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Spatial Analysis for Potential Water Catchment Areas using GIS: Weighted Overlay Technique

Disyacitta Awanda*, Anugrah Nurul H, Zahrotul Musfiroh, Dinda Dwi N P

Undergraduate Student of Universitas Gadjah Mada, Bulaksumur, Yogyakarta, Indonesia 55281

disyaawanda@hotmail.com

Abstract. The development of applied GIS is growing rapidly and has been widely applied in various fields. Preparation of a model to obtain information is one of the benefits of GIS. Obtaining information for water resources such as water catchment areas is one part of GIS modelling. Water catchment model can be utilized to see the distribution of potential and ability of a region in water absorbing. The use of overlay techniques with the weighting obtained from the literature from previous research is used to build the model. Model builder parameters are obtained through remote sensing interpretation techniques such as land use, landforms, and soil texture. Secondary data such as rock type maps are also used as water catchment model parameters. The location of this research is in the upstream part of the Opak river basin. The purpose of this research is to get information about potential distribution of water catchment area with overlay technique. The results of this study indicate the potential of water catchment areas with excellent category, good, medium, poor and very poor. These results may indicate that the Upper river basin is either good or in bad condition, so it can be used for better water resources management policy determination.

Keywords: water catchment area, GIS, modelling, recharge zone

1. Introduction

The existence of groundwater is strongly influenced by the vegetation contained on it. In the scope of water ecosystem, known as Watershed which will further influence the existence of ground water. The development of applied GIS is growing rapidly and has been widely applied in various fields. Preparation of a model to obtain information is one of the benefits of GIS. Obtaining information for water resources such as water catchment areas is one part of GIS modeling. Water catchment model can be utilized to see the distribution of potential and ability of a region in water absorbing. The existence of water in the earth is very important for the sustainability of living beings.

The Opak River flows through the Sleman and Bantul districts where these two districts are fairly populated areas, thus causing relatively high levels of development in the region. Increased development in urban areas causes the amount of runoff [1]. Meanwhile, exploitation of water resources excessively causing a decrease in soil surface air, salt water intrusion, soil degradation, and drought [2]. The potential constriction of the water catchment area will directly affect the groundwater recharge zone. The groundwater recharge zone is the main determinant of the presence of water in the soil. If the land that serves as a catchment area is experiencing a continuous decline, then the groundwater recharge zone cannot work optimally [3].

The catchment area is an area that serves as a water catchment area that has important benefits to maintain the sustainability of the function of water sources in a. catchment area is closely related to watercourses. Watershed is an area that limits the mountain ridges where rainfall that falls on the area will be accommodated by the ridge and will be channeled through small rivers to the main river [4].

In general, the process of groundwater entry occurs through two sequential processes, namely infiltration (movement of water from the top into the soil surface) and percolation of water movement down from the unsaturated zone into the water saturated zone. The infiltration power is the maximum possible infiltration rate, determined by the ground surface conditions. The percolation power is the maximum possible rate of percolation, which is determined by the soil conditions in the unsaturated zone [5]. Infiltration rate will be equal to rain intensity if infiltration rate is still less than infiltration power. Percolation will not occur if the porosity in the zone is not saturated yet contains maximum water. The infiltration process plays an important role in replenishing the soil moisture and ground water. Replenishment of soil moisture is equal to the difference between infiltration and percolation [6]. So, the process of water entry into the soil is greatly influenced by water catchment areas and groundwater recharging zones. If the potential distribution of water catchment areas for the recharge zone is well distributed then the availability of water in the soil will be balanced.

GIS is an organized support of computer hardware, software, geographic data, and personnel designed to efficiently store, store, update, manipulate, analyze and display all geographic information [7]. The application of GIS is an effective way to map water catchment zones where modeling can use data from several parameters: rainfall, land use, geological data, slope, and water table height [8]. Modeling is done by using the overlay technique with tiered method by giving weight to each parameter in use. The purpose of this study is to obtain information on the potential distribution of water catchment areas for the recharge zone with overlay techniques using weighted methods, so that the results of the research can be used for better determination of water resources management policy. The purpose of this research is to get information about potential distribution of water catchment area with overlay technique. The results of this study indicate the potential of water catchment areas with excellent category, good, medium, poor and very poor.

