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RESEARCH ARTICLE

ANALYSIS OF BIOPHYSICAL FACTORS AND THEIR INFLUENCE ON INFILTRATION IN SOME LAND USES OF THE ULAKAN SUB-WATERSHED IN THE CENTRAL PART

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ABSTRACT

Biophysical changes in land in sub-watershed areas (DAS) due to uncontrolled population pressure cause a decrease in the biophysical characteristics of the watershed. This has caused the loss of the hydro-organological attributes of the watershed. This can be seen from the frequent surface flows, erosion, and flooding in this watershed area. This condition is also supported by the nature of the watershed morphology in the upstream region, which is steeper than in the middle and downstream parts. This research aims to see the influence of what biophysical properties are dominant in determining infiltration in watersheds. The method used is the land survey method. Soil sampling was done using purposive random sampling, and each land use was based on the slope. The soil samples taken were disturbed and intact soil samples. This soil sample is analyzed in the laboratory to determine the value of the physical properties of the soil (texture, permeability, volume weight, total pore space, organic matter content, soil structure). The infiltration rate was also measured in the field using a double-ring infiltrometer. The data is processed using the Horton model to calculate the infiltration rate. Soil parameter data is processed using the Principle Component Analysis (PCA) model to determine the factors that determine the biophysical properties of the watershed in influencing infiltration in the watershed. The analysis results of all research soil data parameters show that sand and clay fractions, soil structure, and soil density level (volume weight) greatly determine the biophysical character of the central Ulakan watershed. The main soil fraction that influences biophysics is the sand fraction. The highest infiltration rate was found in shrubland compared to mixed gardens. The soil will be saturated in 25-30 minutes.

KEYWORDS

watershed, biophysics, infiltration, land, erosion

1. INTRODUCTION

Biophysical factors are essential in influencing infiltration rates in various land uses. For example, land use changes have been shown to influence surface runoff's spatial distribution significantly (Zhang et al., 2018). This means that changes in land use can cause changes in infiltration patterns, thus potentially affecting the availability and quality of water in the area. Apart from that, the type of vegetation in an area can also influence infiltration. River watersheds in forests, woodlands, and grasslands are the primary source of high-quality water that humans can use because of their ability to infiltrate, store, and channel rainfall efficiently.

Forested, vegetated river basins and grasslands worldwide are the primary sources of high-quality water that humans can use because of their soil, which can infiltrate, store, and channel rainfall rather than quickly drain it into surface runoff. This characteristic is caused by the high infiltration rate, porosity and hydraulic conductivity produced by biological and physical processes in the ecosystem. In addition, hydrogeochemical processes and human activities in an area can also influence infiltration rates. Based on the high level of variable factors, natural hydrogeochemical processes, agricultural fertilizers, and human activities were found to have a significant influence (Li et al., 2021). Overall, it is clear that various biophysical factors, such as land use, vegetation type, and hydrogeochemical processes, play an essential role in influencing infiltration rates across multiple land uses. These factors interact with each other and can vary depending on an area's particular geographic and climatic conditions. The interaction of these biophysical factors is complex and can have significant implications for water resource management. In addition to land use and vegetation type, soil properties also play an essential role in regulating infiltration rates. The texture, structure, and organic matter content of soil can significantly influence the soil's ability to absorb and retain water.

In addition, climatic conditions such as rainfall patterns and temperature variations can further modulate the influence of biophysical factors on infiltration. For example, in regions with high rainfall, the impact of land use change on infiltration may differ significantly from areas with dry climates. Therefore, understanding and measuring these biophysical factors is critical for effective land use planning, water resources management, and sustainable development (Eigenbrode et al., 2018).

