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RESEARCH ARTICLE

Sediment Flow Characteristics in The Upper Slope of Volcanic Landscapes With Dryland Agriculture

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Abstract

Increasing population densities and food demands are major factors contributing to the widespread use of agricultural drylands in upper volcanic slope areas. This phenomenon poses a high risk of severe erosional events that are environmentally hazardous. Therefore, this study aims to analyze the sediment flow characteristics, based on the relationship between sediment flow and water level as well as the sediment discharge rate and soil loss. Field surveys were conducted to determine the soil measurement, slope morphology and dryland cover characteristics. The sediment flow was evaluated at the gully outlet, where 169 suspension data pairs for the modeling and 130 suspension data pairs for the validation, as well as the bed load, water level, rainfall and water flow characteristics were obtained. Tables and figures were subsequently used to represent the measurement data and analysis results for the correlation between the flow rate effects, sediment and soil loss on the water surface. The results showed that the sediment flow in volcanic landscape slopes with dryland agriculture were possibly characterized by the polynomial relationship, using the suspension discharge model, Q_s=0.0322Q^2+6.0625Q–1.2658. Under this condition, the average rate of soil loss in the form of sediment load and erosion rate of the catchment area occurred at 953.53 and 1,657.94 ton/ha/yr, respectively. Furthermore, the sediment sources in the soil loss were believed to originate from 83% of the suspended sediments and 17% bed loads.

Keywords: Discharge; Dryland; Landscape; Sediment; Volcano

1. Introduction

Indonesia is home to more than 400 volcanoes, out of which 127 occur in the active category (Badan Geologi Indonesia, 2011). Also, the country's volcanic landscape exhibits a distinctive utilization pattern, starting from the cone to the upper and foot slopes (Sartohadi & Pratiwi, 2014). The general trend shows that these regions are not exploited intensively, due to possible high-intensity fire hazards. However, the middle slope is used for agro-forestry and agriculture production activities (Nandini & Narendra, 2010; Alstrom & Akerman, 2016;

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Zhou et al., 2016). The land is typically developed for agricultural practices from the foot slope and downstream (Bachri et et al., 2017). Sediment flow due to the erosional process in the upper volcanic gradient appears relatively sensitive to the land use. Population pressures and food demands progressively transform the utilization of these areas into dryland agriculture. Furthermore, tropical climate with high topographic rainfall on volcanic slopes, increases the risk of soil erosion, leading to sediment flow.

Sediment flow is generally a potential source of soil loss in the watershed, and its adverse impact encompasses water quality deterioration and siltation (Panagos et al., 2015; Wulandari et al., 2014; Mondal et al., 2015). In addition, there is need to control the flow rates from the upper volcanic watershed, based on the level of tolerated soil loss for sustainable application. Various methods have been employed in predicting the soil loss (Li et al., 2015; Nocoń, 2016; Maltsev & Yermolaev, 2020), including USLE equations (Sharma et al., 2011), GEOWEPP (Maalim et al., 2013) and GSTARS4 (Ahn & Yang, 2015). Each technique has its unique advantages and disadvantages, as viewed from various aspects, such as the research scope and scale, data input, labor, cost and time (Maalim et al., 2013; Verma & Jha, 2015). However, certain challenges tend to occur, due to the limitations in the developing prediction methods, including the overestimation or underestimation of the real field conditions.

These weaknesses are possibly overcome through the optimization of specific forecast patterns by increasing the levels of detail on a small coverage area and simultaneously applying the key area methods. In a minimal watershed, these key area procedures have the ability to improve the prediction quality, where the sediment flow and the accompanying processes in land and channel erosion are easily observed. Sediment Delivery Ratio (SDR) is a major prediction technique that matches with the key area method. Based on this concept, the total erosion rate in watersheds is estimated by detecting the sediment flow (Ayuningtyas, 2012; Lazzari et al., 2015).

Erosion process dynamics and the watershed geophysical conditions represented by the channel outlet, are practically depicted, using hydrograph discharge and sediment grain analyses. The hydrograph discharge assessment describes the relationship between flow and sediment release by erosion determinants, while the sediment grain test provides clues to erosion sources contributing to the sediment flow. Furthermore, sediment flow has the capacity to navigate an outlet in the form of suspended and bed load sediments. The watershed specific geophysical characteristics tend to generate a unique hydrological response and sediment flow properties typical of dryland agriculture. The sediment flow characteristics are commonly concluded from a set of information, such as the relationship pattern between sediment flow and water level flow rate, as well as the sediment flow rate and grain size texture (Kellner & Hubbart, 2018; Hadini et al., 2019).

Soil thickness and other associated properties, including texture (Rusdi et al., 2013), structure (Renard et al., 1977), organic matter, fertility and permeability, are used to determine the soil erodibility and, consequently, the resultant sediment flow attributes. Previous study correlated the soil depth with soil loss in karst areas, where the thin soil region demonstrated a gradual infiltration and rapid water flow (Utomo et al., 2012). This outcome produced a suspension curve of $Q_s= 8.561Q^{0.893}$ and soil loss of 0.77 tons/ha/yr. Another earlier study also reported spatially typical sediment flow characteristics in various soil types, including a unique sample in Sermo reservoir (Wulandari et al., 2014). Apparently, no studies have been conducted on the physical characteristics of watershed landscapes with homogeneous land use as a key area. However, suspension flow dynamics have been analyzed extensively in basins with varied land use patterns, alongside diverse geophysical conditions, based on certain assumptions or generalizations. The results are dependent on presumed uniformity, potentially generating a bias towards the real field situations. As a consequence, investigations on sediment flow dynamics need to employ a key area approach in providing broader coverage for a minor watershed with homogeneous land use and geophysical conditions. This method further supports the planning of the basin's physical features in a more comprehensive and uniform manner, to produce a report that matches real field conditions. The key area technique also create studies that appropriately enable the generalization for other watersheds with similar characteristics.

