

RESEARCH ARTICLE

THE ROLE OF LAND USE COMPOSITION ON SURFACE FLOW UPSTREAM OF THE SUMANI WATERSHED

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ABSTRACT

The Sumani Watershed plays a critical role in maintaining hydrological balance and water resource management. This study evaluates the effects of different land use compositions—forests, agriculture, settlements, and rice fields—on surface runoff using the Soil Conservation Service Curve Number (SCS-CN) model. Rainfall and soil properties, such as texture, organic matter, and infiltration rates, were analyzed to determine their impact on runoff generation. Soil samples showed that forests had the highest infiltration rate (up to 81 mm/h), significantly reducing surface runoff, while settlements with compacted soils had the lowest infiltration rate (28.97 mm/h), contributing to the highest runoff. SCS-CN analysis revealed that settlements contributed 77% runoff, compared to only 35% in forested areas. These findings emphasize the importance of sustainable land management practices, such as reforestation and improved soil conservation techniques, which can potentially reduce surface runoff by 30% in critical areas. This research contributes valuable insights for the development of sustainable land-use strategies and watershed conservation planning, particularly in tropical regions.

KEYWORDS

runoff, land use, soil properties, infiltration, SCS-CN method

1. INTRODUCTION

Land use changes from vegetation areas to impermeable surfaces can have a significant impact on hydrological processes within watersheds (Yusuf et al., 2021). Improper land use, such as the conversion of forests to plantations or agriculture without considering soil conditions, can lead to increased erosion and sedimentation in downstream areas (Syahdiba and Kusumandari, 2021). Deforestation and land-use change that ignores conservation principles can also disrupt the hydrological cycle, reduce groundwater recharge and increase surface runoff (Pambudi, 2019). The Sumani Watershed, located in Indonesia, is no exception to this challenge, as it faces problems related to land degradation and its impact on surface runoff (Savitri and Industry, 2020). The upstream Sumani watershed is an area that has an important role in maintaining the balance of the Sumani watershed. This is because the upstream part of the watershed is a conservation area, and a water catchment area. Therefore, the composition of the land use must be maintained, and in accordance with the conservation status, the forest veto must be maintained by more than thirty percent. In addition, the upstream area of the Sumani watershed also has a slope that is sloping to very steep, because the upstream area is Mount Talang, whose tributaries come from the foot of Mount Talang. Furthermore, the upstream area also has the capital of Solok regency, namely Aro Suka.

The current development of this area is getting more crowded and there are many areas built for settlements, offices, trade and services, as well as other public facilities and infrastructure. This has resulted in an increase in land use intensity in the upstream Sumani watershed area (Mukhtar, 2015). The increase in impervious surfaces due to this development can

lead to a greater volume of surface runoff, which can contribute to downstream flooding and water quality issues (Yusuf et al., 2021). In addition, community activities such as agriculture and plantations in upstream areas, which are not supported by proper soil and water conservation techniques, will also contribute to surface flow (Putri et al., 2014; Sujarwo et al., 2020). Therefore, it is crucial to understand the contribution of land use to surface runoff in the Sumani watershed in order to develop appropriate mitigation strategies. Land use and land management have a tremendous effect on the soil by triggering processes such as detachment and soil dislocation (Dotterweich, 2013). Soil released and mobilized through water erosion is usually transported to the lower slope and deposited within the catchment area or directed to adjacent waters. Soil can be mobilized as rill, interrill, ditch, tillage erosion, or landslide (Scheper et al., 2024). Especially in the mountainous agro-ecosystems, the combinations of steep slope and rainfall intensity provided favorable conditions for soil erosion to cause surface runoff and sediment migration occurred (Long et al., 2024).

The Soil Conservation Services Curve Number Method is a method used to produce surfaces that are based on land use type, soil composition, and previous wet conditions. This SCS-CN technique calculates the maximum retention potential and the corresponding curve number to determine the amount of surface flow resulting from a given rainfall. In this analysis, the SCS-CN method is applied to the Sumani Sub Watershed by utilizing spatial data on land use, soil type, and topography. The first problem is the possible relationship between initial abstraction and maximum potential retention. The second is the determination of maximum potential retention, which is also closely related to the CN estimation (Kang and Yoo, 2020). Land use maps and soil types are then superimposed on the sub-

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watersheds taking into account the slope, as these key factors affect the runoff potential. The coefficient of the Curve Number in the SCS-CN model. The difference is that the rational model uses the rain intensity factor in determining the coefficient value, and the SCS-CN model uses the previously known groundwater content condition called AMC. Estimation of peak discharge using rational models and SCS-CN (Rasional et al., 2012).