One of the Ulakan Sub-watersheds, which is located in the western part of Sumatra, has morphometric characteristics that have steeper river gradients due to the large number of mountainous areas or row hills. Volcanoes greatly influence variations in soil types, such as Andisol or Inseptisol orders. Soil is an essential component that determines the characteristics of a watershed. Among the physical properties of soil that greatly influence soil quality are texture, volume weight, total soil pore space, hydraulic conductivity, infiltration, and soil structure. One of the properties of soil, namely soil structure, greatly determines soil

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erodibility, whether or not the energy of the raindrops easily destroys the soil. The vulnerability of the soil to the impact of rain energy depends on the properties of the soil profile. Soil blades are very fragile, so surface flow easily carries soil grains (Belasri1 et al., 2017). Soil that experiences erosion has the consequence of soil fertility becoming degraded due to many of the nutrients carried by erosion entering river bodies so that sedimentation deposits are formed (Jana Podhrázská et al., 2015). The study also states that the drainage density factor in a river basin greatly influences the rate of soil erosion (Amiya Gayen et al., 2022).

Damage to the biophysical environment of watersheds is faster due to land conversion from forest to land to agriculture, which does not apply soil conservation methods. If surface flows and erosion occur, the organic material content will decrease because it is lost and transported by erosion. Losing a lot of organic material will also cause other soil physical properties to decline, such as volume weight, total soil pores, and soil infiltration (Chase B. Bergeson et al., 2022). It also states that there are changes in soil properties and infiltration rates on land occupied by city residents, which affects surface rainwater runoff—knowing the infiltration rate in various types of soil and several kinds of ground cover plants and the effect on the infiltration capacity of river basins.

The physical properties of soil are the key to determining the quality of land and the environment. Land with good soil physical properties will provide good environmental quality. Good soil physical properties can improve the plant root environment and indirectly facilitate nutrient absorption, making it relatively beneficial for plant growth. Apart from that, the physical properties of soil are closely related to the incidence of erosion and landslides during the rainy season, especially in several sub-districts in the Batang Ulakan watershed. The analysis stated that the area of vegetation decreased, whereas the area of open land and dry land farming increased, causing a decrease in land productivity (Natsir et al., 2009). This research also states that the upstream watershed is a conservation area, the dominant vegetation in the upstream area must be dominated by forest, the upstream area becomes a catchment area, and the upstream area also has a steeper gradient and many tributary networks due to poor drainage Meeting (Asdak 2014). Meanwhile, the middle area is a transition area and has become a buffer to reduce environmental pressure on upstream regions. This research aimed to observe and assess the biophysical properties and patterns of soil infiltration rates in the central river basin, which often experiences hydrological disasters.

2. Materials and Methods

2.1 Description of Research Area

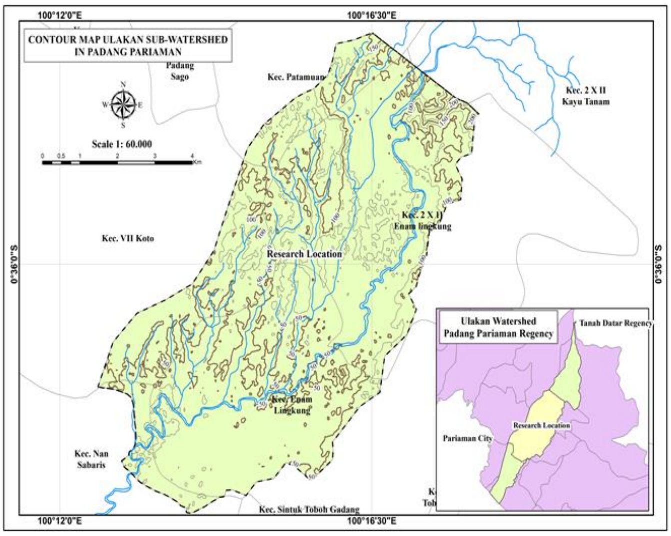

Figure 1: Topography of the research area of the Central Ulakan sub-watershed

In November, the highest is 4127.4 mm/year, and the highest is 762 mm/month. Rainfall is high and evenly distributed from upstream to downstream, often experiencing flooding, erosion, and high sedimentation. Apart from that, floods usually cause people's property to be damaged due to flooding. In terms of conservation, the middle area of the river basin includes buffer areas to reduce pressure on upstream regions. However, with high population growth, population pressure in this area means that hydrological disasters often occur. This is due to the large, sparse, and open land cover.