The geophysical characteristics of a volcanic watershed appear unique, indicating possible hydrological response in the form of sediment flow and soil loss that only simulates sedimentation. Meanwhile, Bompon refers to a volcanic watershed with a soil thickness above 10 m-categorized super thick soil (Sartohadi et al., 2013). This area serves numerous purposes, in terms of agro-forestry, settlements, rice fields and dryland agriculture. The typical features of Bompon watershed are very suitable for key areas in the study of sediment flow and soil loss characteristics in volcanic landscapes for each land use. Therefore, this study aims to analyze the sediment flow in a volcanic watershed for dryland agricultural area, with several challenges, including the relationship pattern between sediment flow and water level flow rate, sediment discharge rate and soil loss, as well as the sediment source types.

2. Methods

Bompon volcanic watershed along the borders of Magelang, Purworejo, and Wonosobo regency, Central Java, served as the key area (Figure 1). This region stretches between 9,163,200-916,400 mN and 396,300-397,800 mE, with an elevation ranging from 377 up to 539 m above sea level and a large area of ±300 ha (0.03 km^2).Uneven rainfall conditions are known to characterize its climate, due to the influence of geomorphological features. Also, between September 2015-August 2016, the average annual rainfall in Bompon attained 2,214.5 mm.

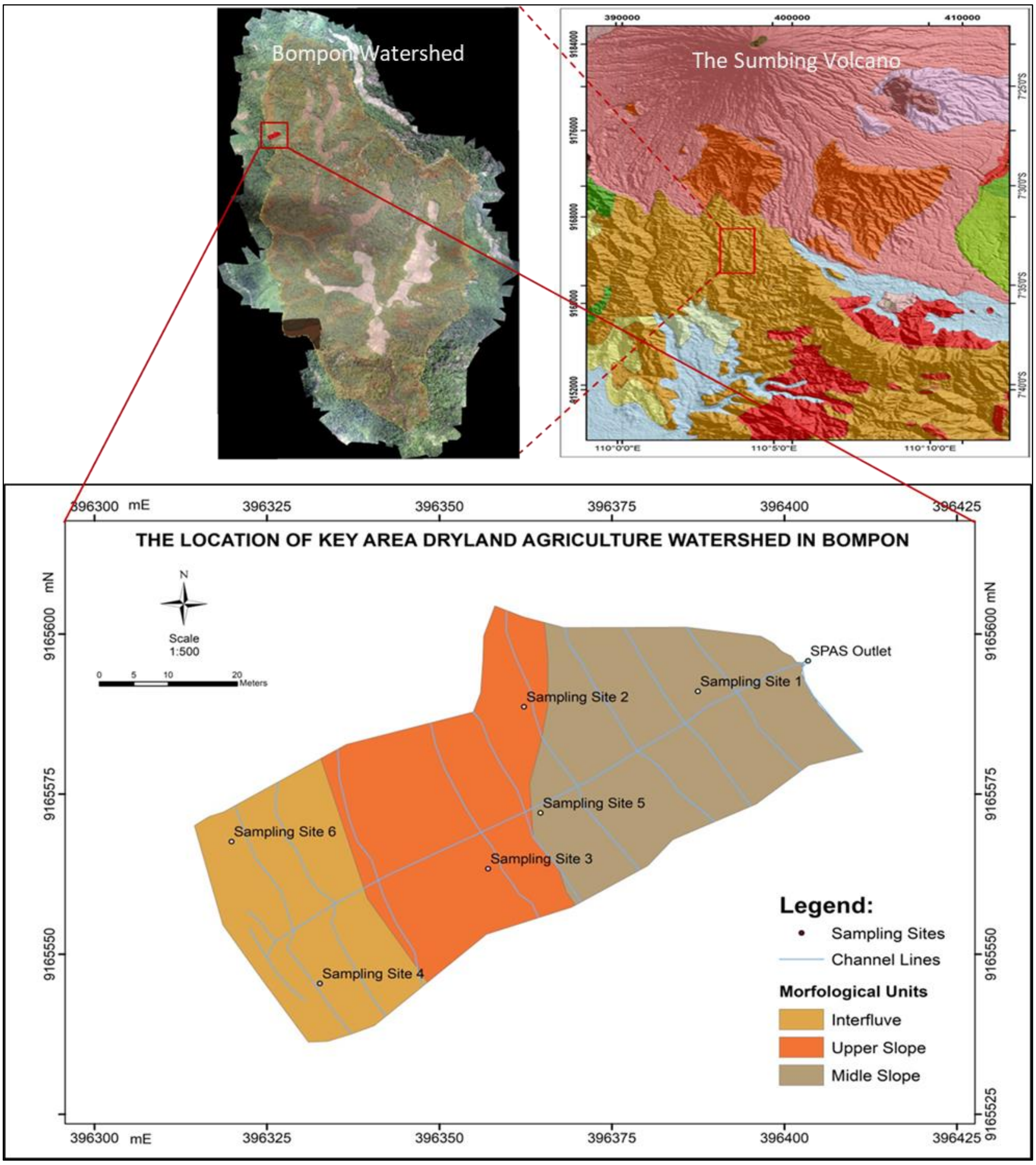

Figure 1. Locations of Key Areas in Bompon, a Volcanic Watershed for dryland agriculture

