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Water Catchment Zone Mapping for Watershed Management in Gesing Sub-Watershed, Purworejo

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Abstract

Water is a very important resource involved in almost all life processes on earth, especially for human life. The rapid growth of water consumption with a decrease in the quantity and quality of water sources certainly creates problems of water scarcity or even flooding, which already occurs in some areas of Indonesia. In the last decades, some areas in Purworejo District, Indonesia have experienced floods, landslides, and droughts. This condition indicates that there has been a water quantity problem in the watershed in Purworejo. This study tends to focus on water resource management in terms of management planning. The purpose of this research is to create a water catchment zone map with the integration of remote sensing and geographic information systems methods. Identification of potential water catchment considers several parameters, such as soil permeability, rainfall, soil surface type, slope, and groundwater level. The results map consists of five classes of water catchment zone in the Gesing Sub-watershed. The higher classes were found in the upper watershed and the center of the watershed, especially in the valley section of the river. The lower classes, such as in the center of the watershed were considered as suitable areas to protect the water quality. With the mapping of water catchment zone, it is expected that the government can make appropriate policies related to water resources management of each sub-watershed so that in the end the water supply problem-especially in terms of quantity-can be managed and controlled effectively.

Keywords: water catchment zone, watershed management, remote sensing, geographic information system, Gesing Sub-watershed

1. Introduction

Water is a very important resource where it is involved in almost all life processes on earth, and its function can not be replaced by other substances. All organisms on earth contain 50-90% water; if water becomes scarce or has poor quality, plants and animals will die; humans also must drink about two liters of water per day (Lozan & Karbe, 2007). In social, economic and environmental dimensions, water is also a core part of sustainable development programs that contribute to improving social welfare and inclusive growth, affecting the livelihoods of billions of people (WWAP, 2015).

UN (2002) states that in Indonesia, freshwater consumption is dominated by the agricultural sector which reaches 98% of water resources and it is projected that by 2015 water use for irrigation, domestic demand, and industry will grow rapidly. While, it is needed to know that clean water supplied by the Regional Water Supply Company of Indonesia only provides water for only 20% of Indonesia's 200 million people (UN, 2002). The rapid growth of water consumption with a decrease in the quantity and quality of water sources certainly creates problems of water scarcity or even flooding, which already occurs in some areas of Indonesia.

In the last decades, some areas in Purworejo District, Indonesia have experienced floods, landslides, and droughts. The latest condition in Purworejo Regency is the occurrence of a clean water crisis until the establishment of an emergency status of drought or lack of clean water through the Purworejo District Regent Decree on 28 June 2018. Until mid-August, the impact of the drought was increasingly widespread. A number of villages that were not included in the list because of previous years not being affected, are now beginning to be affected and have submitted assistance for dropping clean water and water storage. The villages affected by the drought and clean water crisis included Jatiwangsan Village, Kemiri District, Sucen Village, Central Juru, Bayan District, Polowangi Village, Pituruh District, Kalirejo Village, Bagelen District and Cengkawakrejo Village, Banyuurip Sub-District. Meanwhile on March 17, 2019, heavy rains that flushed Purworejo District caused floods and landslides. Floods generally occur in villages located downstream of the watershed, while landslides occur in the villages of Jatirejo, Kaliharjo, and Kaligono, Kaligesing District. Thus, Purworejo Regency became a district that was hit by floods and landslides during the rainy season and drought during the dry season. This condition indicates that there has been a water quantity problem in the watershed in Purworejo. It was indicating that there's water supply problems which may be caused by proper watershed management have not implemented yet. In UN (2002) it is also mentioned program protection of the quality and supply of freshwater resources with application of integrated approaches to the development, management and use of water resources. This study tends to focus on water resource management in terms of management planning. Therefore, mapping the water catchment zone is one of the efforts to support sustainable development goals, especially number 15 (Life on Land).