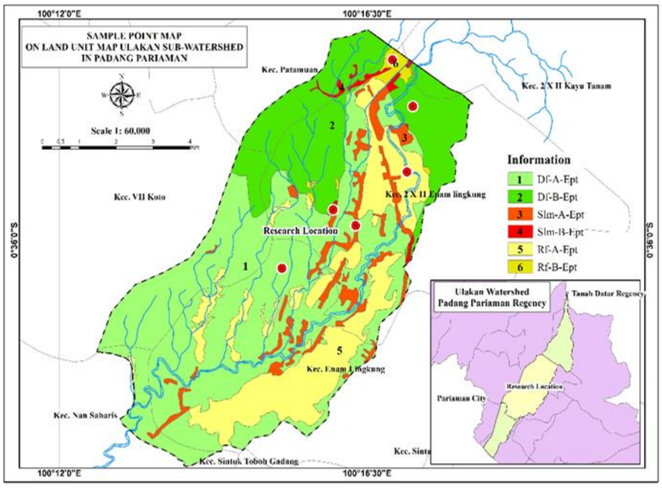

Figure 2: Map of infiltration measurement points and soil sampling in the Central Ulakan sub-watershed

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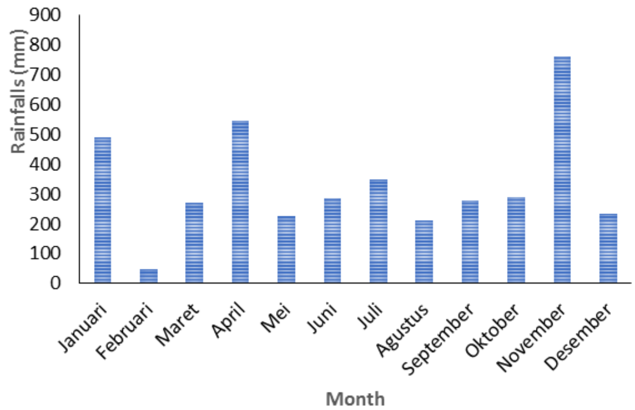

Figure 3: Graph of rainfall in the study area

2.2 Soil Sampling

Soil samples were taken on two slopes, namely 8-15% and 15-25% slopes for three land uses: rice fields, mixed gardens, and shrubs. To analyze soil properties, disturbance samples are taken to analyze soil texture and organic matter at a 0-30 cm depth, determining permeability, volume weight, total pore space with sample rings, and soil structure. This example is explained in the soil laboratory, soil science department at the Faculty of Agriculture, Andalas University. Then, the data is processed and compared with soil property criteria to see whether there are soil properties that exceed the threshold.

2.3 Analysis of soil physical properties

The soil samples' physical properties were analyzed in the soil laboratory of the Department of Soil Science at Andalas University. The physical properties of soil explained are texture, volume weight, total pore space, and permeability. Meanwhile, the chemical properties of the soil described are c-organic soil. The results of soil texture analysis look at the distribution of soil fractions, then group them into texture classes with a soil texture triangle. Meanwhile, soil property variables are averaged and compared with standard soil property criteria.

2.4 Infiltration Rate Measurement

The infiltration rate was measured using a double-ring infiltrometer. The measurement points are the same as the soil sample points for analyzing soil physical properties. Then, this measurement point is marked with GPS

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(Global Positioning System) coordinates. This air infiltration measurement data is processed using the Horton method, an infiltration data processing method whose parameters are obtained directly from the field.