The area is geomorphologically located in the foot slope of Sumbing volcano, with rolling to hilly topographies, and is infiltrated by a volcanic intrusion, which causes the bedrock to experience intensive alteration. Furthermore, the combination of this process and weathering has the capacity to generate a super thick soil layer, that is more than 10 meters, with high clay contents. Bompon vegetation cover is primarily an aspect of an agro-forestry system known to cultivate various tree species, including durian, coconut, sea hibiscus (*Hibiscus tiliaceus*), mahogany, Chinese albizia (*Albiziachinensis*), rosewood, *Gnetumgnemon*, *Lansiumdookoo*, *Lansiumdomesticum* cv. Kokossan, jackfruit, teak, bamboo, banana, salak (*Salaccazalacca*), turmeric, ginger and cardamom. In the lower stand layers, creeping surface plants, such as grass and galangal, are observed. Multi-level vegetation stands of various heights create a very dense and wide canopy spanning between 1-12 m, with a multilayer covering. However, the erosion occurrence in agro-forestry varies significantly, although its rate appears relatively mild (Hadini et al., 2019).

Dryland agriculture in Bompon volcanic watershed has started to intensively support human lives amid the increasing economic pressures and reduced movement capacity of other commercial sources. This system generally cultivates seasonal crops, such as cassava, maize, peanuts and vegetable, although the cultivation practices leave the soil surface relatively open, leading to an increase in erosion hazard and the concomitant sediment flow.

This study employed a field survey to identify the soil measurement, slope morphology and the characteristics of the sample land for dryland agriculture. The suspension flow was measured at the gully outlet, using a natural plot, such as a catchment gully watershed. Also, the sediment flow, comprising suspended sediments and bed loads was evaluated at every rainfall event for ± two (2) years, resulting in 169 pairs of suspension data for model building and another 130 data pairs for verifications.

Rainfall conditions and water level suspension flow were recorded with an Automatic Rain Recorder (ARR) and Automatic Water Level Recorder (AWLR), respectively. This was followed by representing the resulting data in tables and graphs to describe the relationship between rainfall and sediment flow. Subsequently, a sediment flow analysis was conducted, depending on the water level and suspension flow, while the suspension data was analyzed using the filtration method, where the suspension weight and concentration were determined. The multiplication of this concentration by flow rate resulted in the suspension discharge for each water level flow rate (Wulandari et al., 2014). Meanwhile, the flow discharge was obtained by observing the water level at a broad-crested weir installed at the outlet and then calculated using weir discharge equation (Herschy, 2009). The flow discharge at a particular water level and the sediment concentration at a certain interval were correlated with the suspended sediment discharge. This relationship was modeled into a sediment discharge curve, which refers to a regression line between sediment discharge and flowrate, using the Eq. 1 (Wulandari et al., 2014):

$$Q_s = aQ^b \tag{1}$$

Where: Qs= sediment discharge (g/s); and Q= flowrate (l/s).

The water level data was plotted into a flow hydrograph to provide information on the flow rate at each rainfall, while the hydrograph and water level data formed a graph representing the relationship between the water level and the stage-discharge rating curve of Eq.1. Flow rate data were used to determine sediment discharge, although both the flow and sediment discharge generated a sediment-discharge rating curve. However, to plot the sediment discharge curve (suspension), the flow rate and sediment discharge data were positioned on x and y axes, respectively. The plotted data described a series of instantaneous correlation between flow and suspended sediment discharges, and further analyzed to identify the average suspension discharge as a function of the average flow rate at each rainfall. This was followed by statistically evaluating the calculations for the relationship analysis, using Microsoft Excel 2010, with correlation and regression test features (Santoso, 2007). Furthermore, the sedimentation process produced erosion and sediment values that indicates the level of watershed degradation. These indicators were determined from SDR with the Eq. 2 (Ayuningtyas, 2012):

$$D=SDR=Y/T \tag{2}$$

where D= sediment delivery ratio; Y= sediment yield obtained at watershed outlets (ton/ha/yr); T= total erosion of the catchment area (ton/ha/yr).

The SDR value was then calculated from the watershed area, using formula by Boyce (1975) in Eq. 3:

$$SDR = 0{,}41\ A^{-0{,}3} \tag{3}$$

where SDR= sediment delivery ratio; A=watershed area (ha)

3. Results and Discussion

This study focused on the sediment flow in a volcanic watershed for dryland agriculture encompassing several challenges, including the relationship pattern between sediment flow (suspension discharge) and water level (flow discharge), the sediment discharge rate and soil loss, as well as the sediment source type.

3.1 The Relationship between Suspension and Flow Discharges

The relationship pattern between the suspension discharge and water level is presented in the form of a correlation between suspension discharge and flow rate. This is possible considering that changes in the water level influences the flow rate. Meanwhile, the alterations in the flow rate tend to control the changes in the suspension discharge.

