Geosfera Indonesia
p-ISSN 2598-9723, e-ISSN 2614-8528
available online at : https://jurnal.unej.ac.id/index.php/GEOSI
Vol. 8 No. 1, April 2023, 19-34

https://doi.org/10.19184/geosi.v8i1.30921 **Research Article**

Analysis of the Dynamics of Water Flow and Suspension Flow Discharge in Volcano Watershed with Settlement Land Use

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ARTICLE INFO

Received :
1 May 2022

Revised :
30 March 2023

Accepted :
10 April 2023

Published :
18 April 2023

ABSTRACT

Suspension flow into the upstream of volcano watershed is sensitive to land use. In Indonesia, a settlement is a form of land use in several volcanic landscapes. There is currently no detailed study on the suspension flow sediment from the settlement land use. The purpose of this study is to investigate the characteristics of the relationship between water and suspension flow discharge. The study was conducted through the measurements at a gully outlet that produced 747 suspension load data. For each rainfall event, suspension load measurements were made in the field, followed by laboratory analysis. Additionally, field surveys were used to determine the characteristics of settlement land use and the water flow into the gully system. According to the findings, the peak flow discharge corresponds to the peak suspension discharge, the peak flow discharge comes before the peak suspension discharge, and the peak flow discharge happens after the peak suspension discharge. The average time lag between initial rainfall events and suspension flow was 10.36 minutes, and the suspension peak content varied by an average of 2.22 gl^{-1}. The grain size was also dominated by the clay fraction, averaging 67.86% on the ascending branch and 67.82% on the descending branch.

Keywords: Erosion; Discharge; Settlements; Suspension; Watershed

INTRODUCTION

The dynamics of suspension flow in a volcano watershed can cause a critical land problem as a result of land use activities. In Indonesia, there are over 400 volcanoes, of which 130 are categorized as active (Badan Geologi Indonesia, 2011; Handayani, et al. 2013). Generally, the cones and upper slopes are not used intensively because there is a threat of high-intensity mountain hazards (Asriningrum, et al. 2004; Sartohadi & Pratiwi, 2014). However, the central slope is used for settlements (Nandini & Narendra, 2012; Alstrom & Akerman, 2012; Zhou et al., 2016), and foot slopes are used for farmland (Bachri et al., 2017). Suspension flows from the upper part of volcanic landscapes are sensitive to land use patterns. Furthermore, suspension flow dynamics can relate water flow responses to the dynamics of watershed properties through land-use activity in volcanic landscapes. It is very important for the qualitative identification of watershed criticality. The use of dynamics of suspension flow for qualitative identification was developed considering that quantitative identification requires a large investment input in terms of time, effort, and cost (Kimmins et al. 2007; Verstraeten et al. 2007; Kironoto, 2008; Verma & Jha, 2015).

Suspension flow is closely related to the critical state of the watershed. This is because it is an important part of soil erosion process from a watershed area resulting in soil loss or decreased soil fertility, triggering sedimentation and silting downstream of the water body, which is an indicator of the criticality (Panagos et al., 2015; Suripin, 2000; Merritt et al. 2003; Ma'wa & Andawayanti, 2009). Dynamics of suspension flow properties and changes in watershed conditions can be observed during specific periods of precipitation events by hydrographic analysis of suspension hydrographs. Suspension flow dynamics are described in a hydrograph based on flow and suspension discharge parameters (Parsons & Wainwright, 2000; Handayani et al., 2005; Oktarina, 2005; Walker & Mostaghimi, 2009; Handayani & Indrajaya, 2011; Bisantino et al., 2013; Miller et al., 2015; Yan et al., 2015; Gao et al., 2017). This dynamic is related to the equilibrium system of rainfall inflow, infiltration and groundwater storage in the catchment (Hergarten et al., 2000; Poesen et al., 2003; Arsyad, 2006; Fryirs & Brierley, 2013).

Several studies have shown that the dynamics of suspension flow in settlements can control the formation of suspension flow (Soemarto, 1999; Dariah et al., 2003; Morgan, 2005; Nicótina et al., 2011; Rusdi et al., 2013; Miller et al. 2015). However, in general, there is no report on the condition of the physical characteristics of the watershed and landscapes with homogeneous settlement land use. Until now, the study of suspension flows has been carried out in a wide watershed area with various types of land use. Although rainwater input parameters and watershed physical characteristics in a wide watershed are generally heterogeneous, they are assumed to be uniform. Therefore, based on the assumption of uniformity, the results have the potential for a large bias toward the real situation in the field.

The study of suspension flow of settlement volcanic watersheds needs to be carried out with a key area approach on a small watershed location and homogeneous settlement conditions. The use of the key area approach can make it easier to plan the physical condition of watersheds in the case of uniform land use. This will provide reports that are close to the real situation in the field. Furthermore, this can be generalized and applied to volcanic watersheds and settlement land uses with similar physical properties. The study of suspension flow dynamics in the upper part of the settlement volcanic watershed has a different aim. This includes the correspondent response to water flow and suspension flow discharge, the lag time of rainfall occurrence, the beginning of suspension flow formation, as well as the particle size of suspension flow content.