Data processing using the Horton method is expressed mathematically as follows;

$F(t)= fc + (f0 - fc)\ e^{-kt}$

Information :

f = infiltration rate (cm/hour)

f0 = initial infiltration rate (cm/hour)

fc = final infiltration rate (cm/hour)

e = 2.718

k = -1/(m log 2.718)

a) Initial Infiltration Rate (f0)

The initial infiltration rate is calculated from the initial air entry into the soil layer through the soil surface in units of cm/hour.

b) Constant Infiltration Rate (fc)

The constant infiltration rate is the infiltration rate at a particular time (t), and the infiltration capacity value is close to continuous, with units of cm/hour. The fc value depends on the type of soil and surface.

c) Horton's Constant (k)

The value of the constant K can be obtained from the Horton method infiltration capacity curve equation, namely:

$f = fc + (f0 - fc)\ e^{-kt}\ f - fc = (f0 - fc)\ e^{-kt}$

Logarithmized the left side and right side of log (f - fc) = log {(f0 - fc) e-kt} log (f - fc)= log (f0 - fc)+ log e^{-kt}

log (f - fc) = log (f0 - fc) -kt log e -kt log e = log (f0 - fc) -log (f0 - fc)

t = (-1k log e) log (f - fc) + (1k log e)) log (f - fc)

Using the general linear formula, y = mX + C, so:

y = t, m =-1k log e, X =log(f - fc), C = (1kloge)log(fo - fc)

By taking the equation, m= -1/(k log e), then, K = -1(m log e), or K = -1(m log 2.718) or K = -1/0.434 m, where m = gradient .

The difficulty with Horton's method is determining the values of fo and k. The k value can be calculated by observing variations in infiltration with time and plotting in a curve; then, an equation is obtained to obtain the m value. The k value depends on the texture of the soil surface. K = -1/(m log 2.718)

2.5 Relationship Between Infiltration Rate And Soil Physical Properties

To determine the factors of soil physical properties that influence watershed biophysics, principal component analysis (PCA) is used. The PCA method is beneficial if the existing data has many variables and there is a correlation between the variables.

The calculation of principal component analysis is based on the calculation of eigenvalues and eigenvectors, which express the data distribution from a dataset (Karlen et al. 2008). Using PCA, previously n variables will be selected to become k new variables called principal components, with k less than n. Using only k principal components will produce the same value as n variables. The resulting variable from selection is called the principal component (Gewers et al., 2018). PCA is used to explain the structure of the variance-covariance matrix of a set of variables through a linear combination of these variables. In general, principal components (PC) can be helpful for feature selection and interpretation of variables.

3. Results and Discussion

3.1 Rainfall

The climate in the watershed area greatly influences hydrological conditions. One of the climatic factors is rainfall. As a natural input, the rainfall will affect the river basin area. Suppose the land cover or land use is poorly managed in a watershed. In that case, the hydrological response of the watershed to rainfall will also not be good from the aspect of watershed health, for example, high river regime coefficients, flooding, erosion, and river shallowing. Based on data from the Sicincin climate station (2020), rainfall in the Ulakan watershed is shown in Figure 3. It can be seen in the picture that rainfall ranges from 48 mm (extremely dry) in February while the highest rainfall is 762 mm in November. Extreme rain reaching 762 mm in a short time can cause a rapid increase in the volume of water in rivers. If the river system cannot accommodate high volumes of water, the water can overflow into surrounding areas, causing flooding.

3.2 Physical Properties Of Soil

The soil of this research location is classified in the Inceptisol order. The dusty clay texture class dominates the soil texture of this research location. This soil is easy to develop and has already formed A and B horizons. This soil uses mixed garden land, shrubs, and rice fields; the two slope classes have a relatively different fraction distribution but have the same texture class (Table 1). Inceptisol soil has not matured in its development and still resembles its parent material (Hardjowigeno, 1993). The soil in this watershed mostly has a clay or dusty clay texture. This analysis to loose soils have relatively high pores, so these characteristics play a role in the infiltration rate, thereby reducing inundation (Manfaliza et al., 2011). However, inceptisol soil is often vulnerable to erosion because it does not have solid aggregates or a good soil structure to retain water and soil.