3.1.1 The Relationship between Flow Discharge and Water Level

Based on the land utilized for dryland agriculture, the relationship between flow rate and water level generated a flow rate model with an equation $Q=0.9328h^{1.5247}$. Figure 2 represents the determination coefficient of the curve at $R^2= 0.9999$. This flow discharge model was developed from 299 pairs of flow rate and water level data. Meanwhile, the value of $R^2= 0.99$ indicates that the flow rate variations were influenced by 99% of water level change and 1% of other factors.

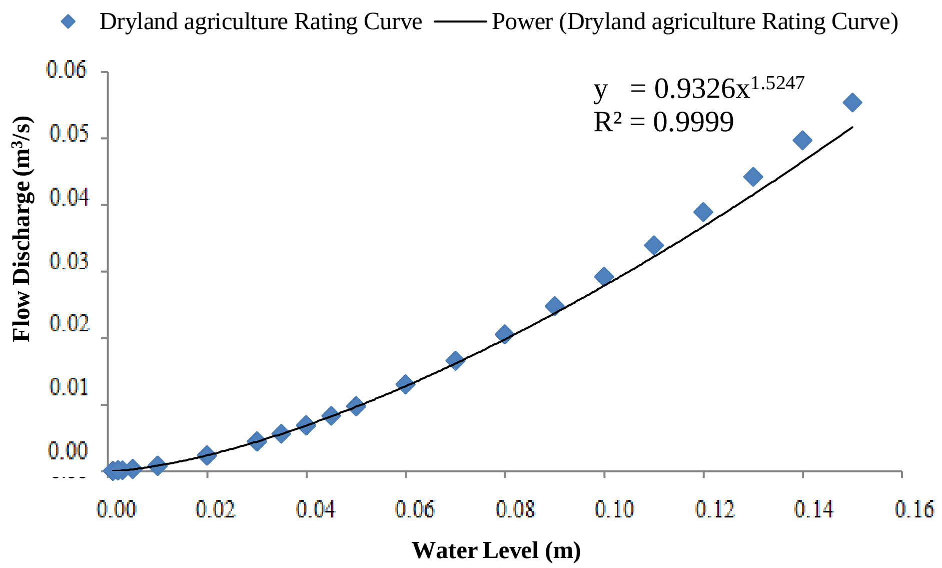

Figure 2. Flow discharge model of water level in the key area for dryland agriculture in bompon watershed

The t-test resulted in t_{hit}= -0.163 and the use of Microsoft Excel application obtained t_{tab}= t_{inv} (0.05; (299-1))= 1.97. This t_{hit} value appeared minimal, compared to t_{tab}, indicating no significant difference between the discharge with direct field measurement and the counterpart from the flow curve analysis. Therefore, the flow discharge model on super thick soil in upper volcanic slopes with dryland agriculture fulfilled the requirements in flow rate calculation for various outlet water levels.The observation data analysis and the flow curve model calculation generated an average flow rate of 1.64 and 1.61 m^3/sec, respectively. Also, the difference between the observed and the modeled flow rate was 0.0034 m^3/s, indicating a percentage error (deviation) of 2.04%. According to Widasmara & Hadi (2016), the allowable deviation value occurs between 10-20%. Therefore, the flow rate model in this study appears suitable for predicting the watershed flow discharge, with deviation value probably above 10%. This is because the data distribution in building the model has been altered, including the zero water level value during the measurement. Field observation showed that the zero water-level change also tends to occur, due to the sediment accumulation.

This circumstance influences the flow morphology upstream of the gauging station. Also, the sediment accumulation contained sand and silt capable of altering the flow morphology during rainfall. The error sources responsible for producing irregularities, involved the use of mean value in daily flow calculations, although the calculation does not represent the peak discharge. Suripin (2000) stated that the use of flow rating curves from the mean value of a series of daily discharge data possibly generates 50 % or more errors. The deviation value in this study was more preferred compared to the previously reported flow rate model. This deviation is probably caused by the cross-sectional channel properties responsible for triggering the sediment, or a control section. In a centralized control section, the downstream channel flow appears centered because its basic morphological shape experiences channel narrowing (Soewarno, 1991; Gao et al., 2017).

3.1.2 The Relationship between Suspension Discharge and Flow Discharge

The flow discharge model in the form of a flow curve type in dryland agriculture ($Q= 0.9328h^{1.5247}$) was used to simulate a suspension sediment discharge in the study area. Figure 3 shows that the suspended sediment discharge and the flow discharge produced a polynomial relationship, $Q_s=0.0349Q^2+5.9374Q-1.0601$, with a determination coefficient of$R^2=0.82$ (Q_s=Suspension discharge (g/s); Q=Flow discharge (l/s)). As a consequence, the suspension flow variations were possibly described as the influence of 82% flow rate factors and 18% other determinants. The t-test of the suspension curve model yielded t_{hit}=-0.000605, while the Microsoft Excel results obtained t_{tab}=t_{inv}(0.05;299-1)= 1.97. Furthermore, the t_{hit} value appeared minimal, compared to t_{tab}, indicating no significant difference between the field measured suspension discharge and the simulated value from the suspension curve model.