METHODS

This research was conducted in the Bompon watershed is located on the foot-slopes of the Sumbing volcano in the border area of Magelang, Purworejo, and Wonosobo Regencies, Central Java (Figure 1). The Bompon watershed was chosen as the key area because it has a form of land use in the form of settlements at 9163200 mU – 916400 mU and 396300 mT – 397800 mT at an average altitude 458 m above sea level (Wardhana, 2016).

With an average annual rainfall of 2,214.5 mm, the climate in this region is characterized by uneven precipitation. The watershed is also in a zone of transition between the Tertiary and Quaternary volcanic material deposition zones on the foot-slopes of the Sumbing Volcano. Bompon watershed experienced volcanic intrusion which resulted in intensive alteration of the bedrock. The existence of this alteration and weathering process produces a layer of soil more than 10 meters thick (Candraningrum, 2013), which is categorized as super thick soil (Sartohadi, 2013).

The settlement key area has dimensions of 288.28 m length and 223.29 m width with a catchment area of about 5.64 ha (5.64 x 10^4 m^2) and a slightly rounded watershed shape (Figure 1). The physical characteristics of the settlements are residential buildings, mosques, and road networks which are in the form of concrete and solid soil surfaces. Residential housing spreads over most of the settlement, totaling about 40 units, and covering an area of about 0.322 ha (or 3220 m^2) with a roof span of approximately between 63 m^2 - 98 m^2. The height of the roof stands varies between 3 m – 6 m. Vegetation cover can be found among residential land uses in the form of annual plants such as *coconut*, *mahogany* and *sonokeling*, and *mpon-mpon* plants such as turmeric, Javanese turmeric and cardamom. Moreover, there are grass and aromatic ginger attached to the surface of the soil at the base of the plant stand.

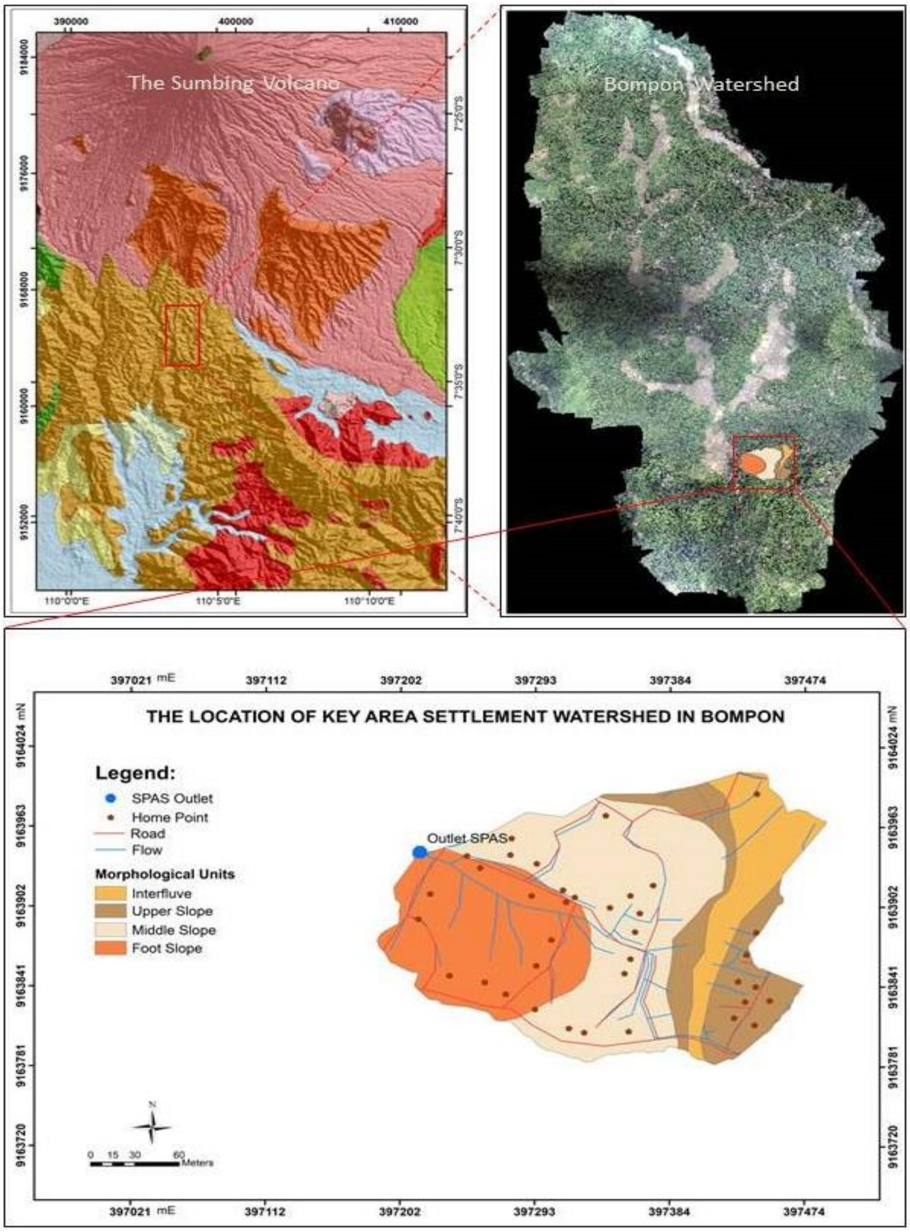


Figure 1. The geomorphological units of the settlement land use in Bompon watershed on the foot-slopes of the Sumbing volcano, Central Java