2. Methods

The study sites are located in the Upper Opak Sub-watershed until the Opak-Oyo river meeting. In general, the research area covers the southern slopes of Mount Merapi which is still active today. Determination of the air absorption area absorbed some physical parameters that contribute to the infiltration and percolation process. Each parameter has a different role with different constituent parameters. The layers of each parameter are overlapped so that a new result will be classified as a potential for the airflow region. Simply put, the method used to construct a water catchment model is a weighted, tiered overlay that weighs on the guidance and guidance of the existing literature.

Parameters used in this study include rock types, soil texture, land use, rainfall, slope and ground air. Rock type parameters increase through geological map scale 1: 100.000 then known geological information that is equal to the level of permeability. Soil texture is known based on morphological approach and form of land through image and DEM data. Land use is obtained by digitally performing with a pitcher with maximum likelihood. The land use class is then reviewed based on the permeability level of each land use. Rainfall results of interpolation of rainfall data from several observation stations from related institutions. Interpolation method used by inverse Distance Weighted. Slope information is extracted through DEM processing data and its classification on Cook. Ground water is obtained through interpolation by Kriging method based on direct field observation data on the population wells. All parameters are done based on each weight (Table 1).

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Table 1. Scoring of Recharge Zone (Wibowo, 2006 with modified)

Parameter	Score
Geology	6
Rainfall Intensity	5
Soil Texture	4
Land use/cover	3
Slope	2
Water table	1

3. Result and Disscusion

Water catchment areas are affected by several physical parameters such as geology, soil texture, slope, rainfall, water table fluctuation and land use. Each of these parameters has its own contribution in the ability to absorb water to become a groundwater reserve. Some extraction of physical parameters is done by using remote sensing technique with certain approach. Several other parameters were obtained through direct measurement in the field and also the acquisition of secondary data. The technique used to get the water catchment model is to utilize GIS application with weighted overlay technique.

3.1. Land Use

Land use Opak River Basin Map made by image data processing, supervised classification method using maximum likelihood. Land use maps are classified into: settlements, grasses, gardens / moorlands, pine forests, forests, rivers, paddy fields, wet fields, open land. Images used for land use information extraction are Landsat 8 OLI images (Fig.1).

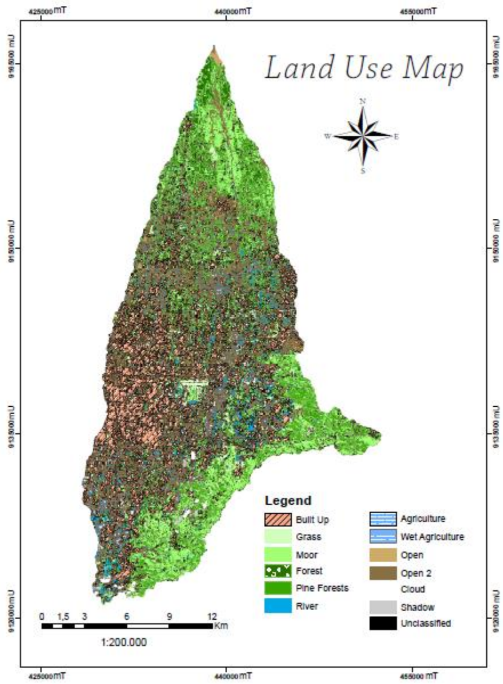

Figure 1. Land Use Map in Opak sub-watershed

Table 2. Scoring of Land Use

Infiltration	Land Use	Score
Very High	Forest	5
High	High Production Forest, Garden, Open Land	4
Moderate	Shrubs, Grasses	3
Low	Field	2
Very Low	Urban, Rice Field	1

Land use information is also used to estimate the difference in the amount of groundwater due to changes in land use and vegetation by measuring changes in groundwater levels. Areas overgrown with trees have the ability to absorb water runoff is very good so that the amount of ground water in the area more. Areas overgrown by trees will be better able to absorb larger runoff water, so the amount of groundwater contained in the area quite a lot, but runoff water flows slowly because of the roots and trunks of the tree so that the run time of water runs longer to get to the river. Land use of the Opak watershed is classified into; forests, gardens / fields, rice fields, wet rice fields, grasses, pine forests, urban, open land and rivers. Land use in the OPAK basin is largely a settlement in the transport zone or in the middle and downstream areas, while in the north or upstream areas there are fairly dense forests, especially the area around Merapi Volcano. Dense urban in the central and downstream areas has resulted in flood vulnerability in the middle to downstream areas quite higher than the level of flood vulnerability in the upstream or northern parts.