Appropriate watershed management in order to overcome the water supply problems could be done by mapping the potential water distribution using remote sensing and geographic information systems (GIS) methods. Remote sensing and GIS techniques have emerged as powerful tools for watershed management programs. Remote sensing data can be used for delineation of ridge lines, characterization, priority evaluation, problem identification, assessment of potentials and management needs, identification of erosion-prone areas, evolving water conservation strategies, sites selection for check dams and reservoirs, etc.(Dutta *et al.,* in Sindhu *et al.,* 2015).

Wibowo (2006) explained that the water catchment area is the area where the rainwater absorbed into the soil which then becomes groundwater. Not only as of the addition of groundwater reserves, but water catchment areas also served to reduce the potential for flooding. After the potential of water distribution based on the water catchment zone map is known, the integrated watershed management to address the problem of water availability in the study area can be done.

Groundwater generally has advantages compared to surface water because it is protected from contamination of bacteria and pathogenic organisms that can cause diseases related to low water quality. However, groundwater is not always available and if available it is limited. Therefore, if the amount of rainwater becomes groundwater is less, the amount of groundwater that can be taken from the aquifer is limited. Under certain conditions, the addition of groundwater can be attempted artificially by making artificial recharge areas. Infiltration areas are usually characterized by high rates of infiltration so that water flowing into the area easily enters the soil and becomes groundwater.

The objectives of watershed management (Asdak, 2010) are: a) ensuring sustainable use of watershed-scale natural resources, b) achieving ecological balance as a life support system, c) guaranteeing water quantity and quality throughout the year, d) controlling surface flow and flooding, and e) control of soil erosion and other land degradation processes. In the context of watershed management planning, the enactment of Law No. 32 of 2004 concerning the Regional Government provides a greater role for local governments and their partners in watershed management planning. One of the authorities delegated to the regions and is of a strategic nature is the determination of the regional arrangement criteria for the catchment ecosystem in the watershed. The aspect of watershed management that was targeted in this study was a organizing policy. In the preparation of spatial planning, it is necessary to have an area designated as a conservation area as a groundwater recharge area.

The purpose of this paper is to create a water catchment zone map with the integration of remote sensing and geographic information systems methods and to know the potential of water distribution as well as provide recommendations for watershed management in the study area.

2. Methods

2.1. Study Area

Gesing Sub-watershed (Figure 1) is located on the border between Kulonprogo Regency and Purworejo Regency. The landforms located in this area were fluvial and denudated structural. The upstream part of the watershed is a denudated structural landform, Menoreh Hills which is known for its massive erosion. Vegetation cover in the Gesing Sub-watershed is dense. This can be seen from Landsat 8 OLI Image Composite 543 (Figure 2) which shows the dominant red color in almost all watershed areas. The red color indicates the presence of vegetation whose appearance is prominent on the infrared band.

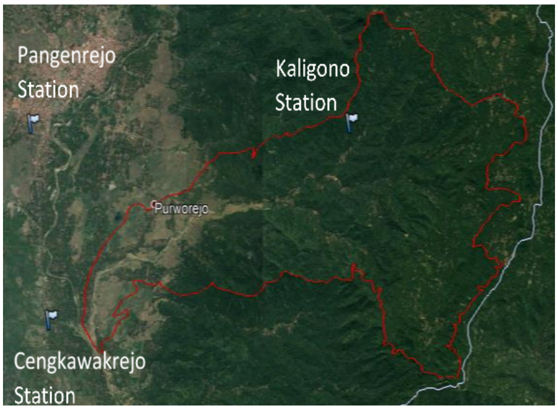

Figure 1. Study Area: Gesing Sub-watershed and rainfall stations distribution (Source: Google Earth)

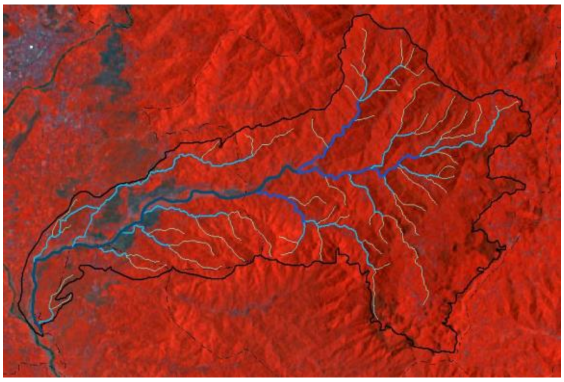

Figure 2. Landsat 8 OLI Composite 543 indicates the presence of vegetation in dominant red color