Based on the physical characteristics of the land use, the direct water from the rain falling on the housing roof, ground surface of the open yard, and the vegetation stands converges on the furrows and subsequently flows into the drainage or ditches connected to settlement SPAS outlets. The appearance of watershed erosion in the key areas of the settlement is controlled by the physical characteristics of the land, such as climate, especially rain intensity, topography (relief), vegetation, soil, and anthropogenic activity.

In order to measure the suspension flow in a gully outlet that yielded 747 suspension data, the key area approach was applied in this research. Field and laboratory measurements were used to measure the suspension flow during each rainfall event. In addition, field measurements were used to record the catchment area's plant characteristics in detail. In the meantime, field surveys were used to observe the characteristics of water flow into the gully system. Then, tables and graphs (suspension hydrographs) were used to show the data and explain the linkage between rainfall and suspension flows.

Data from rainfall and water level (TMA) measurements were used to analyze suspension flow. The data on rainfall were based on the dynamics of the thickness, intensity, and duration of the precipitation just before the formation of the suspension flow. The parameters of the sediment load were used to examine suspension flow, which was later referred to as suspension. The weight and concentration of the obtained suspension were analyzed by filtering. The concentration that passes through a certain outlet per time unit is called suspension discharge or suspension flow discharge (Hadini et al., 2021).

The suspension discharge can be obtained from the multiplication between suspension concentration and water flow discharge (Wulandari et al., 2004; Mondal et al., 2015).

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

where Q_s= Suspension discharge (g/s, gs^{-1}); Q= Water flow discharge (l/s, ls^{-1}).

The water flow discharge can be obtained for each water level (TMA) observations at settlement SPAS outlets with a type of broad-crested weirs, which are calculated by the weir discharge equation as follows Herschy (2009).

$$Q = 0.633\sqrt{(g)}bH^{3/2} \tag{2}$$

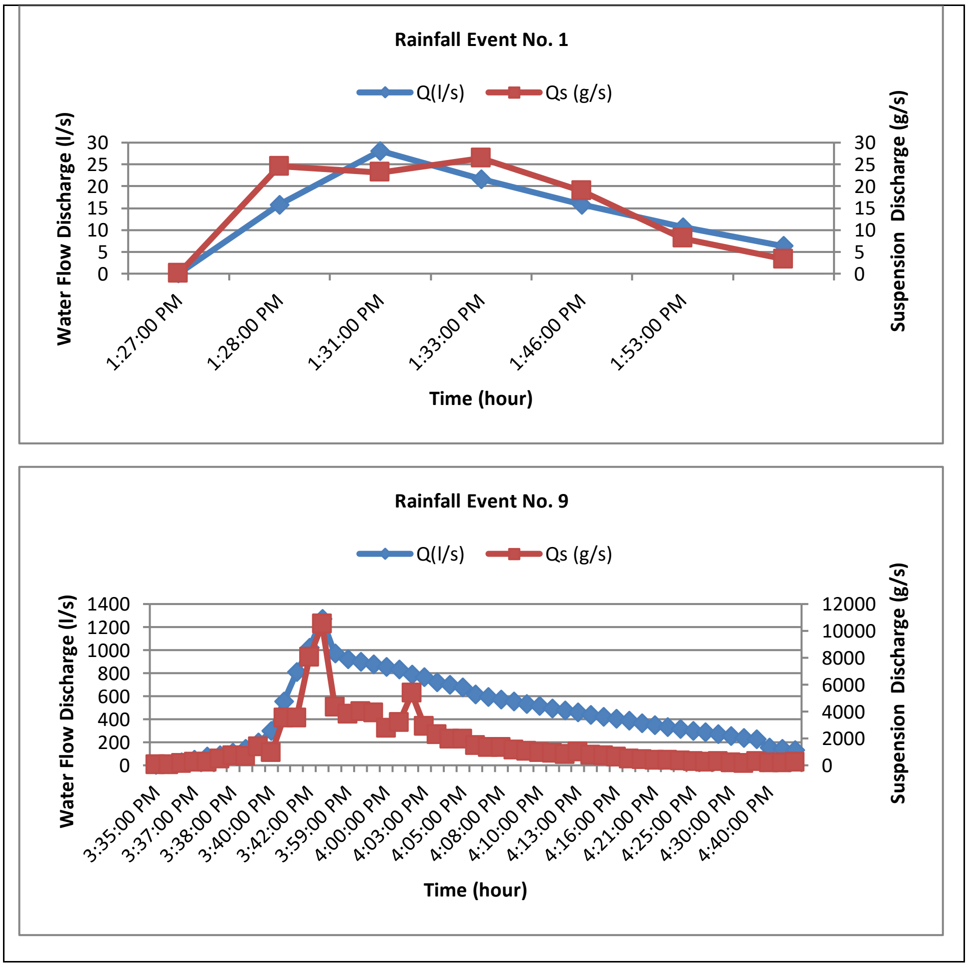
where Q= Water flow discharge (ls^{-1}); g= acceleration due to gravity (m/s^2); b= breadth (m); and H= Total Head (m).