2. RESEARCH METHODOLOGY

2.1 Research Location

This research was conducted in the Sumani Sub-watershed located in West Sumatra Province, Indonesia, with an area of 12,837.54 ha. Geographically, the research location is at 100°32' East Longitude to 100°40' East Longitude and 0°52' South Latitude to 0°56' South Latitude. This sub-watershed is a conservation area on the slopes of Mount Talang which has a topography that varies from gentle to very steep. The research location includes forests, mixed gardens, rice fields, bushes, and settlements that are growing rapidly along with the development of the capital city of Solok Regency.

2.2 Research Design

This research uses a descriptive survey method with a quantitative approach to analyze the effect of land use composition on surface flow. Data were collected through field surveys and laboratory analysis, and combined with rainfall data from local rainfall stations.

2.3 Soil Sampling

Soil sampling was carried out using purposive sampling to represent each type of land use in the Sumani Sub- watershed. The soil samples taken include:

Disturbed soil samples: Taken using a soil drill at a depth of 0–30 cm for analysis of soil texture and physical properties.

Intact soil samples: Taken using a sample ring to measure soil infiltration and permeability in the laboratory.

2.4 Infiltration Measurement

Soil infiltration was measured directly in the field using the double ring infiltrometer method. Measurements were taken at each sample point representing the type of land use to ensure accuracy.

2.5 Rainfall Data

Rainfall data were obtained from two local rainfall stations, namely the Aro Suka Rainfall Station and the Twin Lakes. The data used covers the period 2014 to 2022 to ensure representation of annual climate variations.

2.6 Soil Data Analysis

- Soil samples were analyzed at the Soil Laboratory of the Faculty of Agriculture, Andalas University with the following parameters:
- Soil texture: Using the pipette method to determine the percentage of sand, silt, and clay.
- Soil specific gravity.
- Soil permeability.
- Soil organic matter content.

2.6 Surface Flow Calculation with SCS-CN Method

Surface flow calculation is done using the Soil Conservation Service Curve Number (SCS-CN) method. The basic formula used is:

$$Q = (P - I_a) \frac{2(P - I_a) + S}{S}$$

Where:

- Q = surface flow volume (mm),
- P = rainfall (mm),
- I_a = initial abstraction, assuming I_a = 0.2S I_a = 0.2S I_a = 0.2S,

S = potential maximum retention (mm). The S value is calculated based on the curve number (CN) determined from the type of soil, hydrological conditions, and land use. CN is determined using a standard table by considering soil texture, land cover, and previous soil moisture factors.

From empirical research, it is obtained, that S can be guessed by the equation

$$S = \frac{25400}{CN} - 254$$

CN is a curve number whose value ranges from 0-100. The CN value can be calculated based on a procedure made by considering the type of soil related to the rate of soil infiltration, land cover or use in a watershed and the content of groundwater Mc Cuen (1982). This number expresses the influence of soil conditions, hydrological conditions, and previous water content. These factors can be assessed from land surveys, local research, and land use maps. Table 2 is a compilation of CN tables that show CN values for various soil uses, treatments, and hydrological conditions. The parameter S representing the maximum retention potential depends on the soil-vegetation-land use complex of the catchment area and also on the antecedent soil moisture conditions in the catchment area just before the onset of the rainfall event. This variable is expressed in the form of a dimensionless CN parameter, known as a curve number, according to the relation.

2.7 Data Processing

Rainfall data is analyzed to calculate monthly averages and annual distributions.

Soil parameters are compared between land uses using descriptive statistical analysis.

The relationship between soil texture, infiltration, and surface runoff was analyzed using simple linear regression.

Principal Component Analysis (PCA) was used to determine the dominant variables affecting surface runoff.

2.8 Maps and Data Visualization

Topographic maps, land use, and sampling points were created using GIS (Geographic Information System) software to assist in spatial data visualization. Spatial data were superimposed to generate a surface runoff distribution model based on land use variations.