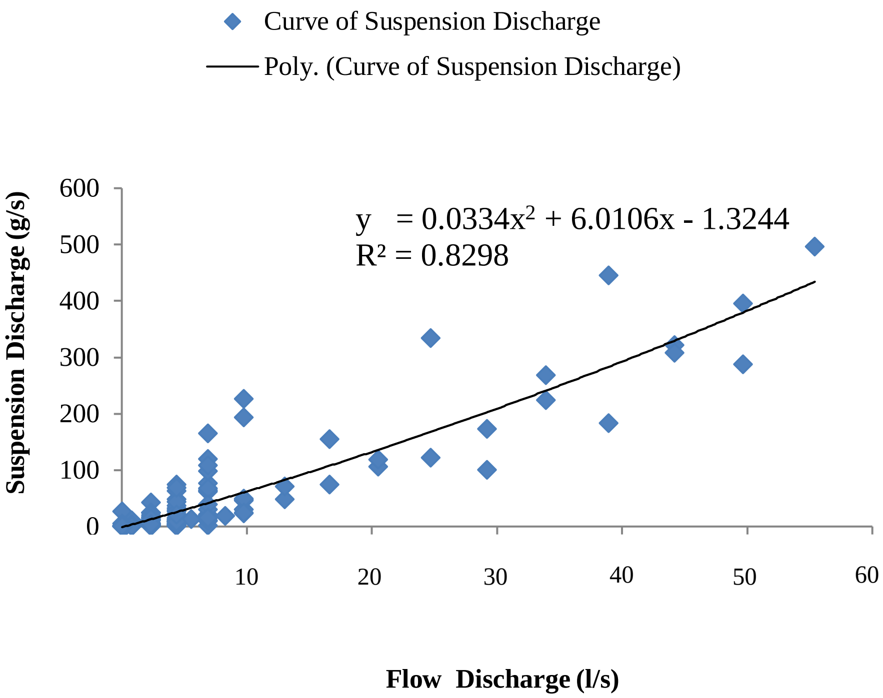

Figure 3. Graph of the suspension discharge model and flow discharge at the dryland agriculture in bompon watershed

The results of the suspension sediment calculations from the suspension discharge model matched the requirements for assessing the suspension discharge at various water levels, with error rate at approximately 18%. Particular factors known to contribute to these errors include the sampled sediment and discharge concentrations using conventional tools that potentially did not measure the overall suspension, leading to smaller values, and secondly, limited time interval for the sampling discretization, specifically during high-intensity rainfall with rapid flow rate changes. However, the need to address the vulnerabilities by correcting both error sources appears very significant. The modification is also performed by examining the data quality, specifically based on the requirements in data homogeneity and outliers (Wulandari et al., 2014; Neno et al., 2016; Yan et al., 2015).

3.1.3 Verification of Suspension Discharge Model

The suspension discharge model was verified to ensure the consistency of its application. This process was conducted by collecting suspension and water level samples in similar gauging stations at different time intervals from January-March 2018. The t-test results showed that the discharge curve model was not applicable to the overall rainfall states, although the two test conditions obtained t_{Stat}= -4.066, that is, greater than t_{tab}= 1.969. Subsequently, various rain conditions were analyzed, including the low-moderate and high-extreme rainfall occurrences. This test was aimed at determining the possibility of a consistent suspension discharge model under certain rain conditions (low-moderate or high-extreme). The results showed a stable suspension discharge model only in low-moderate rainfall, as evidenced in the test value t_{Stat}=1.1478 (smaller than t_{tab}=1.996). This finding indicatesthat the suspension discharge model in areas of dryland agriculture appears applicable only for water level variations in low-moderate rainfall.

3.2. Calculation of Flow Discharge and Suspended Sediment Discharge

3.2.1 Calculation of Flow Rate and Suspension Sediment Discharge on AWLR

The suspension discharge model was used to obtain a suspension discharge for the flow rate (Q) of each water level. This parameter was calculated from the individual daily, monthly, and annual flow rates recorded by AWLR. The daily suspension discharge refers to the average of suspension discharge in a day, while its summation in a month is called the average monthly suspension discharge. Consequently, the variation of the monthly suspension discharge in a year is possibly identified. Meanwhile, the unit adjustment in expressing the suspension discharge as an annual period is achieved by converting g/s to tons/year, using a multiplier of 31.536. Table 1 presents the average monthly suspension discharge for a year at 262.01 ton/yr, with an average flow rate of 1.80 L/s. The maximum suspension flow discharge at 563.34 ton/yr, occurred in May during raining season. This event produced a flow rate of 3.64 L/s, while the minimum occurrence in September, 20.77 ton/yr, also in raining season, generated the lowest flow rate of 0.10 L/sec. Therefore, rainfall factors that control the flow rate conditions are very influential towards sediment flow (suspension) and soil loss in a volcanic watershed mainly used for dryland agriculture. In summary, each rainfall event demonstrated different characteristics with separate flow rates and suspension discharges. Based on the suspension flow rate model calculation, a significant difference was observed in the suspension discharge for different flow rates.