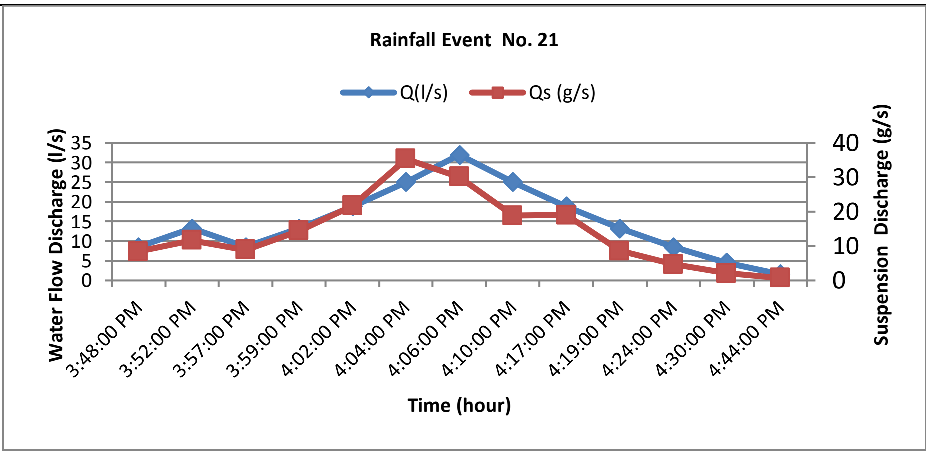
RESULTS AND DISCUSSION

The Relationship between Water Flow and Suspension Discharge

The conformity patterns between water flow and suspension discharge during the rising and falling limbs on the hydrograph are shown by the dynamics of suspension flow during rain events in the watershed of key settlement areas. Suspension discharge increased in tandem with an increase in water flow discharge at the rising limb. On the other hand, at the falling limb, there was a decrease in suspension discharge as well as a decrease in water flow discharge (Figure 2). The three patterns of water flow conformity and suspension discharge are the peak water flow discharge, peak water flow discharge, and peak water flow discharge. The peak water flow discharge occurs after the peak suspension discharge, the peak water flow discharge, and the peak water flow discharge. In the field, there were 38 rain events, with both peaks occurring in 28 of those events. In 5 of those events, the peak of flow discharge occurred before the peak of suspension, and in 5 of those events, it occurred after the peak of suspension (Table 1). This information indicates that the dynamics of flow discharge significantly influence suspension discharge and consequently affects the correspondent patterns of its peak. This significant influence is in line with Soewarno (1991); Arianti et al. (2012); Maulana et al. (2014). Additionally, it was mentioned that the dynamics of rainfall inputs, infiltration rate, and groundwater storage are all parts of a balanced system, along with the dynamics of runoff discharge (Handayani et al., 2005). When parameters for infiltration rate and groundwater storage are satisfied, rainfall input causes the production of suspension flow, which follows the dynamics of runoff formation (Parsons & Wainwright, 2000; Oktarina, 2005; Walker & Mostaghimi, 2009; Triatmodjo, 2013; Neno et al., 2016).

The hydrograph analysis's depiction of the dynamics of runoff production and suspension flow may be used to explain the changing suspension flow that corresponds to rainfall dynamics (Handayani & Indrajaya, 2011; Bisantino et al., 2013; Miller et al., 2015; Gao et al., 2017). At the beginning of the rainfall event, the flow rate tends to be low when the intensity and duration of rain are still low. Along with the increase in intensity and duration of rainfall, suspension discharge increases with flow discharge (Figure 2). This is because raindrops are producing more sediment and grinding (erosion) flow at ground level.





Note : The conformity of water flow discharge and suspension discharge occurs in 3 patterns: a. the peak of flow discharge occurs after the peak of suspension discharge; b. the peak of the water flow discharge corresponds to the suspension discharge; c. the peak of the water flow discharge precedes the peak of suspension discharge.