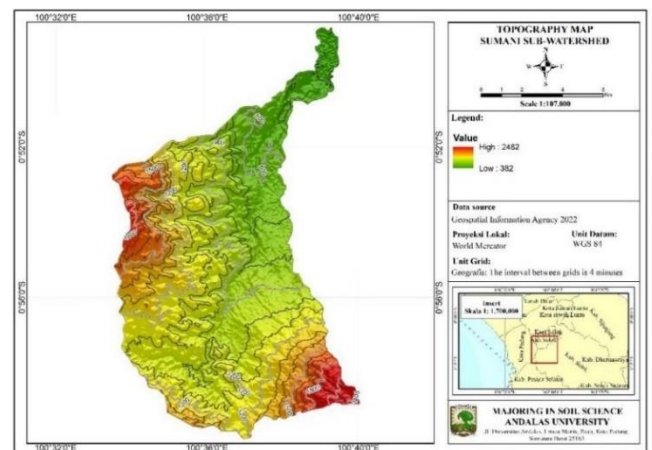


Figure 1: Topographic map of the Sumani sub-watershed research location in West Sumatra.

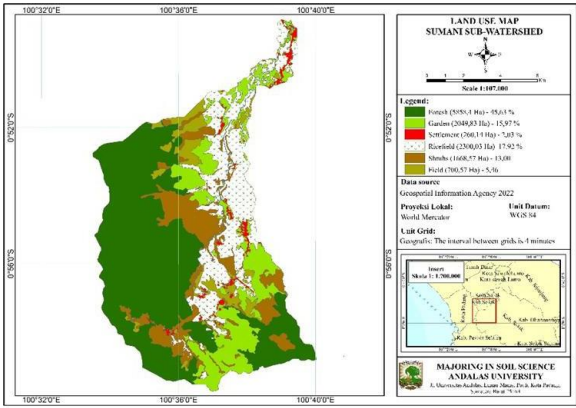


Figure 2: Landuse map at the Sumani sub-watershed research site in West Sumatra.

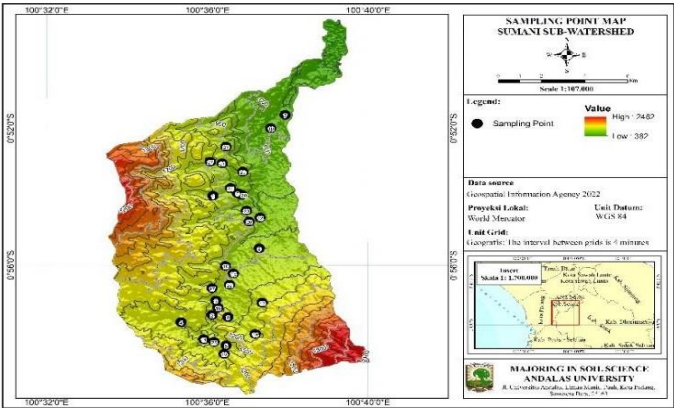


Figure 3: Map of sampling points of the Sumani sub-watershed research location in West Sumatra.

3. RESULTS AND DISCUSSION

3.1 Rainfall In The Study Area.

Rainfall in pnelitian locations is included in wet areas because in areas the total amount of rainfall every month is more than 100 mm and some are more than 600 mm, namely 635 mm in months (Table 1). The distribution of rainfall will affect the amount of surface flow that occurs. This is because the total amount of water that enters the watershed system will saturate the soil quickly. If the soil is saturated quickly, surface flow on the land will also occur immediately (Amalia et al., 2019).

In summary, the SCS-CN analysis of the Sub Das Sumani watershed revealed that several key factors, including soil texture, land use, and slope, influenced the surface runoff. The dominance of fine-textured soils increased built-up and agricultural areas, and steep slopes all contributed to higher surface runoff rates. To effectively manage the watershed and mitigate potential flood risks, it is crucial to consider these factors and implement appropriate soil and water conservation measures, such as promoting vegetation cover, improving infiltration, and adopting sustainable land management practices (Ardana et al., 2021).