3.2. Geology

Map of geology made with reference to the geological map of Yogyakarta Province. Classification is done by giving weight to each geology of rocks. The map is created with scale 1: 450.000. The result consists five class; low, moderate, sufficient, high and very high. One of the parameters to be considered for the determination of water absorption areas is, the constituent rocks. Constituent rocks have a close relationship with permeability levels. The greater the permeability level of a rock, the higher the rate of air passage. Constituent rocks have an influence on water absorption into the soil distinguished by weight values.

The result of the classification of the constituent rocks shows that upstream of the permeability level of the Opak watershed is sufficient because it is dominated by the rock of the quarter era (Fig.2). In the middle of Opak watershed, permeability levels are moderate and dominated by tertiary age rocks. While the downstream area leading directly to the Indian Ocean the permeability level is sufficient. In general, the influence of the constituent rocks against the water absorption zone in the Opak watershed is in the middle region often floods. In addition to the level of permeability that is leading to low, high sedimentation in the middle region also affect the shallow watershed. So the possibility of flooding in the area is quite high.

Table 3. Scoring of Geology

Permeability	Rock	Score
$>10^3$	Aluvial Deposits	5
10^1 - 10^3	Young Quarter Deposits	4
10^{-2} – 10^1	Old Quarter Depostis	3
10^{-4} – 10^{-2}	Tertiary Depostis	2
$<10^{-4}$	Intrusion rock	1

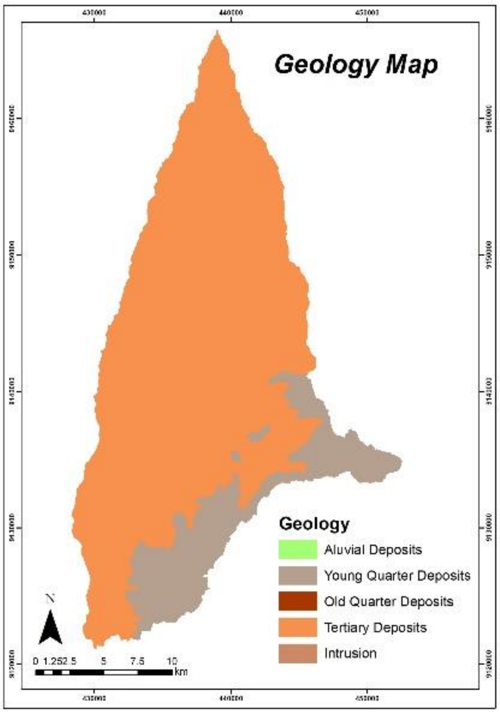

Figure 2. Geology map of Opak sub-watershed

3.3. Rainfall

Rainwater data is obtained through secondary data through related institutions. The distribution of rain stations to be used as interpolation is spread evenly throughout the study area. The rain stations used are not only within the study area but also outside the study area so that interpolation results can cover all areas of study. The interpolation method used is Inverse Distance Weighted (IDW). Interpolation results with the method is good enough to give an overview of the intensity of rain that occurred in the last 10 years. There are 3 different classes in the study area.

The last 10 years of precipitation in Opak sub-watershed ranges below 1500 to 2500 mm / year (Fig.3). In the upstream part, rainfall is higher than the area below it. It is influenced by the topographical condition or the phenomenon of orographic rain. The high rainfall in the upper reaches the water absorption potential, because the higher the rainfall, the higher the infiltration process that occurs in the soil surface to the subsurface. The pressure of water in the soil due to the high infiltration process will also enlarge the ground water supply. In the middle and downstream part of the rainfall it tends not to be as high as the upstream, it is very natural to happen. Based on these results rainfall has a big role in determining the potential of water catchment areas in the upstream, so that the parameter of rainfall for the water catchment area is quite potential.