Figure 2. The types in the correspondence patterns of the peak suspension discharge and the peak water flow discharge during several rain events

Table 1. The Situation For The Suspension Measurement Elements In Every Rainfall Event

No	Rainfall Event	The amount of data	Peak of suspension concentration C_p (gl^{-1})	Peak Runoff Q_p (ls^{-1})	Peak of Suspension Discharge Q_{sp} (gs^{-1})	Type of tQ_p and tQ_{sp}
1	2	3	5	6	7	8
1	01-Mar-17	6	0.82	28.11	23.15	tQp>tQsp
2	01-Mar-17_1	5	2.92	312.07	909.70	tQp>tQsp
3	20-Mar-17	3	2.58	1.51	2.63	tQp=tQsp
4	20-Mar-17	12	1.51	106.74	161.57	tQp>tQsp
5	25-Mar-17	49	1.57	154.82	242.56	tQp=tQsp
6	25-Mar-17_1	17	1.23	95.74	117.35	tQp=tQsp
7	26-Mar-17	48	2.11	401.52	847.67	tQp>tQsp
8	03-Apr-17	17	1.11	25.10	27.91	tQp=tQsp
9	05-Apr-17	51	8.26	1270.53	10494.56	tQp=tQsp
10	06-Apr-17	24	2.18	0.62	1.30	tQp<tQsp
11	10-Apr-17	6	1.63	4.54	7.40	tQp=tQsp
12	11-Apr-17	5	0.84	4.54	3.81	tQp=tQsp
13	19-Apr-17	5	1.38	4.54	6.28	tQp=tQsp
14	19-Apr-17_1	16	1.47	39.53	58.16	tQp=tQsp
15	19-Jan-18	7	1.71	6.40	10.95	tQp=tQsp
16	20-Jan-18	13	1.42	32.01	45.57	tQp=tQsp
17	22-Jan-18	19	1.32	56.26	74.28	tQp=tQsp
18	24-Jan-18	37	3.20	167.80	537.05	tQp=tQsp
19	27-Jan-18	24	1.48	130.00	192.93	tQp=tQsp
20	29-Jan-18	7	1.08	4.54	4.92	tQp=tQsp
21	30-Jan-18	13	0.94	32.01	30.09	tQp<tQsp
22	01-Feb-18	20	2.31	95.74	220.77	tQp=tQsp
23	02-Feb-18	3	0.53	0.55	0.30	tQp=tQsp
24	04-Feb-18	20	1.94	47.62	92.45	tQp<tQsp
25	04-Feb-18-2	30	4.20	167.80	761.52	tQp=tQsp
26	11-Feb-18	2	0.28	1.58	0.44	tQp=tQsp

No	Rainfall Event	The amount of data	Peak of suspension concentration C_p (gl^{-1})	Peak Runoff Q_p (ls^{-1})	Peak of Suspension Discharge Q_{sp} (gs^{-1})	Type of tQ_p and tQ_{sp}
1	2	3	5	6	7	8
27	13-Feb-18	37	7.38	419.44	3096.66	tQp=tQsp
28	14-Feb-18	18	2.42	106.74	258.65	tQp<tQsp
29	15-Feb-18	17	2.09	142.22	296.82	tQp=tQsp
30	16-Feb-18	11	2.00	39.53	79.16	tQp=tQsp
31	20-Feb-18	10	0.74	18.83	13.89	tQp<tQsp
32	22-Feb-18	9	1.20	32.01	38.33	tQp=tQsp
33	23-Feb-18	17	3.69	283.89	1047.62	tQp=tQsp
34	24-Feb-18	4	0.59	0.55	0.33	tQp=tQsp
35	24-Feb-18_2	19	1.11	52.95	52.95	tQp=tQsp
36	06-Mar-18	11	2.53	47.62	120.49	tQp=tQsp
37	07-Mar-18	21	4.48	167.80	750.96	tQp=tQsp
38	08-Mar-18	26	6.10	456.05	2781.93	tQp=tQsp
	Amount	659	84.38	4959.83	23413.12	
	Min	2.00	0.28	0.55	0.30	
	Average	17	2.22	130.52	616.13	
	Max	51.00	8.26	1270.53	10494.56	

The Time Lag of Suspension Flow Formation and Rainfall

At the beginning of the rainfall and the formation of suspension flow there is a time lag that varies greatly (Table 2). The lowest time lag value is 2 minutes, while the highest is 41 minutes so that the average time lag is 10.36 minutes with a standard deviation of ±7.6 minutes. The standard deviation of the time lag for residential land use is relatively lower than for agroforestry land use, namely ±13 minutes (Hadini et al., 2021). There is a time lag between the start of suspension flow formation and the start of rain in this study which is controlled by several aspects of watershed conditions, including the dynamics of rain intensity, duration of previous rain events, and baseflow conditions in the channel. This can be seen in the results of statistical tests with positive correlation test values for aspects of the time lag, namely Time lag with the previous rain (0.092), maximum intensity (0.057), and rain duration (0.574) in the previous rain event. Several others showed a negative correlation, namely rain intensity (-0.157), runoff discharge (-0.075), suspension discharge (-0.084), and baseflow conditions in the channel (-0.276) (Table 3).