Table 1: Annual rainfall from 2014-2022 at the research site

Moon	2014	2015	2016	2017	2018 mm	2019	2020	2021	2022	Total
January	106	153	185	311	129	180	116	173	131	1484
February	38	79	249	198	152	143	202	33	54	1148
March	114	116	278	97	210	100	108	277	119	1419
April	189	389	249	196	219	130	228	183	93	1877
May	340	173	150	287	172	132	344	301	109	1958
June	204	84	127	85	161	203	274	188	271	1700
July	94	114	122	115	111	95	186	83	128	1048
August	227	112	244	243	186	51	92	256	147	1558
September	198	73	128	250	259	217	215	241	225	1678
October	239	51	217	157	512	186	259	228	267	2126
November	470	513	392	668	449	194	290	149	635	3760
December	375	288	423	376	347	299	102	468	239	2917

3.2 Biophysical Properties Of Soil

The bio-physical properties of the soil play a crucial role in determining its ability to absorb and retain water. Factors such as soil porosity, organic matter content, and soil structure all affect the rate of infiltration and groundwater holding capacity. The analysis reported that the combination of tillage and mulch application improved crop yields, soil organic carbon, moisture content, aggregate stability and infiltration rate, reduced soil

evaporation, and soil bulk density and moderated soil temperature (Selolo et al., 2023). In the context of river area development, understanding soil characteristics is essential to find effective ways to keep the soil clean and stop erosion. Additionally, implementing techniques to conserve forests, such as felling trees and replanting, can help improve forest health and air quality, which will ultimately have a greater impact on ecosystems in river areas. The biophysical properties of the soil of the Sumani sub-watershed are as shown in Table 2.

Table 2: it can be seen that the upstream Sumani sub-watershed area is dominated by by forest use, gardens

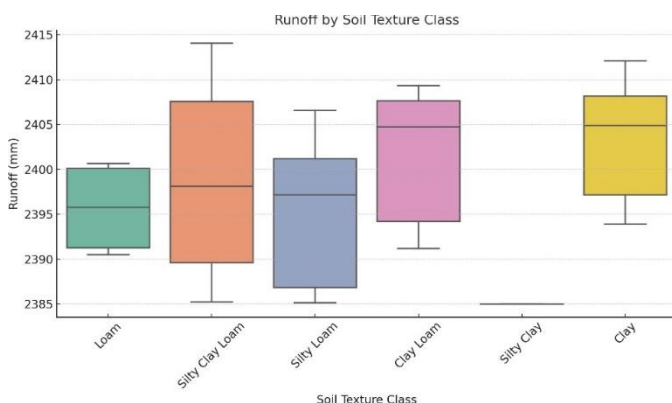
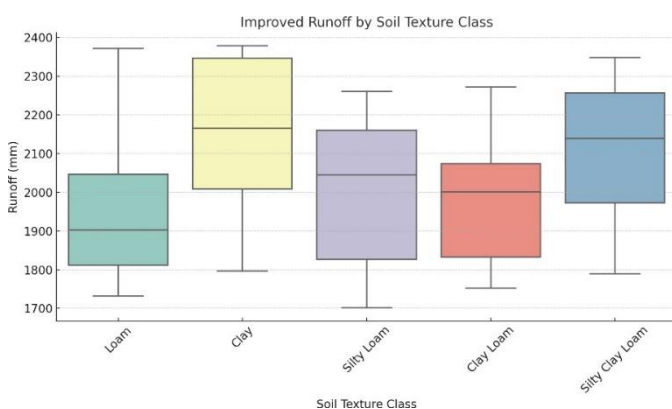
Land Use	Sand (%)	Silt (%)	Clay (%)	Texture Class	Infiltration Rate (mm/h)	HSG	AMC	CN
Forest 1	14.00	46.39	39.61	Silty Clay Loam	76.62	A	II	36
Forest 2	17.27	54.39	31.22	Silty Loam	81.00	A	II	35
Forest 3	12.59	50.40	39.11	Silty Clay Loam	72.80	A	II	36
Forest 4	10.86	49.55	41.40	Clay Loam	79.26	A	II	35
Garden 1	16.85	53.53	32.60	Silty Loam	95.79	A	II	67
Garden 2	17.18	46.63	37.06	Loam	76.27	A	II	61
Garden 3	28.12	47.76	28.61	Loam	76.27	A	II	60

Table 2(Cont.): it can be seen that the upstream Sumani sub-watershed area is dominated by forest use, gardens