From the calculation using GIS, the area of the Sub-watershed is 4624.78 Ha, the shape of this watershed is obtained by the roundness ratio of 0.2545, which means the Gesing Sub-watershed is linear. Chandrashekar *et al.,* (2015) stated that a low roundness ratio indicates strong elongation and a homogeneous and permeable geological material while a high value shows a low relief with an impermeable surface. Steep contour lines in the upstream area indicate a V-shaped river cross-section, while in the middle section shows a U-shaped river cross-section and in the lower part shows a wider U-shaped river cross section. The slope of the river flow obtained a value of 0.034 or a slope of 1,956º. The value of the relief indicates that the relief conditions in the Gesing Sub-watershed are low. The low slope of the river channel and the linear shape of the watershed indicate that the occurrence of erosion and sedimentation is more dominant in the Gesing Sub-watershed than in the event of flooding. This is due to the longer surface runoff and easily eroded parent material originating from deformed structural landforms. Regional topography of Gesing Sub-watershed is shown in Figure 3.

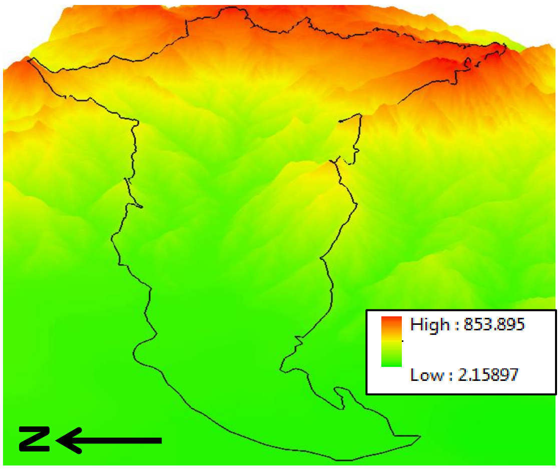

Figure 3. Gesing Sub-Watershed in 3D

2.2. Materials and Methods

This research uses ArcGIS 10.1 software to do data processing. The data used in this research is shown in Table 1.

Table 1. Research materials.

Data	Process	Source
Vegetation density	Land cover interpretation	Landsat 8 OLI Image Path 120/row 65
River, Contour	Watershed border delineation, DEM, Slope	Indonesia Topography Map (RBI) of Purworejo Sheet 1408-231 and Bagelen Sheet 1408-213 Scale 1: 25,000
Soil permeability, Soil texture, Groundwater level	Landform interpretation	Geological Map of Yogyakarta Sheet 1408-2 & 1407-5 Scale 1: 100,000
Rainfall	IDW interpolation	Daily Maximum Rain Data of Pangenrejo, Cengkawakrejo and Kaligono Stations in 2001-2010

Sudaryatno (2017) said that variations in groundwater potential depend on rainfall, vegetation, slope, rock porosity, and permeability. Meanwhile, Asdak (2010) classified the factors that influence groundwater into two, namely above-ground factors, in the form of rainfall and altitude, as well as sub-surface factors, namely geological formations. The parameters used to identify potential water absorption in the Gesing Sub-watershed refer to the Wibowo (2006) study, which consisted of soil permeability, rainfall, surface soil type, slope, and groundwater level. These five parameters are carried out in a weighted overlay with parameter scores presented in Table 2.

Table 2. Parameters score for water catchment zone (Wibowo, 2006).

