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EFFECT OF SOIL PHYSICAL PROPERTIES ON SURFACE RUNOFF IN LUKULO UPSTREAM WATERSHED

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ABSTRACT

Lukulo upstream watershed is one of the watersheds in Central Java Province, which passes through 3 districts; Kebumen, Wonosobo, and Banjarnegara. Lukulo upstream watershed has eight sub-watersheds located in areas with diverse topography and lithology. The diversity of topography and lithology affects the characteristics of the area, as does the physical condition of the soil. The physical condition of this soil affects the runoff. Soil's physical properties control rainwater to run off and have important effects on runoff behavior in watersheds. This study aims to determine the physical properties of the soil against runoff in each sub-watershed and each part of the watershed. The method used uses a laboratory, studio, and field approach. The results obtained show that the physical properties of the soil in the Lukulo upstream watershed affect the amount of runoff resistance in the upstream area; in the downstream area the runoff is relatively good. The study also shows two different results. In the Loning watershed, the velocity of downstream runoff is higher than the upstream, while in the Lokidang and Medana watershed, level of surface water flow is lower in the downstream area.

Keywords: *Characteristic, Lukulo Upstream, Runoff, Soil, Watershed*

INTRODUCTION

A Watershed is a place where the process of rainwater becomes an output in the form of runoff, discharge, or sediment. The process in this watershed is a surface response that acts like an operator in changing inputs into outputs (Seyhan, 1977). A Watershed is also a spatial unit in hydrological studies in the form of a basin or reservoir which indicates that rainwater will flow to a lower place (Davie, 2002). Soil conditions are one of the factors that determine water processes that occur on the surface (Sosrodarsono & Takeda, 1978). Soil is one of the key parameters in hydrology, this is because it can control rainwater into runoff and infiltration and has an important effect on runoff behavior in watersheds (Scipal et al., 2005).

Geomorphology is the dominant factor in influencing surface characteristics and affecting the condition of the physical properties of the soil so that it will also affect runoff in a watershed. Each soil characteristic has a deep resemblance to limit layers of water transmission rate, texture, and degree of saturation (Mockus et al., 2009). The analysis of the genesis geomorphological types can be used to know the characteristics of land and

soil mapping units (Chai et al., 2015). Soil analysis based on the landscape is a geographical distribution of soil characteristics that can be used as a unit (Schaetzl & Anderson, 2005; Zinck, 2013). So that the landscape reflects soil geography that is based on soil-forming factors at a scale of analysis (Miller & Schaetzl, 2016).

The upstream Lukulo watershed is one of the watersheds located in the area of 3 district administrations, namely Kebumen Regency, Wonosobo Regency, and Banjarnegara Regency. The physiography of this watershed is in the form of hills, mountains, and valleys between mountains. The upstream Lukulo watershed is located in the Karangsambung Geological Reserve Area which has a diversity of rocks, from tertiary to pre-tertiary rocks (Raharjo, 2010; Raharjo & Saifudin, 2008). Rock diversity affects the speed of runoff. The process of forming the Karangsambung area affects the physical characteristics of the land and the soil that affects runoff. The relatively large rock outcrops at this location make the soil formed thin and greatly affect the rate of runoff. Analysis of soil physical properties in units based on geomorphological units is very necessary to determine the effect of runoff on each sub-watershed and also in the upstream, middle, and downstream areas of the upstream Lukulo watershed.

RESEARCH METHODS

This research was conducted in the upstream Lukulo upstream watershed which is in the Karangsambung. Geological Nature Reserve area. The upstream Lukulo watershed administratively covers the districts of Kebumen, Banjarnegara, and Wonosobo Regencies with coordinates 340,000-365,000 mT and 916.0000-917.5000 mU. (Figure 1). This location was chosen because the upstream Lukulo watershed has very diverse characteristics due to geological and geomorphological factors. Morphologically, most of the upstream Lukulo area is a complex area of hills with steep to very steep slopes. Areas with flat morphology are very limited in their distribution in river valleys

Primary material data such as Landsat-8 imagery, DEM data, Geological Maps, and Indonesian Maps are used as basic data in making characteristic units and determining sample locations. The software used in this study, among others, uses ILWIS for processing spatial data in the form of rasters and QGIS for processing spatial data in the form of vectors. The tools used in the field are GPS, geological compass, meter, and 4-inch tube for sampling. Soil physical properties samples taken in the field, analyzed in the laboratory in the form of; moisture content, porosity, void ratio, saturation, percentage of clay, percentage of silt, percentage of fine sand, percentage of medium sand, percentage of coarse sand, and percentage of gravel.