Table 1. Average flow rate (Q) and Suspension Discharge (Q_s) based on Dryland Agriculture Practices in the Watershed Key

No	Months	Flow Discharge Q (L/s)			Suspension Discharge Qs (Ton/yr)			Total Suspension Qs/A (Ton/ha/yr)		
		Year		Average	Year		Average	Year		Average
		2017	2018		2017	2018		2017	2018	
1	January	-	3.00	3.00	-	390.78	390.78	-	1207.46	1207.46
2	February	-	2.09	2.09	-	286.83	286.83	-	886.26	886.26
3	March	-	1.98	1.98	-	285.31	285.31	-	881.58	881.58
4	April	-	0.10	0.10	-	40.24	40.24	-	124.33	124.33
5	May	5.85	1.03	3.44	984.33	70.50	527.42	3041.46	217.85	1629.65
6	June	1.33	1.34	1.33	173.94	171.60	172.77	537.46	530.22	533.84
7	July	0.84	0.42	0.63	76.06	19.96	48.01	235.03	61.68	148.35
8	August	0.84	0.31	0.57	76.06	55.40	65.73	235.03	171.19	203.11
9	September	0.39	0.57	0.48	5.86	35.69	20.77	18.09	110.28	64.19
10	October	2.07	1.67	1.87	352.10	238.61	295.35	1087.93	737.27	912.60
11	November	1.42	5.85	3.64	152.34	984.33	568.34	470.73	3041.46	1756.09
12	December	4.77	0.10	2.44	879.32	5.86	442.59	2716.99	18.09	1367.54
Average				**1.80**			**262.01**			**809.59**
Max				3.64			568.34			1756.09
Min				0.10			20.77			64.19

Note: ton/yr = 31.536 g/s

The suspension discharge in dryland agricultural areas appeared relative extensive, strongly reflecting the suspended sediments as well as the study area conditions. Field observations indicated that the flow at the gauging station drained the suspension with reasonably large sediment at every rain event, particularly with high intensity and lengthy durations. The watershed capacity to store and drain water into the soil in these regions was considerably minimal, leading to the flow stoppage immediately after the rain. Furthermore, the annual distribution of the suspended sediments in the sample areas observed two (2) peak periods, termed May and November. In both months, the rain occurrence appeared more frequent with high intensity, resulting in extensive average flow rates.

3.2.2 Calculation of Sediment Discharge and Soil Loss

Sediment discharge known to instigate soil loss,occurs in the form of sediment load and also refers to the accumulation of all sediment types, including the suspended sediments and bedloads into the channel outlet. The sediment load was subsequently calculated depending on the weight of suspended sediment and bed loads from the field data measurement and analysis. Table 2 shows an average sediment load of 86,660.11 g, comprising sediments and bed loads of 81,385.04 g and 6,045.02 g, respectively.

Table 2. Calculation of sediment discharge and soil loss

No	Sample Codes	Bedload	Suspended Sediment					Weight of Suspended Sediment	Total Weight of Sediment	Percentage of Sediment	
		Wb (g)	Concentration C (g/l)	Discharge Q (l/s)	V (l)	Qsh (g/s)	Rain duration t (Minute)	Ws (g)	W (g)	%Wb	%Ws
1	2	3	5	6	7	8=5*6	9	10=8*9	11=4+10	12	13
1	06-Mar-17	1,024.59	1.4601	1.8036	4328.6682	2.6335	40	6,320.47	7,345.06	13.95	86.05
2	07-Mar-17	2,237.37	0.3260	2.6586	6699.7409	0.8666	42	2,183.96	4,421.33	50.60	49.40
3	25-Mar-17	8,677.65	2.5124	3.8433	11299.3855	9.6560	49	28,388.72	37,066.37	23.41	76.59
4	05-Apr-17	36,885.24	4.7698	20.3478	70810.4379	97.0551	58	337,751.90	374,637.14	9.85	90.15
5	23-Apr-17 (1)	2,034.24	0.7023	0.2274	573.1064	0.1597	42	402.48	2,436.72	83.48	16.52
6	23-Jan-18	10,852.17	13.0875	1.8036	1623.2506	23.6048	15	21,244.32	32,096.50	33.81	66.19
7	24-Jan-18	19,673.13	60.1184	3.8776	6979.6812	233.1151	30	419,607.19	439,280.32	4.48	95.52
8	25-Jan-18	4,240.20	83.9386	1.0164	1036.7737	85.3190	17	87,025.36	91,265.55	4.65	95.35
9	31-Jan-18	823.87	23.9045	1.0047	723.3792	24.0167	12	17,292.03	18,115.90	4.55	95.45
10	04-Feb-18	4,351.76	26.8223	1.0047	2833.2353	26.9482	47	75,993.80	80,345.56	5.42	94.58
11	05-Feb-18	3,104.01	14.4334	1.8036	2705.4176	26.0323	25	39,048.48	42,152.49	7.36	92.64
12	07-Feb-18	1,393.46	7.8116	1.0047	361.6896	7.8483	6	2,825.37	4,218.84	33.03	66.97
13	08-Feb-18	3,001.26	6.6616	1.0047	964.5056	6.6929	16	6,425.18	9,426.44	31.84	68.16
14	09-Feb-18	4,338.04	8.0985	2.7640	2653.4714	22.3844	16	21,489.04	25,827.08	16.80	83.20
15	11-Feb-18	3,514.37	13.4374	3.8729	3485.6101	52.0416	15	46,837.43	50,351.81	6.98	93.02
16	12-Feb-18	3,619.36	10.9801	3.8776	3489.8406	42.5763	15	38,318.70	41,938.06	8.63	91.37
17	20-Feb-18	2,039.02	17.9242	1.8036	5194.4018	32.3283	48	93,105.62	95,144.64	2.14	97.86
18	22-Feb-18	4,203.97	18.6944	3.8776	5816.4010	72.4893	25	108,733.99	112,937.97	3.72	96.28
19	23-Feb-18	6,085.91	7.6122	11.3742	22520.8717	86.5830	33	171,434.39	177,520.30	3.43	96.57
20	24-Feb-18	2,647.68	7.3504	6.5150	19154.1038	47.8880	49	140,790.80	143,438.48	1.85	98.15
21	04-Mar-18	2,198.06	5.8921	3.8776	7444.9933	22.8472	32	43,866.63	46,064.69	4.77	95.23
	Total	126,945.36	336.5379	79.3634	180698.9653	923.0866	632	1,709,085.88	1,836,031.25		
	Average	**6,045.02**	**16.03**	**3.77**	**8,604.71**	**43.96**	**30**	**81,385.04**	**86,660.11**	**17**	**83**
	Maximum	36,885.24	83.94	20.35	70,810.44	233.12	58	419,607.19	439,280.32	83	98
	Minimum	823.87	0.33	0.23	361.69	0.16	6	402.48	2,436.72	2	17