Settlement	21.70	33.05	51.30	Clay	28.97	C	II	77
Rice Field 1	11.98	43.65	46.37	Silty Clay Loam	45.25	D	II	84
Rice Field 2	10.27	42.82	46.62	Silty Clay Loam	57.42	D	II	84
Shrubland 1	30.59	51.30	21.42	Loam	75.68	B	II	45
Shrubland 2	23.20	50.70	29.97	Silty Loam	70.59	B	II	57
Shrubland 3	19.49	43.77	39.99	Loam	74.64	C	II	63
Field 1	11.27	39.13	51.48	Silty Clay Loam	30.26	D	II	85
Field 2	18.78	44.13	40.22	Loam	35.45	C	II	45

3.3 The Role Of Soil Texture On Surface Flow.

Soil texture is one of the important components that affect surface flow. Soils with fine textures (clay and clay) have a greater ability to hold water compared to gravelly or sandy soils (Abas and Hashim, 2014). The results of soil texture analysis show that the Sumani Sub Watershed area is dominated by soil with clay texture and clay clay. When connected with water absorption by the soil matrix, the fine-textured soil absorbs and overwhelms the soil (Figure 4). This is because the soil is dominated by micro soil pores. Furthermore, the research data was analyzed using the matching method. However, it should be noted that soils with large pores such as sandy soils have a higher infiltration capacity than soils with small pores, so the ability to absorb and store water is also greater. Land use greatly affects the amount of surface flow, because each type of land use has different characteristics in retaining rainwater (Figure 5). Areas with dense vegetation land cover will have a low runoff coefficient value compared to areas dominated by built-up or agricultural land (Miardini et al., 2016). SCS-CN analysis shows that there is an increase in surface flow in the Sumani Sub Watershed due to land conversion. The increase in built-up and agricultural areas will cause an increase in the surface flow coefficient. This increase is due to the increase in waterproof area and the decrease in the ability to infiltrate rainwater into the soil.

**Figure 4:** Relationship of soil texture class to surface flow**Figure 5:** Relationship of soil texture class with increased surface flow

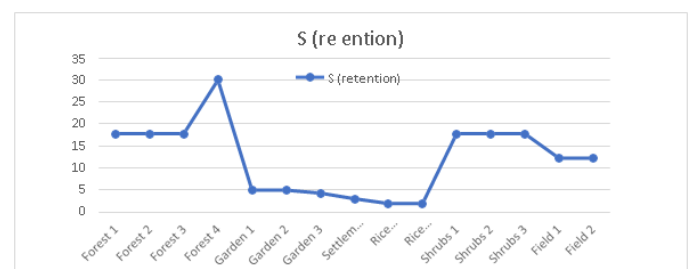
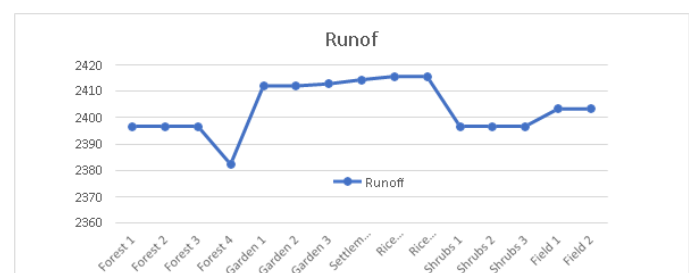
3.4 Groundwater Retention

Groundwater retention is the ability of the soil to store water absorbed from rainfall or irrigation. Groundwater retention capacity is the maximum amount of water that the soil can store at field conditions without flowing out as an underground water stream. These two concepts are important in

the fields of hydrology, agriculture, and water resource management. Groundwater retention occurs when water enters the soil and is stored in the pores of the soil (Souza et al., 2023). The depth distribution of soil organic carbon (SOC) is governed by the interaction of many ecosystem features, including differential C inputs in shallow and deep soils and the redistribution of C via water flow through the profile. Factors that affect groundwater retention include: Soil type: Fine-textured soils such as clay have better water retention capabilities than coarse-textured soils such as sand (Figure 6). Soil structure: A good soil structure with stable aggregates can improve the soil's ability to hold water. Organic matter content: Soils with a high organic matter content have a better water retention capacity because organic matter helps to form micropores that hold water. shows how the runoff ratio, the fraction of precipitation that emerges as runoff, depends on the soil moisture content. Soil moisture content must exceed the threshold before significant runoff occurs. Figure 4 shows the relationship between groundwater depth and runoff at two different hillside locations which also shows threshold behavior, with runoff more closely related to groundwater depth near the river than on higher hillsides (Seibert et al., 2003). Several factors affect groundwater retention. According to Hu and Si (2014), other important parameters that are directly related to soil properties are soil moisture content, and climate. In addition, land use and topography factors also greatly affect groundwater retention (Magdić et al., 2022).