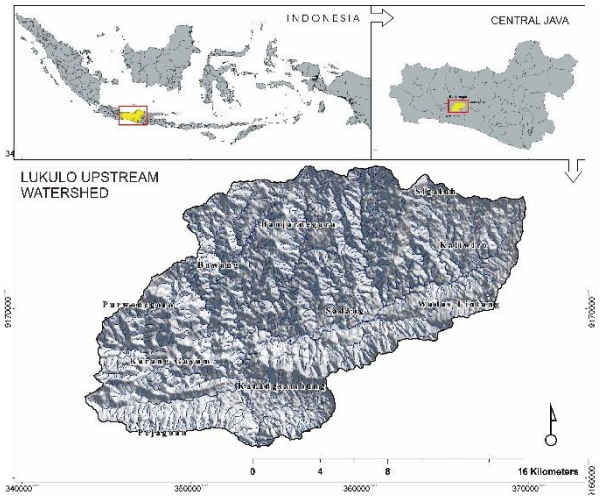


Figure 1. Lukulo upstream watershed research area

The research uses spatial data materials in the form of Landsat-8 images, dem data, and geological maps. The research stages use 2 approaches, namely the laboratory and studio approach and the field stage. At the pre-field stage, spatial data processing is carried out to create terrain units and physical characteristics in each of the upstream Lukulo watersheds. Sampling and field checks to determine physical characteristics were carried out during the field stage.

1. Image Interpretation
   a. Landform morphography
   b. Morphometry

c. Straightness
2. Laboratory
   a. Water content
   b. Porosity
   c. Pore number
   d. Saturation
   e. Texture
3. Field check
   a. Soil drainage conditions
   b. Valley shape
   c. River morphometry

Sampling in this study amounted to 106 samples spread evenly in the upstream, middle and downstream areas, and located in each sub-watershed in the upstream Lukulo watershed. The post-field stage is an analysis of the results from the laboratory to determine the surface's ability to drain surface water

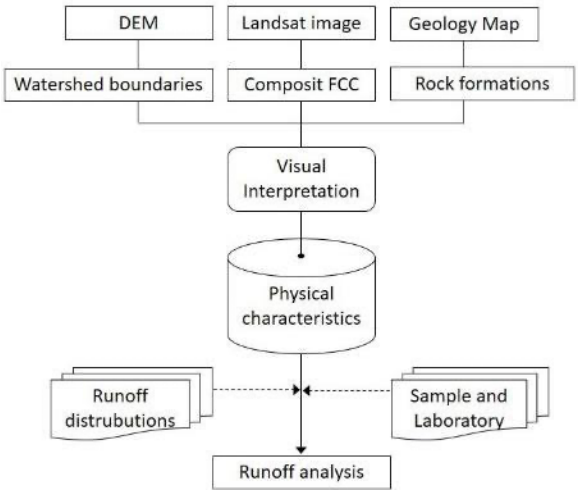


Figure 2. Research flow chart

RESULTS AND DISCUSSION

The physical characteristics of land have similarities in each unit as a function of topography, landform, lithology, soil, and hydrology. The results obtained from the analysis and visual interpretation of the spatial data of the upstream Lukulo watershed obtained units that have similarities in the physical characteristics of the land. In this study, 85 soil samples were taken which were evenly distributed in the characteristic units in each sub-watershed. Samples of each sub-watershed are spread over the upstream, middle, and downstream areas. The upstream Lukulo watershed has 8 sub-watersheds, namely, the Lukulo sub-watershed, the Maetan sub-watershed, the Loning sub-watershed, the Lokidang sub-watershed, the Medana sub-watershed, the Cacaban sub-watershed, the Gebang sub-watershed, and the Welaran sub-watershed (Raharjo, Widiyanto, et al., 2016). The morphometry of the upstream lukulo watershed has a rounded shape so that the runoff flow rate is high and the concentration-time is fast and it will be easy to collect and accumulate in the river system (Raharjo, Winduhutomo, et al., 2016).