Table 4. Scoring of Rainfall

Rainfall (mm/yr)	Rainfall Infiltration Factor *)	Score
< 1.500	< 2.775	1
1.500 – 2.000	2.775 – 3.700	2
2.000 – 2.500	3.700 – 4.625	3
2.500 – 3.000	4.625 – 5.550	4
> 5.550	> 5.550	5

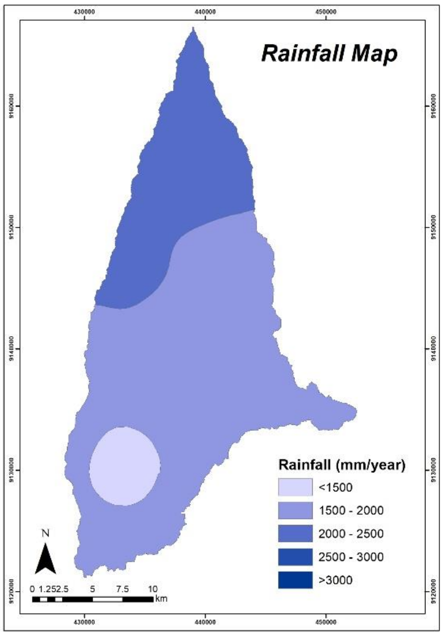

Figure 3. Inverse Distance Weighted for Rainfall Intensity

3.4. Soil Texture

Soil texture is one of the physical parameters that can be detected deductively through remote sensing image. Gradually by using the approach of landform and topography aspects can be known texture of soil in a region. Opak sub-watershed is located around a volcano that is quite young so that most of the area is still strongly affected by the activity of the mountain. Based on the interpretation results, most of the land has sand texture mixed with clay texture and dust. At the top is dominated by the texture of sand and dust, while the bottom is dominated by the texture of sandy clay and clay. Soil texture conditions allow water to be impregnated fairly quickly, because the influence of sand texture is quite dominating. At the upstream the permeability level is the fastest because the soil texture of the upstream area is mostly sand texture (Fig.4). At the center and downstream are already mixed with the texture of the clay so that the permeability level is lower. It shows physically reviewed based on sub-watershed Opak soil texture has good upflow potential at upstream.

Table 5. Scoring of Soil Texture

Permeability (10^{-5}m/dt)	Rock	Score
Very slow (<2)	Clay	1
Slow (2-7)	Silty Clay	2
moderate (7-15)	Sandy Clay	3
Fast (15-30)	Silty Sand	4
Very Fast (>30)	Sand	5

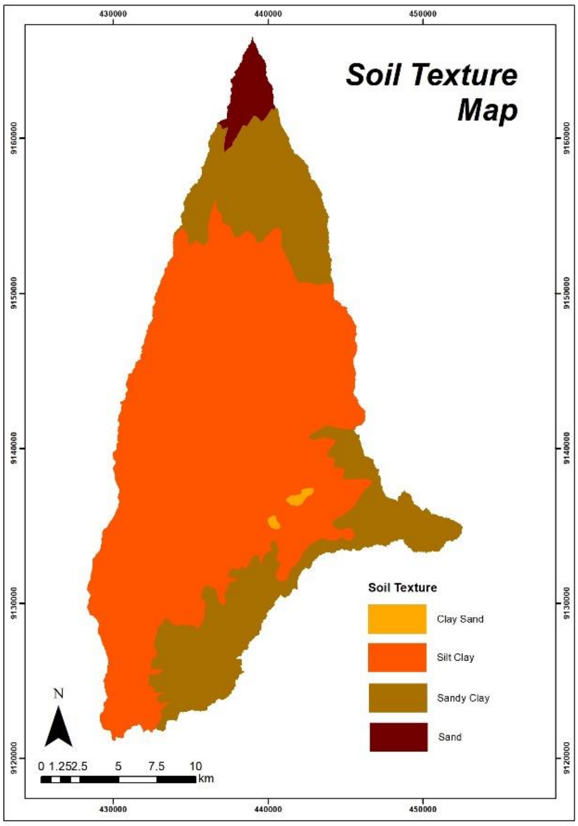

Figure 4. Soil Texture based on Landform approach

3.5. Slope

Slope can be obtained from the processing of elevation data or radar image data or commonly called with DEM data. The slope slope of this research is obtained through SRTM data which is processed and recycled according to the classification according to Cook classification. The slope at the upper sub-watershed Opak ranges from 10% to more than 25%, while the lower part tends to be relatively data with slope slope ranging from 5% to 10% (Fig.5). In the East, there are hills that have a slope similar to the upstream. It shows the variation of the gradual gradient slope from the upstream to the downstream and the eastern to the downstream. Judging from the spread of most of the slope of the slope on Opak sub-watershed relatively flat to choppy.