3.5 Surface Flow

Surface flow in various land uses in the upstream Sumani sub-watershed, it can be seen that the land has the lowest surface flow compared to other land uses (Figure 7). According to (Blanchy et al., 2023). The synthesis showed that the amendment of organic soil and the adoption of practices that maintain soil pore cavities that function to regulate soil aerase contain groundwater content. This soil organic carbon comes from soil biological processes. The effect is also the formation of loose soil aggregates so that it can increase groundwater absorption or infiltration. Factors can reduce surface flow. The development of aggregates or soil structures greatly affects all activities in the soil and the balance between infiltration with surface runoff as well as drainage and retention of groundwater

**Figure 6:** Relationship between groundwater retention and land use**Figure 7:** Relationship of landuse to surface flow

The physical characteristics of the soil, such as porosity and texture, also affect surface runoff. Soils with more pore spaces tend to have a higher rate of infiltration, while fine-textured soils tend to have fewer pore spaces. This is consistent with the statement that the permeability or ability of the soil to allow water to pass through it is related to the texture of the soil (Mulyono et al., 2019). Coarse-textured soils, such as sand, have higher permeability compared to fine-textured soils such as clay. The high soil infiltration capacity can be reduced due to soil compaction, which reduces the total soil porosity. In addition, the slope of the soil also affects surface runoff, with steeper slopes generally having a higher rate of surface runoff. Based on the analysis, it was found that the increase in built-up areas and agricultural land in the Sumani Sub Watershed caused (Rolia et al., 2022; Auliyani, 2018; Sonora et al., 2022; Dahliaty et al., 2020).

3.6 Principal Component Analysis

i. Eigen analysis of the Correlation Matrix

The results of the main component analysis (PCA) presented in Table 3 show that the eigenvalue is an overview of the degree of influence of each variable on the variables that affect the runoff of the Sumani sub-watershed. Determinants that have an eigenvalue greater than 1 are retained, while those that are less than 1 are excluded from the model. From Table xx, the eigenvalues greater than one are in PC1 and PC2. Both PC1 and PC2 have explained 83.7 percent of the variation of variables to runoff in the Sumani sub-watershed. The contribution was

55.4 percent PC1 and 28.3 percent PC2, respectively. Previous research The eigenvalue shows the contribution of a factor to the variance of all origin variables. Only factors that have a variance greater than 1 are included in

the model, while those that are less than 1 are not good because the origin variable is already standardized, with a mean and variance of 0 and 1 (Aprisal et al., 2019). Furthermore, major component analysis (PCA) is a general methodology for calculating the determining factors of several variables (Martín-Sanz et al., 2022).

Table 3: The results of the eigenvalue calculation on the soil biophysical at the upstream of Sumani sub-watershed

Component	Eigenvalue	Proportion	Cumulative
1	3.8764	0.554	0.554
2	1.9835	0.283	0.837
3	0.9214	0.132	0.969
4	0.1723	0.025	0.993
5	0.0461	0.007	1.000
6	0.0003	0.000	1.000
7	0.0000	0.000	1.000

Table 4: The loading matrix value from analysis of soil biophysical properties

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Sand	0.138	0.475	-0.713	0.241	0.050	-0.432	-0.001
Dust	0.409	0.277	0.393	-0.569	0.091	-0.519	-0.001
Clay	-0.367	-0.473	0.147	0.268	-0.064	-0.737	-0.001
Infiltration	0.366	0.290	0.494	0.718	-0.148	0.004	-0.000
CN	-0.430	0.324	0.213	0.108	0.808	0.018	-0.007
S	0.424	-0.377	-0.114	0.098	0.400	0.008	0.704
Runoff	-0.424	0.377	0.115	-0.095	-0.388	-0.010	0.710