Soil permeability (m/day)	Rock type	Score	Description
> 10^3	Alluvial Sediment	5	Very high
10^1 - 10^3	Early Quaternary Sediment	4	High
10^{-2}- 10^1	Late Quaternary Sediment	3	Sufficient
10^{-4}- 10^{-2}	Tertiary Sediment	2	Moderate
< 10^{-4}	Intrusive Rock	1	Low

Rainfall (mm/year)	Rain infiltration factor*	Score	Description
< 1.500	< 2.775	1	Low
1.500 – 2.000	2.775 – 3.700	2	Moderate
2.000 – 2.500	3.700 – 4.625	3	Sufficient
2.500 – 3.000	4.625 – 5.550	4	High
> 3.000	> 5.550	5	Very High

*Rain infiltration factor is measured by the average of the rainy day in Bandung Basin over 185 day/year

Permeability (m/s)	Soil texture	Score	Description
Very slow (< 2)	Gravel	1	Low
Slow (2-7)	Sand-gravel mixture	2	Moderate
Moderate-rapid (7-15)	Sandy clay	3	Sufficient
Rapid (15-30)	Clay loam	4	High
Very rapid (>30)	Loamy clay	5	Very high

Slope (%)	Infiltration coefficient	Score	Description
< 8	> 0.95	5	Very high
8 – 15	0.8	4	High
15 – 25	0.7	3	Sufficient
25 – 45	0.5	2	Moderate
> 45	0.2	1	Low

Groundwater level (m)	Score	Description
> 30	5	Very high
20 – 30	4	High
10 – 20	3	Sufficient
5– 10	2	Moderate
< 5	1	Low

Parameter	Score	Description
Soil permeability	5	Very high
Rainfall	4	High
Soil surface type	3	Sufficient
Slope	2	Moderate
Groundwater level	1	Low

Source: Wibowo (2006)

3. Result and Discussion

3.1 Water Catchment Zone Parameters

Water catchment zone map preparation considers the parameters that affect the potential of water catchment according to Wibowo (2006), are such as soil permeability, rainfall, soil surface type, slope, and groundwater level. The soil permeability parameter influences the determination of the texture and structure of the rock type, which is related to the ability of soil permeability. The faster the permeability rate then the area has more potential to become a water catchment area.

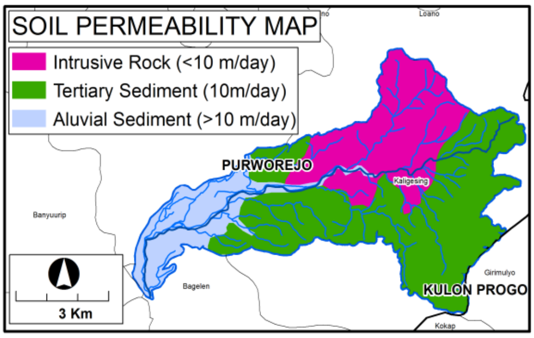

Figure 4. Soil Permeability Map

Rainfall parameters affect the water supply that falls to the surface. The higher and longer the rainfall, the greater the water that can seep into the soil so that the location has the potential to become a water catchment zone.

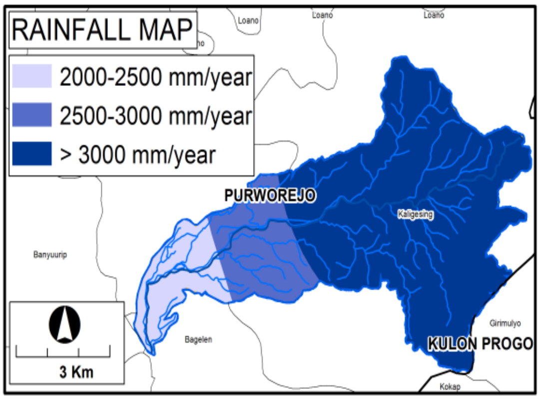

Figure 5. Rainfall Map

Soil texture parameters affect the absorption of soil against falling water, judging from its porosity, permeability, and infiltration ability. The larger the grain size of a soil texture the more likely to become water catchment zone.