This Lukulo subwatershed is part of the upstream Lukulo watershed which is located at the top and has the largest area, which is around 8493.78 hectares. In the upstream area of the Lukulo sub-watershed, the water content level is from 24.40% to 75.70% with an average of about 43.53%. The values of porosity and void ratio have an average of about 69.56% and 1.23, respectively. In these parameters, the porosity has a maximum value of 98.34% and a minimum of 43.82%, while the pore number shows a minimum value of 0.66 and a maximum value of 2.30. The level of soil saturation is at least 32.09% and the maximum saturation is 99.96%. The soil texture shows that most of it are clay loam and clay. The run-off coefficient distribution map for the upstream Lukulo sub-watershed (Raharjo, Winduhutomo, et al., 2016) indicates that the location has a runoff of about 0.40 to 0.6. These data indicate that the upstream Lukulo sub-watershed has a relatively high inundation value. Alluvial plains often experience inundation when there is a flood.

The Maetan watershed is a sub-watershed of the upstream Lukulo watershed which has the smallest area with steep hilly physiography. In this watershed, there is no alluvial plain and is in the melange zone which is pre-tertiary rocks. The water content at that location is around 37.73% with a porosity of 50.5% in the soil pores of 1.02. Soil saturation is about 94.85% with soil conditions with a clay texture of about 74.4% and silt of about 25.6%.

Sand soil texture is not found at this location so the overall Maetan watershed has a soil texture in the form of clay. The runoff coefficient value in this watershed has the highest flow rate when compared to other sub-watersheds in the upstream Lukulo watershed. In the Maetan watershed, the runoff coefficient value ranges from 0.6 to 0.85. The risk of inundation that occurs in the Maetan watershed is relatively small, but because this watershed is located in hilly physiography with thin soil, the possibility of landslides is very high. Landslides in this watershed have a high to very high landslide threat level (Raharjo et al., 2014; Raharjo & Nur, 2013).

