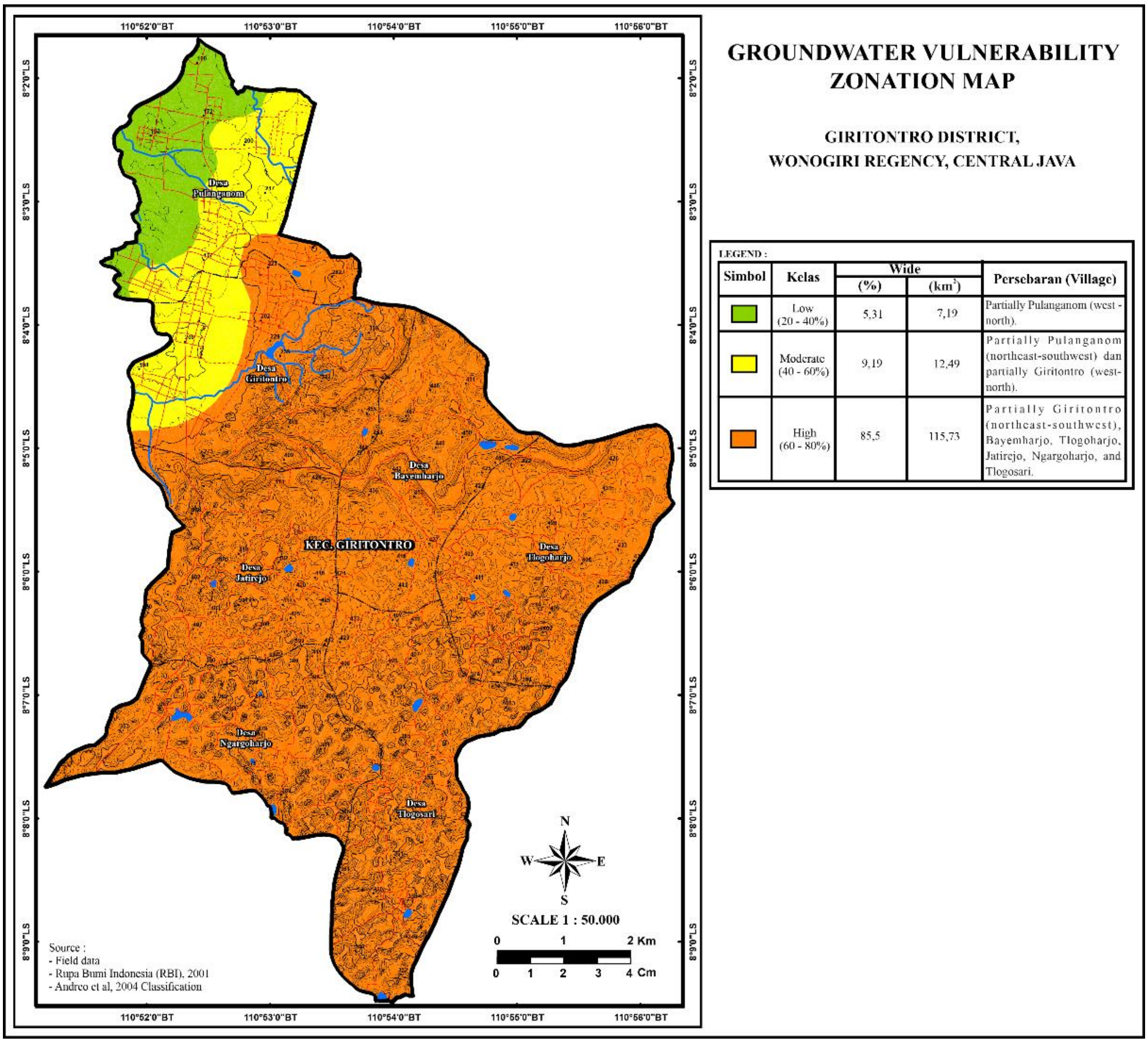

Figure 7. Groundwater Vulnerability Zoning Map

The low groundwater catchment area (20 - 40%) partially occupies the village of Tulanganom (west - north) from loose material deposits of sand - gravel size. Meanwhile, groundwater recharge is moderate (40 – 60%) in layered limestone, which is spread in parts of Pulanganom Village (northeast-southwest) and partially of Giritontro Village (west-north). Meanwhile, high groundwater recharge (60-80%) occupies limestone reefs, including in Giritontro Village (northeast-southwest), Bayemharjo, Tlogoharjo, Jatirejo, Ngargoharjo, and Tlogosari. Areas with loose material deposits have low groundwater susceptibility, layered limestones have a moderate vulnerability, and well-carstified reef limestones have high groundwater susceptibility (Figure 7).

Table 12. Area and score of recharge value and groundwater vulnerability

Addition Value (%)	**Class**	**Large (km^2)**	**Distribution (Village)**
20 – 40	Low	7,19	Pulanganom Village (west – north).
40 – 60	Moderate	12,49	Partially of Pulanganom Village (northeast-southwest) and partially of Giritontro (north-west).
60 – 80	High	115,73	Tlogoharjo , Jatirejo, Ngargoharjo, and Tlogosari.

The groundwater protection zone is a high level of groundwater vulnerability (60 – 80%) and is the most expansive area at 115.73 km^2 (85.5% of the research area). This zone is not allowed activities that cause groundwater pollution, such as mining and industry. We must preserve their natural landscapes and ecosystems in high vulnerability zones.

Agricultural land use (Table 12) occupies areas with thick sediments. Land use for mining, fisheries, settlements, and industrial cultivation occupies a space of 7.19 km2 (5.31% of the research area). The research area shows a high groundwater vulnerability class, considered included in the Karst Region Class I. In contrast, the level of groundwater vulnerability is moderate (40 – 60%), which is an area of 12,49 km^2 (9,19% of the research area), and low groundwater vulnerability (20 – 40%).

Groundwater pollution is a problem found in land use in the form of densely populated settlements and agricultural areas. The farm area is made on a topography lower than the topography of the residential area so that the flow of agricultural waste does not flow into the residential area. Settlements adjacent to agricultural land need special attention, such as making a drainage system and determining the direction of groundwater flow maps as consideration in constructing a drainage system.

Areas with a high level of vulnerability needs to get more attention, especially regarding space utilization in residential areas, to prevent groundwater contamination. If groundwater pollution occurs, it is necessary to take measures to ensure water quality. One quality assurance is managing water quality criteria based on specific classes and uses, such as drinking water and/or other functions.

5. Conclusion

5.1. Conclusion

Conclusions based on research that:

1. The distribution of groundwater vulnerability in the research area is low (20 – 40%), moderate (40 – 60%), and high (60 – 80%). The low level occupies 7,19 km^2 (5,31% of the study area) which consists of loose sand-gravel material in part of Pulanganom Village (west - north). The medium level occupies 12,49 km^2 (9,19 % of the study area), and lithology is layered limestone in Pulanganom Village (northeast-southwest). Part of Giritontro Village (west-north), the level of high groundwater vulnerability occupies the largest area of 115,73 km^2 (85,5% of the study area), with lithology are reef limestone in some of the villages in Giritontro (northeast-southwest), Jatirejo, Ngargohargo, Bayemharjo Tlogosari, and Tlogoharjo.
2. The Karst Class 1 area is a groundwater protection zone with a high level of groundwater vulnerability. Activities that can cause groundwater pollution are not allowed in that area.

4.2. Suggestion

Prevention is needed to protect areas with high groundwater vulnerability from damaged landscapes. Procuring central and regional government regulations regarding space utilization can also control land use and reduce groundwater pollution risk.

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