Note: Q=Cd*Cv*((9.8))^(1/2)*b*((h))^(3/2); Ws=(Qs*60)*t; V=((Qs/(24*60))*t

3. 3 The Type of Sediment Source Material during the Flow

The percentage of suspended sediment loads in the study area varied from 17-98%, with an average of 83%., while the bed load composition to sediment loads ranged between 2-83%, with an average of 17%. These bed loads have been estimated using the Borland & Maddocktables (1951), based on the concentration and grading of suspended sediments in the forms of clay, silt and sand provided the bed load composes 20% of the suspended materials (Soewarno, 1991). The ratio of bed load to the suspended sediments (6,045.02/81,385.04) was estimated at 0.0698 or 7.5%, while the average bed load of 7.5% x 308.60= 23.14 ton/yr, was obtained using similar ratio for the mean value of the annual suspension discharge in Table 1. This study further achieved a bed load discharge of approximately 331.74 ton/yr.

The comparison between the sediment yields in the channels and soil erosion is defined as SDR (Ayuningtyas, 2012; Lazzari et al., 2015). According to Ma'wa et al., (2009), the relationship between the characteristics of the catchment area and SDR is calculated using

Eq. 3. The results also generated a watershed key area of 0.324 ha, while the SDR obtained 0.2472, while the rate or total soil loss was based on the sediment yield, or sediment discharge per unit area (331.74 ton/yr)/(0.324 ha)= 953.53 ton/ha/yr. Eq. 2 was used to generate the total erosion rate in the watershed key area at 1,657.94 ton/ha/yr.

This study indicated that high flow rates were able to influence the sediment flow and erosion process in dryland agriculture areas, leading to soil loss (Sambodo & Arpornthip, 2021). The extent to the effect of flow discharge on the sediments is significantly dependent on erosion, particularly the soil erodibility (Morgan, 2005; Hadini et al., 2019). Soil erodibility refers to a complex property that is based on soil infiltration rate and its capacity to withstand detachment by raindrops and scouring by surface runoff. This parameter is strongly influenced by the state of the soil structure (Renard et al., 1997), organic matter, texture and soil permeability (Desifindiana et al., 2013). Based on the soil texture, fine sand and silt fractions are soil particles possibly affecting soil erodibility (Morgan, 2005; Rusdi et al., 2013; Hadini et al., 2021).

In dryland agricultural areas of Bompon volcanic watershed, the super thick soil is characterized by surface silt-clay and clay texture, with a range of compositions, including sand 7-3%, silt 14-58% and clay 34-57%. Table 3 shows the soil permeability occurrence in the moderate category, with an average of 4.23 cm/hr as well as the bulk density ranging between 0.97-1.20 g/cm^3, averaged at 1.11 g/cm^3. Figure 4 is a map representation of the soil texture distribution in the study area. Based on the dominance of soil texture by clay fractions, a volcanic watershed extensively utilized for dryland agriculture, is classified as hardly erodible. However, the total sediment yield was estimated at 953.53 ton/ha/yr, while the overall watershed erosion attained 1,657.94 ton/ha/yr, which was categorized as 'very heavy' erosion rate (Departemen Kehutanan, 1986). The observation results showed that in dryland applications, certain differences in the sediment discharge were observed at each rain event. These variations occurred with distinct flow rates that are controlled by the rain intensity and duration. Furthermore, the consistency test (t-test) outcomes reported a strong and positive correlation between sediment discharge (suspension) and flow rate, indicating a more intensive land erosion process in triggering sediment flow and soil loss, compared to the erosion effects (scouring) at the bottom of the channel and base load. This statement corresponded to Leopold & Maddock (1953), where a robust association between suspended sediment and flow discharge signified a more intensive land erosion process in triggering sediment flow than the erosion (scouring) in the canal and on the bed load.