Based on the results of the soil sample analysis in Table 2, it can be seen that the soil pores range from 61.75% to 70.70% and include medium criteria. This means that soil with a total pore size of more than 60% has promising implications for letting water into the soil so

that groundwater replenishment can occur properly. We can see the consequences of this in the soil permeability rate ranging from 1.58 cm/hour to 12.05 cm/hour, which falls into the criteria of relatively slow to relatively fast. Ins B Sw and Ins C Sw land has a relatively slow permeability

Tabel 1: Distribution of soil particle size at the point of the research area

Sampling	Soil sample code	sand	silt	clay	Soil textur class
1	Inc B Kc	30	66	3	Silt loam
2	Inc B Sb	38	59	3	Silt loam
3	Inc B Sw	53	43	4	Silt loam
4	Inc C Kc	34	61	5	Silt loam
5	Inc C Sb	25	73	2	Silt loam
6	Inc C Sw	48	46	6	Silt loam

Description: Sw=rice fields,Kc= mixed gardens, Sb=bushes, Inc=inceptisol

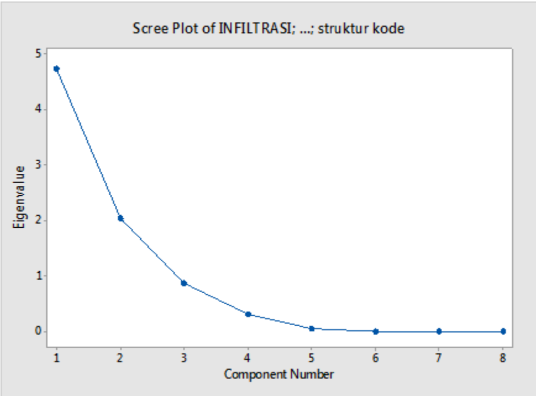
rate because this land is a rice field, where a layer of plow tread has already been formed on the rice field. This layer is formed naturally and functions as a barrier to the rate of water movement into the soil so that rice fields can be flooded. It has clay but is not laminated; most of it is massive and has a weakly developed angular block structure (Mücher, et al. 2018).

Table 2: Physical properties of soil in the central Ulakan sub-watershed

Soil sample code	Bulk density tanah g/cm^3	Soil organic matter %	Total soil pores %	Permeability cm/hour	Infiltration cm/hour
Inc B mix garden	0,92	5,91	63,57	12,05	29,207
Inc B Shrubs	0,76	3,28	70,53	5,90	25,102
Inc B fieldrice	0,88	5,88	65,39	1,82	13,883
Inc C mixgarden	0,99	3,1	61,75	11.61	13,334
Inc C Shrubs	0,93	2,38	64,03	5,25	15,266
Inc C fieldrice	0,75	4,97	70,7	1,58	12,598

3.3 PCA Analysis

Based on principal component analysis (PCA), the soil properties that determine the biophysical properties of the Central Ulakan Sub Watershed are the sand fraction factors (PC1) and soil volume weight (PC2). This is because the eigen value is greater than 1. The absolute value factors that are greater than 1 are PC1 and PC2. The cumulative PC1 and PC2 values can explain variations in soil properties in the Central Ulakan Sub-watershed of 0.845 or 84.5 percent. Proportionally, the PC1 factor contributed 59 percent, and PC2 contributed 25.5 percent. According to researcher PC1 and PC2 each have influenced soil biophysical factors in the Central Ulakan watershed by 84.5 percent (Nasution, 2019). This means that variables from components 1 and 2 can explain the influence of variations in variables on variations in soil quality in potato production centers. The study conducted a PCA analysis on the soil erosion variable (Monitoring and Nosrati 2015). They concluded that an egain value greater than one strongly influenced the value contribution of various variables in several land uses.