In the results of this test, there are no factors that provide a significant correlation for the initial time lag of suspension formation at certain levels in settlements. This shows that the difference in the time between the start of the suspension flow reaching the outlet and the start of the rain is determined by a combination involving the dynamics of the rain intensity, the duration of the rain in the previous rain event and the baseflow conditions in the channel, as well as the dynamics of the ongoing rainfall intensity. The combination factors in intensity and duration of rain for the previous and the ongoing rainfall as well as the state of the base flow in the channel can control the beginning of suspension flow formation in line with the concept of flow formation mechanism. Suspension flow formation occurs when the soil surface gets excess rain input after vertical absorption into the soil. This changes the humidity state of the initial soil surface, making the soil saturated with water, and forming runoff at the surface when there is still excess rainwater (Soemarto, 1999; Arsyad, 2006; Neno et al., 2016; Wang et al., 2015; Yan et al., 2015).

The time lag between the initial formation of suspension flow and the occurrence of rainfall in residential land use tends to be shorter than in agroforestry. As previously mentioned, both forms of land use have the characteristics of very thick soil and high clay content (> 50%) so that they are able to bind and store more water. However, initial runoff formation in settlements occurred more rapidly in this study. This shows that the characteristics of land cover in the form of housing, and land compaction by human activities in settlements encourage the rapid formation of concentrated runoff into surface runoff. Later this situation can practically interfere with the process of water infiltration into the soil layer, thereby reducing the absorption and holding capacity of groundwater (Mbaya et al., 2012). These results reinforce previous studies on the relationship between soil conditions, infiltration rates, and high groundwater deposits in controlling the formation of surface runoff and sediment carriers reported in Handayani & Indrajaya (2011) and Gumiere et al., (2015).

Table 2. Determinants of the Formation of Suspension Flow in The Settlement Land Use

No.	Rainfall events	Previous rain events			Ongoing Rain Events			Suspension flow occurrence		
		The time lag (hours)	Max intensity (mm/hour)	Duration (minutes)	Initial rainfall intensity (mm/hour)	The initial time lag (minutes)	Baseflow state (m)	Suspension flow occurrence	Flow Discharge (ls^{-1})	Suspension discharge (gs^{-1})
1	2	3	4	5	6	7	8	9	10	11
1	01/03/2017	23	39.6	105	12	21.00	0	Formed	15.76	24.59
2	01/03/2017_1	4	12	50	2.4	4.00	0	Formed	1.56	0.47
3	20/03/2017	7	18	193	19.2	13.00	0	Formed	6.40	16.50
4	20/03/2017	4	19.2	99	19.2	12.00	0	Formed	8.48	25.27
5	25/03/2017	17	18	146	20.4	13.00	0	Formed	1.58	3.12
6	25/03/2017_1	6	30	158	36	16.00	0	Formed	47.62	66.77
7	26/03/2017	12	30	104	38.4	7.00	0	Formed	1.58	0.57
8	03/04/2017	18	68	116	3.6	16.00	0	Formed	1.58	2.51
9	05/04/2017	20	31.2	76	4.8	5.00	0	Formed	1.58	1.19
10	06/04/2017	20	97.2	76	22.8	28.00	0	Formed	0.01	0.05
11	10/04/2017	2	48	112	10.8	8.00	0	Formed	1.58	2.30
12	11/04/2017	32	14.4	39	8.4	14.00	0	Formed	1.58	0.98
13	19/04/2017	25	8.4	48	18	8.00	0	Formed	1.58	3.71
14	19/04/2017_1	1	18	27	6	13.00	0	Formed	4.54	2.19
15	19/01/2018	15	18	81	15	17.00	0	Formed	1.58	1.05
16	20/01/2018	14	18	43	6.6	9.00	0	Formed	1.58	0.46
17	22/01/2018	47	6.6	73	23.4	19.00	0.005	Formed	1.58	0.27
18	24/01/2018	14	23.4	104	9.6	3.00	0	Formed	1.58	3.12
19	26/01/2018	16	9.6	158	16.8	5.00	0.005	Formed	0.55	0.13
20	27/01/2018	11	160.2	21	16.8	5.00	0.005	Formed	8.48	14.66
21	29/01/2018	50	10.8	77	28.2	5.00	0.002	Formed	0.55	0.10
22	30/01/2018	23	28.2	81	3.6	5.00	0	Formed	8.48	8.47
23	01/02/2018	21	30	76	13.2	4.00	0	Formed	4.54	2.51
24	02/02/2018	20	6	60	4.8	41.00	0	Formed	0.14	0.06
25	04/02/2018	46	4.8	60	30	7.00	0	Formed	4.54	5.20
26	4/02/2018-2	2	30	114	1.2	5.00	0.002	Formed	13.27	24.05
27	11/02/2018	60	48	300	12	17.00	0.005	Formed	1.58	0.44
28	13/02/2018	23	2.4	45	46.8	2.00	0.01	Formed	25.10	60.13
29	14/02/2018	21	4.8	90	4.8	7.00	0.01	Formed	4.54	2.47
30	15/02/2018	23	20.4	135	19.2	3.00	0.02	Formed	8.48	7.21
31	16/02/2018	23	19.2	53	18	4.00	0.02	Formed	13.27	6.52
32	20/02/2018	23	18	7	21.6	9.00	0.002	Formed	1.58	0.92
33	22/02/2018	19	25.2	80	21.6	7.00	0	Formed	4.54	5.71
34	23/02/2018	21	32.4	120	72	7.00	0	Formed	18.83	49.22
35	24/02/2018	24	86.4	102	36	6.00	0	Formed	0.14	0.06
36	24/02/2018_2	3	36	45	36	10.00	0	Formed	4.54	7.11
37	06/03/2018	21	3.6	150	32.4	9.00	0	Formed	4.54	2.87
38	07/03/2018	24	32.4	54	10.8	11.00	0	Formed	1.58	2.68
39	08/03/2018	23	31.2	99	33.6	9.00	0	Formed	8.48	22.62
	Average	19.9	29.7	91.7	19.4	10.36	0.0		6.1	9.7
	max	60	160.2	300	72	41.00	0.02		47.62	66.77
	Min	1	2.4	7	1.2	2.00	0		0.015	0.048
	Sdev	13.2	29.8	53.7	14.5	7.60	0.0		8.8	16.2