Table 3. Characteristics of surface soil for dryland agriculture watershed

No.	Soil Characteristics	T1	T2	T3	T4	T5	T6	Dryland Agriculture Watershed		
								Max	Min	Average
1	Sand (%)	13.3443	9.2377	8.5904	9.1651	7.7635	6.9694	13	7	9
2	Silt (%)	14.1041	37.2408	39.2815	56.3412	41.3775	14.9183	56	14	33
3	Clay (%)	72.5517	53.5215	52.1281	34.4937	50.8590	78.1123	78	34	57
4	Soil texture classification (USDA)	Clay	Silty Clay Loam	Silty Clay Loam	Clay	Silty Clay	Silt Loam	-	-	Clay
5	Permeability (cm/hour)	4.966	1.433	0.601	8.223	8.412	1.764	8.41	0.60	4.23
6	Permeability classification	S	AL	AL	AC	AC	AL	Fairly fast	Fairly slow	Fair
7	Bulk density (g/cm^3)	1.201	1.068	1.168	1.156	0.971	1.083	1.20	0.97	1.11

Note: T= Sampling sites at the dryland agriculture

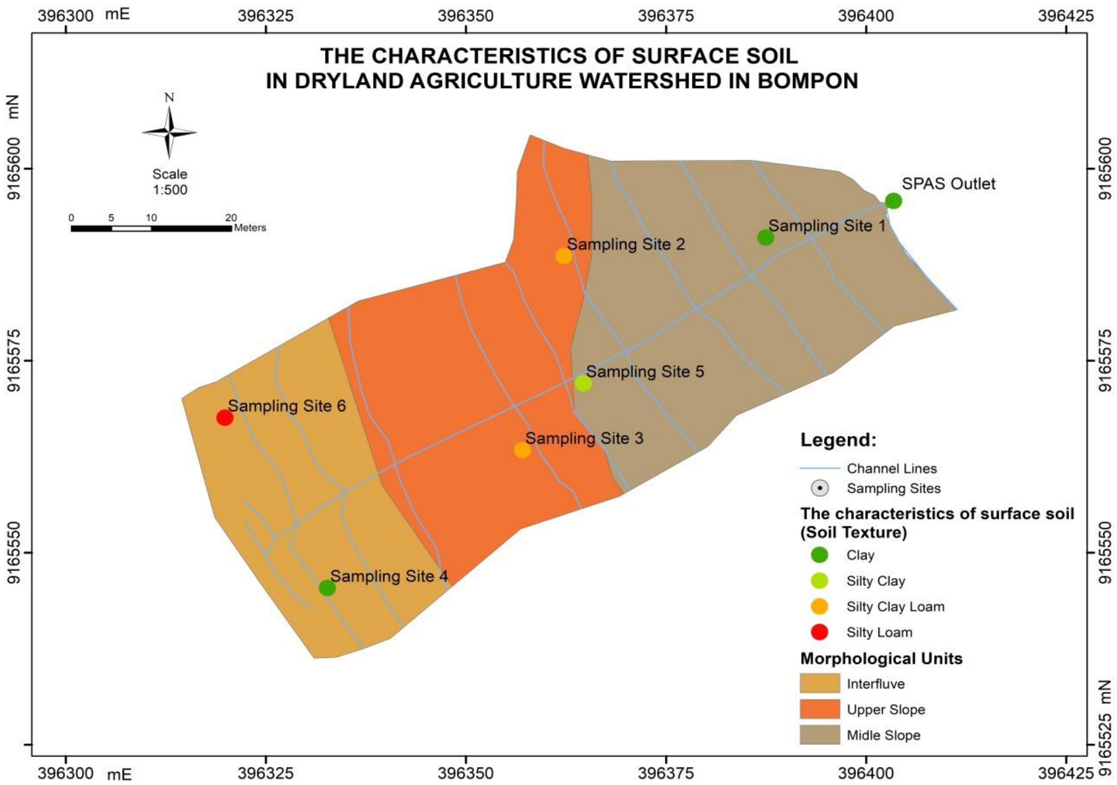

Figure 4. Distribution of soil texture characteristics in the research areas

Rainfall factors and geophysical conditions are known to strongly influence flow discharge, which controls erosion. This process induces sediment flow and soil loss in the watershed key area primarily utilized for dryland agriculture.Sediment flow is also regulated by the dynamics of rain characteristics, such as intensity and duration. An important aspect of the study of sediment flow in the upper watershed region refers to the assessment of the sediment flow characteristics under different land uses, including agroforestry, settlements and dryland agriculture. This study obtained distinct sediment flow for these land use types as a response of the dynamics of the land's geophysical characteristics to specific rainfall.The process commenced with a rain event, known to trigger the breakdown of soil aggregates, leading to splash and sheet erosion. Alongside the increase in rainfall intensity and duration, the accumulation of surface flow becomes more intense, leading to rillerosion, gullyerosion, and sediment transport to the channel outlet (Verstraeten, et al., 2007; Gumiere, et al., 2015). Therefore, the conservation of land resources against erosion and sedimentation effects is expected to prioritize proactive measures towards reducing the raindrop energy and rill erosion occurrence by an extensive rate of concentrated flow.

4. Conclusion

The sediment flow characteristics in volcanic landscape slopes with dryland land use characterized by (1) The relationship pattern between the suspension discharge and flow rate possibly used according to the change in flow rate of the suspension discharge by generating a curved model of the suspension discharge curve $Qs=0.0322Q^2+6.0625Q-1.2658$; (2) Sediment flow that causes very heavy erosion rates by producing an average soil loss rate of 1,657.94 tons/ha/year; (3) Suspension and bed load sediments as the dominant type of soil loss sediment sources, with contribution rates of 83% and 17%, respectively; (4) Soil loss sources with a more dominant proportion of suspended sediments indicating further widespread soil losses due to land erosion processes in the watershed areas, compared to the counterparts from the groove erosion process and channel bed loads.

Conflict of interest

The authors declare that there is no conflict of interest with any financial, personal, other people or organizations related to the material in this study.

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