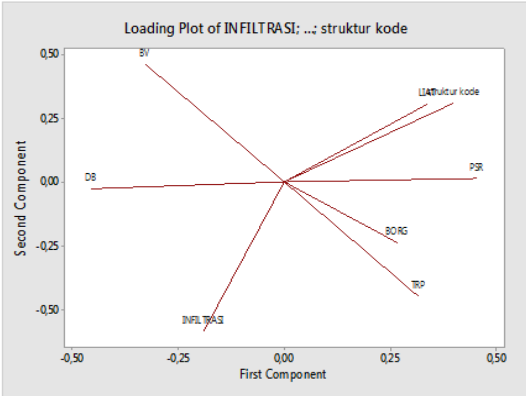


Figure 4 and 5: Screen plot graph and loading plot of the infiltration rate of PCA analysis results

The screen plot also clearly explains (Figure 4) that the eigenvalue is visible, decreasing firmly to component 2 and then sloping to the next component. The main element contributes an influence of 59% by the parameters (clay fraction, structure, sand fraction, organic material, and TRP parameters), which significantly contribute to the main component (Figure 5). Meanwhile, the second component contributed 25.50%, namely parameters (BV, dust, and infiltration. The researchers state that PCA can separate all factors that do not affect the soil through biplot images (Sena et al., 2002). The selected data set for assessing soil quality in Italy also showed that land cultivated for cultivation showed lower soil quality than permanent forest land affects soil components such as sand, silt, and clay (Xiaohu et al. 2022; Marzaioli et al., 2010).

3.4 Infiltration Characteristics

We can see the characteristics of the infiltration rate based on its trend as assessed from simple regression on land use and land slope in the infiltration rate graph (figure 6). On shrubland, it can be seen in Figure 6-7, based on the regression equation, and on scrubland slopes of 8-15% and 15-25%. The infiltration characteristics are shown by graphs (a and b) with the power line equation with a value of R2 = 0 .9761 and R2 = 0.9602. Graph of infiltration rate on a slope at 26 minutes on a slope of 8-15% and 27 on a hill of 15-25%. Ruan off will occur when the soil is saturated at that time.

Eigenanalysis of the Correlation Matrix

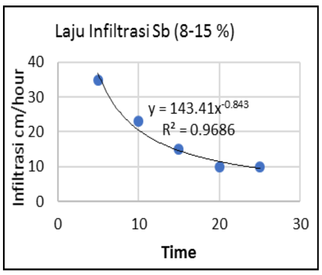
Eigenvalue	4,7224	2,0393	0,8702	0,3164	0,0517	0,0000	0,0000	-0,0000
Proportion	0,590	0,255	0,109	0,040	0,006	0,000	0,000	-0,000
Cumulative	0,590	0,845	0,954	0,994	1,000	1,000	1,000	1,000

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
INFILTRASI	-0,190	-0,584	0,345	0,299	0,180	-0,060	0,220	0,574
TRP	0,316	-0,447	-0,364	0,067	-0,270	-0,202	-0,654	0,149
BV	-0,328	0,461	0,245	-0,077	0,294	-0,242	-0,583	0,360
BORG	0,266	-0,236	0,777	-0,289	-0,066	-0,003	-0,227	-0,361
PSR	0,454	0,013	-0,102	-0,126	0,508	-0,670	0,244	-0,032
DB	-0,455	-0,025	0,068	0,069	-0,522	-0,667	0,139	-0,213
LIAT	0,337	0,307	0,220	0,848	-0,088	-0,042	-0,058	-0,105
struktur kode	0,398	0,309	0,144	-0,277	-0,516	-0,030	0,226	0,575

* ERROR * The covariance matrix is singular; computation cannot proceed.

Furthermore, the characteristics of the infiltration rate in mixed garden land use (Figures 6 and 7). Power infiltration regression equation with values R2 = 0.9885 and R2 = 0.9877). Then, the nature of the infiltration rate in rice fields is shown in (figures 8 and 9). Based on the simple power regression equation of the infiltration rate, the determinant values are obtained (R2) = 0.9908 and R2 = 0.8336. The result shows that the characteristics are greatly determined by the nature of land use, especially on dry agricultural land in the upper reaches of the Sumani watershed (Aprisal et al., 2019). The study also found that the infiltration rate in andisol soil planted with agroforestry farming had a high infiltration rate (Suprayogo et al., 2020). Furthermore infiltration on Semak belukar in figure 10 and 11 with rate infiltration show determinated with R2=0,9761 and R2= 0, 9602.