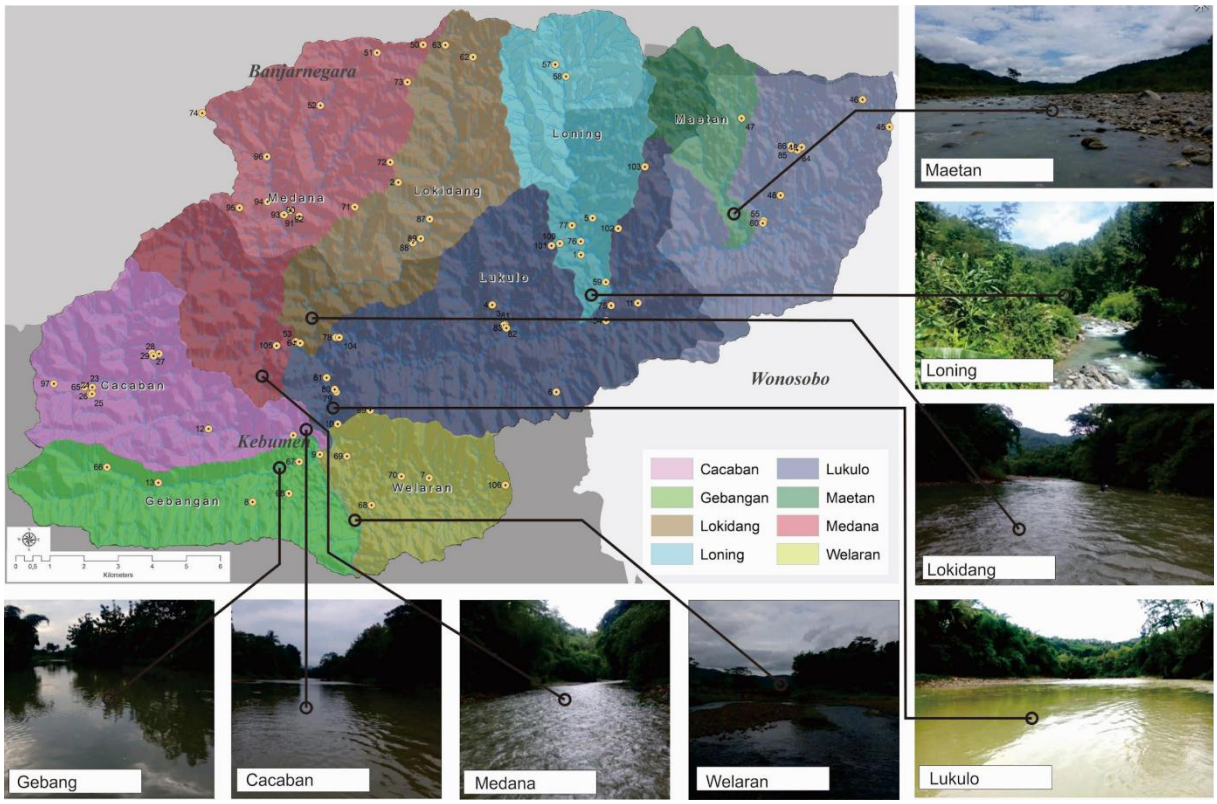


Figure 3. Location of distribution of soil samples in the sub-watershed in the Lukulo Hulu watershed

The Loning watershed has a large area, about 25.92 km2 or about 9.71% of the total watershed area. The Loning watershed has a general soil moisture content of about 42.74% with an overall porosity and pore content of about 73.23% and 1.38, respectively. This high water content and porosity also affect the level of soil saturation on the surface with a value of about 72.83%. In the area above the soil texture in the form of Loam, this soil has a relatively balanced composition of sand, silt, and clay. It has low binding capacity in dry or wet conditions and contains sufficient nutrients and humus. Soil conditions are crumbly and moist, and easily bind water and nutrients making it ideal for use in agriculture. The Loning watershed is a watershed that is still maintained in terms of conservation, this can be seen in terms of water resources (surface and groundwater), the percentage of vegetation cover is still dense, and erosion is relatively small (Raharjo et al., 2019).

The Lokidang watershed is one of the sub-watersheds in the Hulu Lukulo watershed which has a long river segment with an elongated shape. The water content from upstream to downstream of the watershed was 59.77%, 29.895%, and 25.32%, respectively,

but the highest soil porosity was in the middle watershed with an average of 96.02%.

The highest average soil saturation is in the upstream area of the Lokidang watershed, which is around 79.27%. The high soil saturation in the upstream area is closely related to the relatively high understorey vegetation, and the low saturation in the downstream area indicates that this watershed has a relatively low flood threat. However, the Lokidang sub-watershed has a relatively high value of the weighted erosivity index, which is around 1082.62, this indicates that there has been an imbalance of land that has resulted in the criticality of the watershed (Raharjo, 2010).

Table 1. Physical properties of the Lukulo Upstream Watershed

Sub Watersheds	Areas	Average of water content (%)	Average of Porosity (%)	Average of Pore	Average of Saturation (%)	Average of Clay (%)	Average of silt (%)	Sand (%)
Lukulo	upstream	51,99	59,59	1,59	87,15	44,50	37,40	18,09
	middle	40,09	79,07	1,07	74,18	35,57	38,76	25,67
	downstream	37,74	65,49	1,02	79,13	39,63	36,88	23,49
Maetan	upstream	37,73%	50,5%	1,02	94,85%	10.70	22.80	66.50
Loning	upstream	53,86	65,99	1,95	75,32	12,95	38,80	48,25
	middle	39,03	75,65	1,19	72,00	29,28	38,30	32,42
Lokidang	upstream	59,77	66,79	2,02	79,27	12,45	33,90	53,65
	middle	29,89	96,02	0,77	78,34	23,95	24,375	51,68
	downstream	25,32	51,69	1,07	67,11	9,90	36,8	53,30
Medana	upstream	32,60	53,27	1,20	81,88	30,93	46,47	22,60
	middle	32,65	96,91	0,85	98,63	41,56	36,47	21,97
	downstream	27,75	76,10	0,93	71,22	16,00	29,10	54,90
Cacaban	upstream	38,43	62,05	1,32	78,74	39,29	38,73	21,98
	middle	18,17	94,78	0,81	16,43	6,00	23,00	11,00
	downstream	20,11	67,43	2,07	26,77	16,50	42,90	40,6
Gebang	upstream	30,13	75,48	0,88	48,36	23,35	35,20	41,45
	middle	46,2	97,88	0,81	30,79	71,00	16,00	13,00
	downstream	26,13	71,81	0,76	93,68	15,05	22,80	62,15
Welaran	upstream	45,02	97,83	1,19	100,0	26,40	27,10	46,50
	middle	46,54	84,70	1,13	79,26	45,17	30,30	24,53
	downstream	34,75	69,61	1,12	79,99	32,30	33,67	34,03