Table 3. Correlation test results of the relationship between parameter aspects on initial time lag for suspension flow to outlets in the settlement wathershed

Correlation in each parameter aspects at the key area of settlement watershed		
Parameter Aspect		The initial time lag to the outlet (minutes)
Time lag with the previous rain (hours)	Pearson Correlation	.092
	Sig. (2-tailed)	.576
	N	39
Previous max rain intensity (mm/hour)	Pearson Correlation	0.057
	Sig. (2-tailed)	.730
	N	39
Previous rain duration (minutes)	Pearson Correlation	.093
	Sig. (2-tailed)	.574
	N	39
Initial rain intensity of suspension flow (mm/hour)	Pearson Correlation	-.157
	Sig. (2-tailed)	.341
	N	39
Suspension flow occurrence	Pearson Correlation	.(a)
	Sig. (2-tailed)	-
	N	39
Runoff Discharge (ls^{-1})	Pearson Correlation	-.075
	Sig. (2-tailed)	.650
	N	39
Suspension discharge (g/s)	Pearson Correlation	-.084
	Sig. (2-tailed)	.611
	N	39
Base flow state (m)	Pearson Correlation	-.276
	Sig. (2-tailed)	.089
	N	39

The initial infiltration rate is influenced by the initial water content in conjunction with infiltration. The mechanism of surface runoff, which involves the fulfillment of groundwater content and infiltration rate in settlements is ineffective because it is disrupted through the formation of faster flow concentrations by land cover from various facilities in the settlement. The concept that the higher the need to meet the initial soil moisture content, the smaller the initial infiltration rate, which in turn can affect the formation of surface runoff to be slower, does not apply in settlements; in fact, surface runoff and suspended flow are faster with the accumulation of faster flow concentrations (Haridjadja et al., 1990; Asdak, 2004).

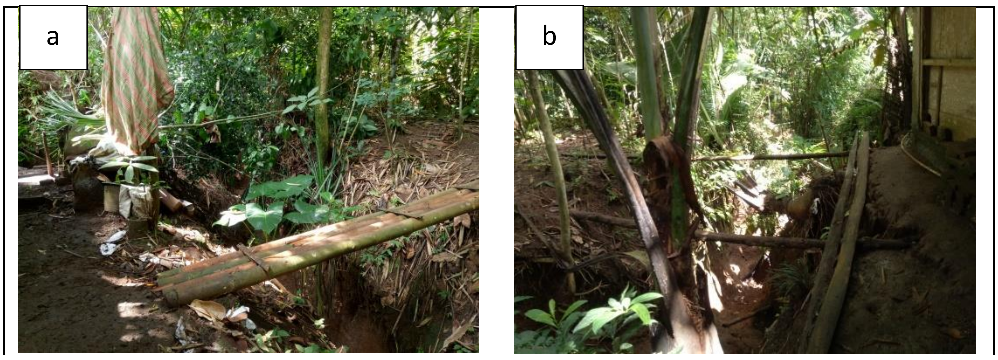
The Characteristics of The Grain Content of The Suspension Flow

In the settlement watershed's key areas, the concentration of the suspension flow content during peak discharge situations ranged from 0.28 gl^{-1} to 8.26 gl^{-1} with an average of 2.22 gl^{-1} (Table 1). During rainfall event 26, the lowest suspension content concentration recorded 0.28 gl^{-1} with a peak water flow discharge of 1.58 ls^{-1}. While rainfall event 36 produced the maximum suspension concentration of 8.26 gl^{-1} and had a peak water flow discharge of 1,270.53 ls^{-1}. The peak discharge of a low water flow has a low concentration of suspension content, whereas the peak discharge of a large water flow has a high concentration of suspension content, showing how the peak discharge of the water flow impacts the level of concentration of suspension content in settlements. In line with some previous studies, the situations regarding flow discharge affects suspension levels, the association of suspension grain content with flow discharge situations (Kellner & Hubbart, 2018; Hadini et al., 2019), and its relation to flow speed (Steegen et al., 2000; Tillinghast et al., 2011).