Table 6. Scoring of Slope

Slope (%)	coefficient of infiltration	Score
< 5	> 0,95	4
5 – 10	0,8	3
10 – 25	0,7	2
>25	0,5	1

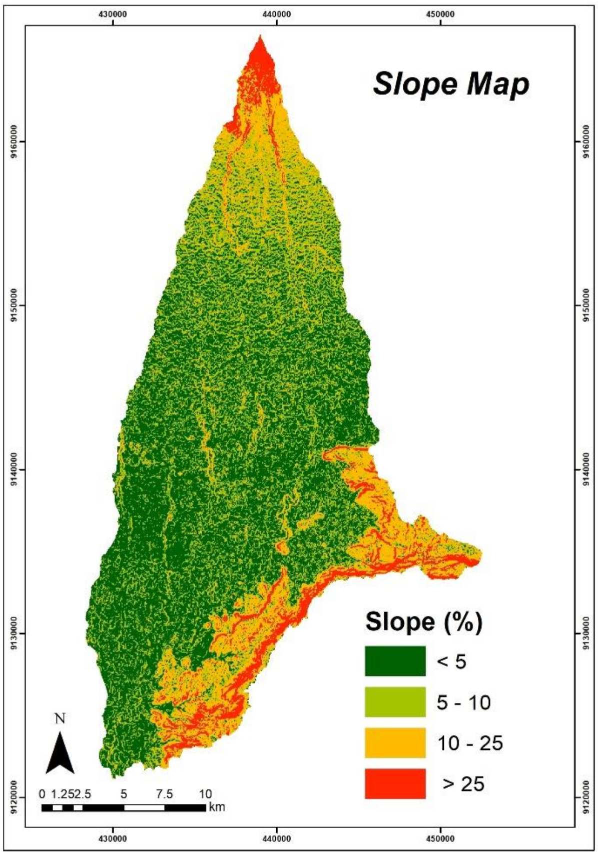

Figure 5. Land Use Map in DAS Opak

3.6. Water Table Fluctuation

Water table fluctuation is obtained through direct measurement of the field in the wells of the settlement. Measurements are made at specified sample points and scattered throughout the Opak sub-watershed region. Groundwater depths vary greatly from 2 meters to a depth of more than 12 meters. The depth of the groundwater level can indicate the level of use or consumption of ground water. In addition, groundwater can show the direction of groundwater flow. Groundwater contours or interpolation results of groundwater using Kriging method indicate that in areas with settled land use the depth of water level is deep enough. This may indicate the linkage of groundwater use to a fairly massive region of acceptance (Fig.6).