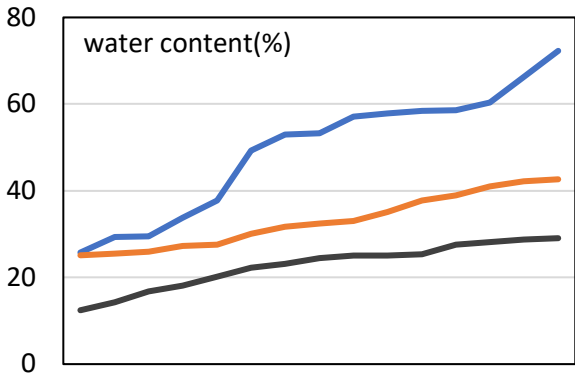
Source: Data analysis and laboratory, 2021

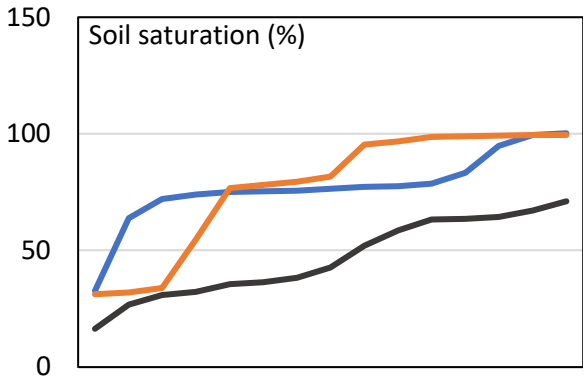
The Medana watershed has an area of 16.21% of the total area of the Lukulo Hulu watershed. The water content in the upstream area of the Medana watershed ranges from 25.55% to 52.93% and the porosity from 41.09% to 64.54% The saturation level is from 63.73% to 99.45% with the soil texture mostly in the form of clay loam. In the middle area, the water content is from 25.11% to 43.27%, while the porosity has a relatively uniform value, with an average of about 96.91% porosity which is higher than at the top. The saturation level of this middle area also has a relatively the same value in each soil sample with an average of about 98.63%. The saturation value of the soil in the middle area

has a higher saturation value than the upstream area. Soil texture in the form of clay about 41.56%, silt about 36.47%, and sand about 21.97%. At the bottom of the Medana watershed, the water content (%) has a small value with an average of about 27.75%, but the relative average porosity value is 76.1%. The Medana watershed as a whole has a low level of surface water flow at the bottom in terms of soil physical conditions. Relatively lower soil saturation and small water content when compared to the other 2 parts provide infiltrated water and higher permeability. While at the top, besides having a steep slope, the physical condition of the soil has a fast drainage rate.

The Cacaban watershed has an area of 116.53 km2 about 10.59% of the total area of the upstream Lukulo watershed. The order of rivers in the Cacaban watershed only reaches order 4 with a level 1 river order of 139 (Raharjo, Widiyanto, et al., 2016). The average surface water content of the top, middle, and bottom of the watershed has a value of 38.43%, 18.17%, and 20.11%, while the porosity is 62.05%, 94.78%, 67.43%. The highest pore number is found in the downstream area with a value of 2.07 and the lowest in the middle area with a value of 0.81.