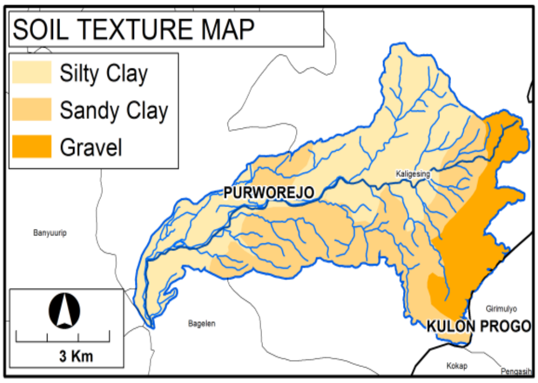

Figure 6. Soil Texture Map

Slope parameters affect the surface flow/runoff. The larger the slope will be the smaller the amount of water pervasive because most will be the flow of the surface and a little to be infiltrated.

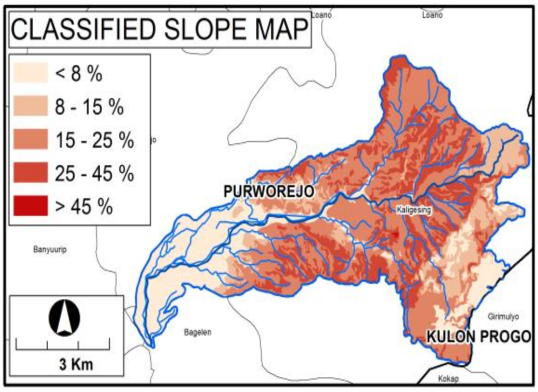

Figure 7. Slope Map

Parameters of groundwater level are related to soil capacity to store water, so that if the deeper the depth of the water table is free then the potential of soil to absorb water will be greater than the area with relatively shallow groundwater level.

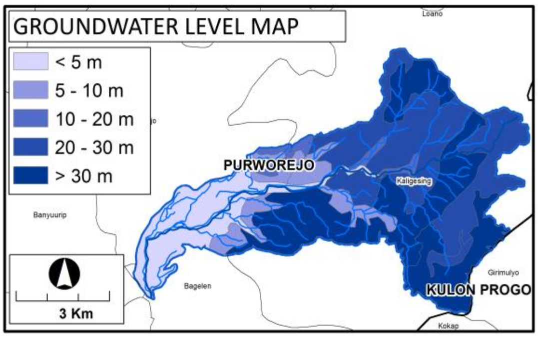

Figure 8. Groundwater Level Map

3.2 Water Catchment Zone Map

The Water Catchment Zone Map was obtained from the weighted overlay analysis to the five parameters mentioned above. Distribution of water catchment potential areas can be seen in Figure 9. Potential water catchment zone obtained into five classes, i.e. low, moderate, sufficient, high, and very high.

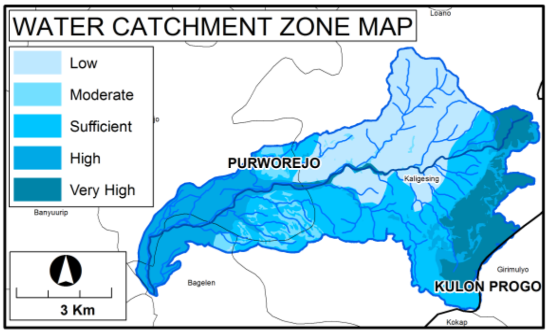

Figure 9. Water Catchment Zone Map

The low classes are located in the northern center of the watershed with a large enough area. The moderate classes are many located on the border between the center and downstream of the watershed, with small areas. The sufficient classes located on the upstream-center south of the watershed. The high classes are located downstream, and very high classes are found in the upper watershed and the center of the watershed, especially in the valley section of the river. The area of each water catchment zone class is shown in Table 3. The upper part of the watershed has very high potential as water catchment areas caused by several things: sedimentary rock type, high rainfall, gravel ground texture, small slope, and deep groundwater level. Meanwhile, the center of the watershed has a low potential as a water absorption area caused by a waterproof type of rock, a silt clay texture, and a large slope. The downstream part of the watershed which is included in the form of the alluvial plain has a high potential to become water absorption.