The clay fraction dominates the grain size of the suspension content. According to the watershed's surface soil layer's clay content, clay is present in the dominating grain size proportion. Based on the proportions of clay fractions measuring less than 0.002 mm, silt fractions measuring between 0.002 and 0.02 mm, and sand fractions measuring between 0.02-2 mm, the analysis of the suspension content's grain size was divided into groups. Averaging 1.76% sand, 25.65% silt, and 72.59% clay make up the suspension content in the grain size on the rising limb. Meanwhile, the average percentage size of consecutive suspension content in the grain size at the falling limb were sand 2.52%, silt 28.04%, and clay 69.45%. The grain size fraction on the surface soil layer had an average percentage of sand 1.76%, silt 25.65%, and clay 72.59%.

The fraction of clay in suspension decreased during the duration of the experiment, going from 72.59% in the rising limb to 69.45% in the falling limb. Meanwhile, the fraction of suspension grain size on sand showed an increase from 1.76% to 2.51% and silt from 25.65% to 28.66%. The increase in the size of the grains of sand and silt and the decrease in the size of the clay in the suspension content during the flow shows the difference in the degree of ease of transportation process in the grain size of the suspension between sand, silt and clay, as well as an increase in the transport of sediment originating from erosion in the channel. Even with a smaller flow rate, the clay fraction continues to build up in the rising limb. This is so that it may dissolve and be carried by water flow since the clay fraction has very tiny and fine particle sizes. The fraction of silt and sand is larger and coarser, therefore, the decomposition and transport process requires energy at large flow discharges and a longer time (Castillo et al., 2007; Haregeweyn et al., 2012; Nugroho & Basit, 2014; Hadini et al. 2021). In other words, the increase in silt and sand content of suspension flow indicates that the increase in water flow discharge triggers the destruction of soil aggregates and intensive sediment transport (Li et al., 2015; Nocoń, 2016; Maltsev & Yermolaev, 2020).

The process of erosion events in key areas of settlements watersheds can be observed in the field. The results showed that the erosion processes were controlled by both physical characteristics of the land, such as the climate, especially the intensity of rain, topography, especially relief, vegetation, soil, and the human activities (Figure 3). Meanwhile, suspension flows derived from erosion in the channel occurred at the mountain watersheds with settlement land use triggered by the accumulation and concentration of streams that experience an increase in flow discharge (Sambodo & Arpornthip, 2021).



Note: **a,b** Forms of erosion channel from activities in settlement buildings. **c, d.** Source of water production that triggers the concentration of flow from the roofs of houses and compaction of roads in settlements.

Figure 3. State of erosion sources and sources of sediment production by several settlement facilities that trigger the concentration of flows in watersheds

Based on this study, natural processes following watershed characteristics and anthropogenic activities such as the type of land use in the volcano watershed area can trigger erosion and sources of suspension production that cause soil loss. Consequently, this can lead to a decrease in soil fertility for the in situ area as well as sedimentation and siltation processes at the downstream. These processes can be indicators for the assessment of watershed criticality.

This study recommends that land-use efforts in the upstream area of the volcano watershed should involve the analysis of geophysical characteristics of the land, covering climate aspects, especially rainfall, topography (relief), land cover vegetation, as well as anthropogenic activities that include the choice of land management techniques and water drainage channels. Moreover, Indonesia is dominant with volcanic landscapes that can have relatively the same characteristics with that of Bompon. Therefore, the results in the form of suspension flow patterns and dynamics on settlement land use in this location can be a reference for managing or selecting land use forms for volcanic landscapes in other areas.

CONCLUSION

The rising and falling limbs display the suitable pattern in the dynamics of water flow discharge and suspension flow discharge. In the case of peak discharge, there are three different ways that this relationship can occur: (1) the peak discharge of the water flow corresponds to the peak discharge of the suspension; (2) the peak discharge of the water flow precedes the peak discharge of the suspension; and (3) the peak discharge of the water flow occurs after the peak discharge of the suspension. The time lag between the start of the rainfall event and the formation of suspension flow at a particular outlet varies from 2 to 41 minutes, with an average of 10.36 minutes. The peak suspension content of the flow discharge varied between 0.28 gl^{-1} and 8.24 gl^{-1}, with an average of 2.22 gl^{-1}. The grain size of the suspension content in each fraction of clay, silt, and sand varied during the rising and falling limbs.

ACKNOWLEDGMENTS

The author would like to thank the relevant parties who have helped with the implementation and preparation of the paper, especially the Education Fund Management Institute (LPDP) for funding doctoral studies as well as funding for this research. The authors also thank the soil laboratory staff and technicians for their assistance during the analysis process, the transbulent team that assisted with field activities and supporting information in the study area in the Bompon watershed.

DECLARATIONS

Conflict of Interest

The authors declare that in the research and preparation of this article, there are no conflict of interests related to certain organizations, institutions, and individuals or groups.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY

Data used to support the findings of this study are available from the corresponding author upon request.

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