Based on the results of PCA, the loading matrix shows that 2 factors (PC) with eigenvalues greater than 1 are PC1, and PC2. According to each PC describes some variation (%) in the total data set, and the percentage gives weight to the variables selected under a particular PC. Furthermore, 2 factors have a greater influence on runoff in the Sumani Sub Watershed. From the analysis of PC1 and PC2: PC1 (x-axis) captures the main variations in the data, driven largely by infiltration, runoff, and soil texture (sand and clay). This suggests that PC1 explains the differences in how land cover and soil texture affect water infiltration and surface runoff. PC2 (y-axis) describes the secondary variation in the dataset. The contribution of

dust (dust) and its proximity to S (Potential Retention) on the y-axis suggests that dust particles may be related to soil retention capacity and small variations in surface runoff. This study show the water retention characteristics of the silt specimens with treated with xanthan gum, gellan gum, and guar gum, respectively increasi (Wang et al., 2023). The researcher conducted a meta-analysis of 939 observations to measure the effect of biochar on the retention capacity of groundwater with different textures (Wei et al., 2023).

ii. Relationship between contributing variables in runoffs

In the biplot in figure 8, you can see the variables "Runoff," "Infiltration," "CN," "Clay," "Dust," and "Sand." "Sand" and "Dust," S are in the same quadrant and close together. This means that the variables of sand, dust, infiltration and water retention contribute greatly to the high and low runoff. The infiltration and dust variables have arrows in the same direction and are closer. This suggests that the two variables may be positively correlated in the dataset. Dust is a smooth fraction with no capacity and incapable of making ligament without adhesive content therefore, it will be easy for erosion to occur on the surface flow (Darlah et al. 2003). In addition, the loamy fraction has the capacity and capable of creating a ligament. Therefore, this fraction will be hard difficult to undergo erosion compared to the dusty fraction. The land which is dominant by loamy fraction will be very cohesive and hard to get ruined. The Organic Substance relation with erodibility (Aprisal et al., 2020). Furthermore

compared to the horizontal absorption, the vertical infiltration is more in line with the soil water movement. Most analytical methods were developed to solve the vertical infiltration by the linearized Richards equation or some assumptions of infiltration parameter (Fangliang et al., 2024).

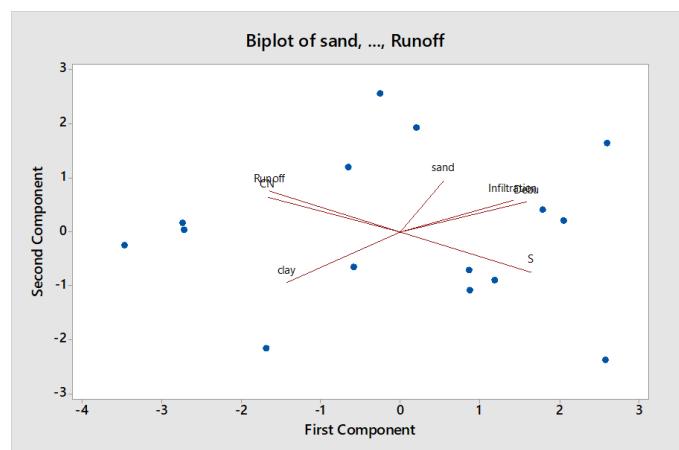


Figure 8: Relationship of data sets to surface flow tightness

Relationship Between Variables: Negative and Positive Correlation: Describe which variables are positively or negatively correlated based on their position in the biplot. Example: Biplots show a strong negative correlation between infiltration and runoff. That analysis Surface runoff and soil erosion are generally low due to surface garbage cover (Elliot et al., 2019). Hydraulic conductivity is more than 15 mm/h. As infiltration increases, runoff decreases. This suggests that increasing soil infiltration capacity, especially in areas with sandy soils, can reduce surface runoff and flood risk. The positive correlation between clay and runoff suggests that areas dominated by fine-textured soils tend to produce more surface runoff, especially when combined with compacted or developed land use, which results in higher CN values.

4. CONCLUSION

From the results of the research on the upstream Sumani sub-watershed, several conclusions can be drawn; first, that the composition of land use in this sub-watershed greatly affects its contribution to surface flow and the land use that contributes high is built land, gardens and rice fields. Second, in addition to the composition of land use, soil matrix suction also greatly affects the volume of surface flow, high soil matrix suction is obtained on forest land and shrubs. The three resultantes of land use, soil matrix retention, and soil texture (sand and dust) affect the rate of water entering the soil (infiltration).

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