The results considered quite strange considering alluvial plain are areas that often inundated due to bad drainage. However, looking at the definition of water catchment itself is an area capable of absorbing water into the soil, it is seen from the geomorphological characteristics of alluvial plain that are not water-resistant then the Water Catchment Zone Map that has been made is considered capable of presenting good enough information, more precisely able to demonstrate the ability land to absorb water into the soil, not in terms of the capacity of the water reservoir into the soil. When looking at the capacity of the water reservoir into the soil the alluvial plain is considered less potential to absorb water into the soil with large amounts due to the soil type which is easily saturated. This saturated soil makes water that passes through this area will turn into puddles or surface flows, due to small infiltration.

Table 3. Water catchment zone class area.

Water Catchment Zone Class	Area (Ha)	Percentage (%)
Low	1339.95	28.97
Moderate	269.67	5.83
Sufficient	1421.15	30.73
High	962.10	20.8
Very High	631.91	13.66

3.3 Watershed Management for Handling Supply Problems Recommendation

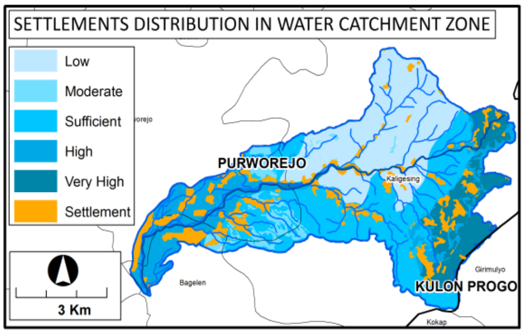

Figure 10. Settlements Distribution in Water Catchment Zone

The water catchment area is included in the spatial planning area of protected areas, which serves as an addition to the groundwater reserves and reduces the potential for flooding (Wibowo, 2006). Seen from the function of the water catchment area, the area that is suitable to be a water catchment area is very high in Figure 10, while the high class is considered less suitable as a water catchment area because it is a potential area of flooding. When it is associated with the Land Use Map of Gesing Sub-watershed, the upland utilization in the form of gardens and settlements is considered sufficient because in that area the groundwater reserves are abundant. Meanwhile, the downstream is used as rice fields and settlements, with huge flood potential. The closure of land by vegetation with all its forms and human activities can affect water management in the watershed so that the recommendations proposed from this study include land use planning and evaluation of the ecosystem services-based environment carrying capacity and capability for settlements and agriculture in the Gesing Sub-watershed.

The method referred to for making water catchment zone map is considered to be less relevant, especially when setting alluvial plains as potential water catchments, so further processing should be done for additional parameters such as landform and vegetation cover. Landform parameters need to be included in building models to reduce errors as in the case of potential alluvial plains in absorbing water, while vegetation cover is one of the driving parameters of water absorption because plant roots can trigger the formation of fractures in rocks so that there are gaps to escape water even though water-resistant rocks. The score of each parameter should also need to be rearranged given that it is the result of high soil permeability scores that make alluvial plains considered to have high potential to absorb water and field measurements should be conducted to complete groundwater level data so that further processing of data becomes better and does not use less appropriate assumptions such as those used in data processing. For further research, it is expected to assess water quality and surface runoff coefficients as indicators of watershed health.

4. Conclusion

Potential water catchment zone in Gesing Sub-watershed is classified into five classes, i.e. low, moderate, sufficient, high, and very high. The low classes are located in the northern center of the watershed with a large enough area, while the high classes are located on downstream and very high classes are found in the upper watershed and the center of the watershed, especially in the valley section of the river.

Areas with the largest water catchment zone are in the upper watershed and considered after the water catchment area. The center of the watershed belonging to a low-class water catchment zone is considered suitable for protected areas to protect water quality. Good handling in upstream and central watersheds can reduce the potential for floods that generally occur in downstream watersheds.

5. Acknowledgement

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