Infiltration rates in several land uses and land slopes range from 12,598 cm/hour to 29,207 cm/hour. Based on the criteria, the range of infiltration rates is classified as fast to very fast. When viewed from the water absorption in the central Ulakan sub-watershed, it is classified as good. To analysis state that this infiltration rate will usually reach equilibrium with increasing time (Aprisal et al., 2018). Furthermore, Minister of Environment and Forestry, 2022, in forestry regulation no.32. 2009, states that the catchment area based on the infiltration rate is divided into six groups.



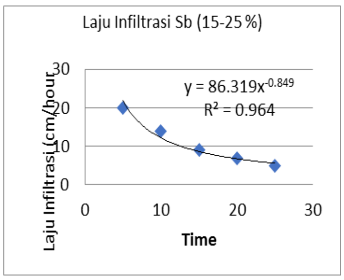


Figure 6 -7: Graph of infiltration rates on slopes 8-15 and 15-25 use of shrubs

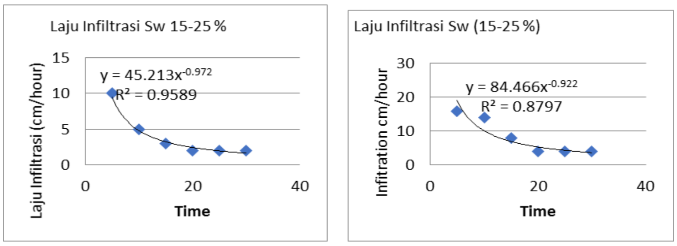


Figure 8-9: Graph of infiltration rates on slopes 8-15 and 15-25 use of field rice

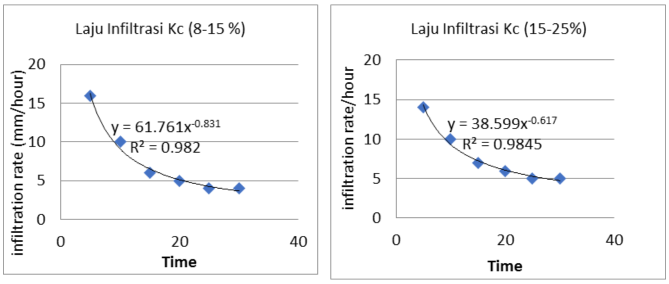


Figure 10-11: Graph of infiltration rates on slopes 8-15 and 15-25 use of mix gardens

Soil is an essential factor that influences water absorption. Soil properties such as texture, structure, porosity, and infiltration ability determine how well the soil absorbs water. Soil with a coarse texture, such as sand, has high porosity and good infiltration ability, so it tends to have fast water absorption. Meanwhile, soil with a fine texture, such as clay, has low porosity and slow infiltration ability, so it has slower water absorption. In addition, soil structure also plays a vital role in water absorption. Soil with a good structure, such as neatly arranged aggregates, will have more prominent and more connected pores, facilitating water flow and increasing water absorption. Apart from that, the infiltration ability of the soil is also influenced by the presence of stabilizing agents. Stabilizing agents can improve the mechanical properties of soft soil and increase its bearing capacity, thereby increasing the ability of soil infiltration and water absorption (Zhuang et al., 2013). The study to vegetation also plays an important role in reducing the rate of surface runoff (Tareke, 2020). Vegetation, through its root system and aboveground biomass, can increase surface roughness and reduce the velocity of surface water flow. This helps slow down water flow, allowing more time for water infiltration into the soil

4. Conclusion

Based on the research results, there are several conclusions, namely that the central part of the Ulakan sub-watershed has biophysical properties, mainly the soil is dominated by a dusty clay texture, with a speedy infiltration rate in the use of scrubland on slopes of 8-15% and 15-25%. Then, in the use of mixed plantations and rice fields, the infiltration rate is relatively fast. Based on PCA analysis, the biophysical condition of the soil is primarily determined by the sand fraction and soil density (soil volume weight). Constant infiltration in the Ulakan sub-watershed ranges from 25 to 35 cm/hour. At that time the ground is saturated and if the rain continues, surface flow will occur, which is the beginning of a flood.

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