Table 7. Scoring of Water Tabel

Fluctuation	Score
> 12	5
8 – 12	4
6 – 8	3
4 – 6	2
< 4	1

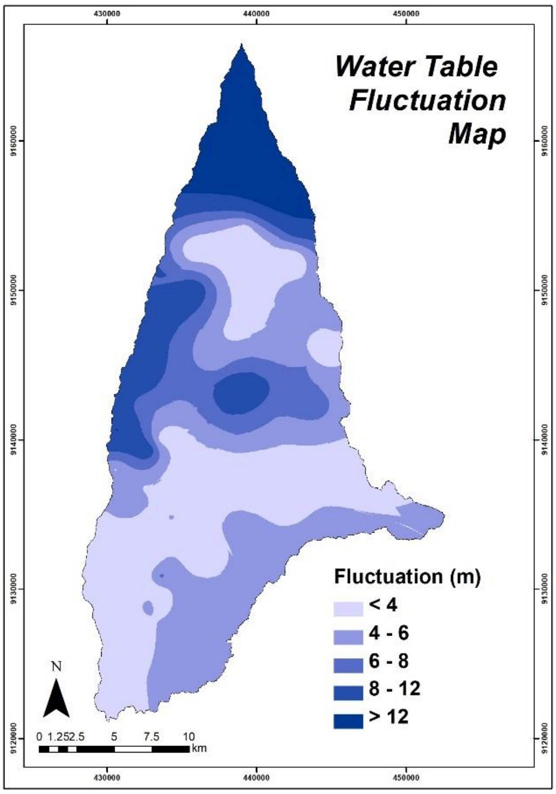

Figure 6. Water Table fluctuation

3.7. Recharge Zone Potential

GIS processing of the parameters used to construct a potential water catchment potential model shows good results. Weighted tiered method based on weighting or weighted literature guidance (Wibowo, 2006) still needs further study, since the weighting still has drawbacks especially on the less detailed geological class on the medium scale. The result of overlay and weighting resulted in 5 potential classes of water catchment area.

The upstream section has the greatest potential for recharge areas, since their supporting parameters are highly suitable as water catchment areas (Fig.7). Texture tends to sand, geologically has a good permeability, high rainfall and adequate land use despite the start of many settlements. This makes the upstream area has the potential for a good water catchment area. At the center of potential water catchment area sebgian large into the category of moderate and on the downstream belong to the category poor. In general, the water catchment maps made based on weighted tiered overlay techniques show good results, but this still needs to be further developed in order to obtain more optimal and accurate results. The weight assessment on each parameter obtained from the literature study still has limitations related to the level of class detail as well as its effect on the potential of water catchment areas.

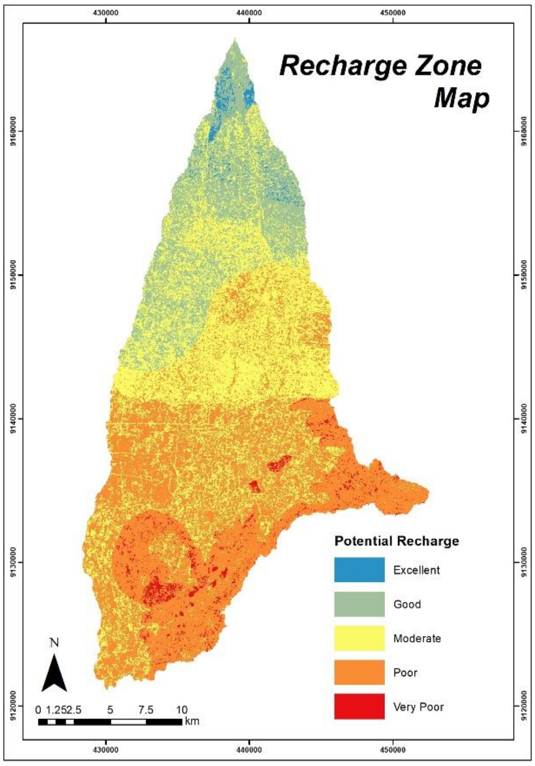

Figure 7. Recharge zone potential map

4. Conclusions

GIS is very helpful in doing the processing of spatial data that has information parameters used to build a model. In addition, remote sensing is also very helpful to perform the primary data extraction quite effectively. Spatial data processing to build a water catchment model needs an in-depth study of the relationship of biophysical characteristics with hydrological properties, since hydrological properties are highly dynamic to biophysical characteristics. Applied GIS in deepening hydrological phenomena can provide a more complete picture because it can be analyzed spatially and the relationships that occur between different locations. A distinct advantage in hydrological research involving applied GIS. In this case, the study of water catchment areas with weighted tiered overalay method can give a good enough result to give an idea of potential or potential model of recharge zone.

In general, Opak sub-watershed has a good potential water absorption potential, especially at the very top. Each influential physical factor shows that the Opak sub-watershed still has good potential, although most Opak sub-watershed should have excellent potential because it is a mofologi upstream area whose function as a place to absorb water. Limitations of this study include the accuracy of each paramater that has not been tested, so the accuracy of the model results built is still not fully used for decision-making. The limited methods in this study are cited in a weighted literature study that refers to a single source. In future work, this research can be developed more optimally to get more accurate results.

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