The water content in the upstream area of the Welaran watershed has a value of about 45.02% with a fairly high soil porosity of about 97.83%. The high porosity is in soils that have pores of 1.19. The soil saturation that occurs is also relatively high, which is around 100.028%. The soil texture in the upstream area (sandy clay loam) of the Welaran watershed has a distribution of about 26.4% clay, 27.1% silt, and 46.5% sand. In the middle area of the Welaran watershed, the average value of water content in the soil is around 46.54% and the value of soil porosity has an average of about 84.70%. The mean pore value is 1.13 with a range of values from 0.89 to 1.42. Soil saturation that occurs in the Welaran watershed in the middle area has an average value of 79.26% with the highest value around 100.24% and the lowest value around 38.27 (sample 7). The clay texture has an average of 45.17%, the silt texture has an average of 30.30%, and the sand texture has an average of 24.53%. The downstream area of the Welaran watershed has an average water content of 34.75% and an average porosity of 69.61%. This situation is in soil conditions that have pores from 0.63 to 1.38 with a total average of 1.12. The state of saturation of the retreat soil is about 79.99% with the soil texture in the form of clay loam. The Welaran watershed in the upstream and middle areas has a high level of soil saturation so the flow rate is also high. This is like the research conducted by Saifudin & Raharjo (2009) that the Welaran watershed in the central area has a function as runoff and not as a catchment.





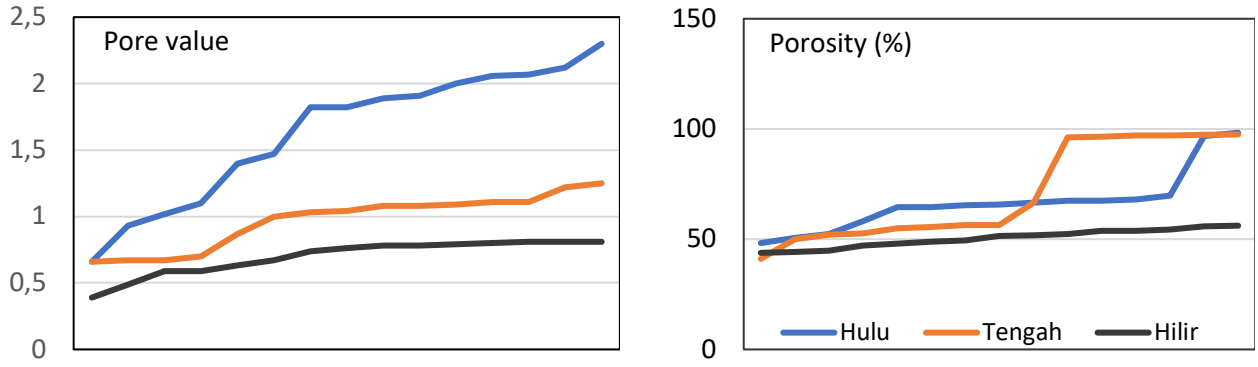


Figure 4. Graph of soil physical properties in each part of the watershed

In the classification of the division of the upstream Lukulo watershed as a whole, from upstream, middle, and downstream, an analysis is carried out to determine the level of drainage in each part. The upstream area has an altitude above 400 meters above sea level, the middle part has an altitude of 200-400 meters above sea level, and the downstream part is 37-200 meters above sea level. In this elevation class, there are also differences in the flow density that occurs in each part (Raharjo, Widiyanto, et al., 2016).

The water content in the upstream Lukulo watershed shows that the highest water content in the soil is in the upstream part, while the next sequence is in the middle and downstream areas. The high water content of the upstream soil indicates that relatively little rainwater can seep into the soil, so the runoff value will be high for the upstream area. High pore numbers are also in the upstream area which will have an impact on high flow rates. At the level of soil saturation and porosity, the pattern that occurs is regular for the upstream and downstream areas, but the pattern for the middle area looks irregular. Irregularities occur in several samples that are in relief with a not so steep slope and are located at the confluence of the main river in the sub-watershed.

CONCLUSION

Soil physical properties are important in determining surface flow conditions, especially in watersheds with thin soil and many rock outcrops. Based on the physical properties of the soil, the Lukulo Hulu watershed affects the amount of surface water resistance in the upstream area, and in the downstream area, the surface water flow is relatively good. In the Loning watershed at the top even though it has a high slope, the water capacity from the porosity side is smaller even though the relative soil saturation is almost the same so that the surface water velocity downstream is higher than in the upstream. The Lokidang watershed has a low level of surface water flow in the downstream area, this also occurs in the Medana watershed.

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