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Hydrological Performance of Way Linti Watershed Based on Discharge Fluctuation Coefficient, Runoff Coefficient, and Sediment Load

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ABSTRACT

The response of the hydrological characteristics of a watershed to rain events is strongly influenced by land cover conditions and topography. The research was carried out in the Way Linti watershed Pesawaran District, Lampung Province. This study aims to learn of hydrological characteristics of Way Linti watershed which is includes the calculation of the discharge fluctuation coefficient (DFC), runoff coefficient (RC) and Sedimentation. The method used in this study refers to the Minister of Forestry Regulation No. 61/2014 concerning Monitoring and Evaluation of Watershed Performance. The data collected includes rainfall, land coverage, river discharge data and sedimentations. The results of the data collection were analyzed to determine the actual condition of hydrological performance of Way Linti watershed. The results of research of the hydrological characteristics of the Way Linti showed that discharge fluctuation coefficient (DFC) of 367.94 which is very high category, runoff coefficient (RC) of 0.193 (very low category), and sediment load (SL) of 58.78 mg/l (very high category).

1. INTRODUCTION

One of the challenges of conserving water resources is the increasing problems in watershed environments. According to Act Number 37 of 2014 concerning Soil and Water Conservation (Presiden RI, 2014) the watershed is defined as land area units where with rivers and tributaries that function to collect, store, and drain water originating from rainfall into lakes or to the sea naturally, the boundary on land is a topographical separator and the boundary at sea extends to water areas that are still affected by land activities. A watershed is an area bounded by topographical separators that collect, store and drain rainwater that falls on it into rivers which eventually empty into lakes or into the sea (Nilda *et al.*, 2014; Gachene *et al.*, 2019).

A watershed can be viewed as a natural system where hydrological biophysical processes take place which are part of the hydrologic cycle or the water cycle. Seyhan (1990) describes the hydrologic cycle as a series of stages through which water moves from the atmosphere to the earth and returns to the atmosphere. This cycle includes evaporation from land, sea, or inland waters, followed by condensation that forms clouds, precipitation, accumulation in soil or water bodies, and re-evaporation. A watershed, also known as a catchment area, is an ecosystem comprising natural resources—soil, water, and vegetation—and human resources involved in the use of these natural resources (Asdak, 2007; Weil & Brady, 2017). The objective of this research is to analyze water management in the Way Linti watershed in order to characterize the watershed performance. The research is expected to find characteristic of the watershed such that a recommendation can be formulated wisely.

2. MATERIALS AND METHODS

This research was carried out in the Way Linti watershed area from March to April 2022. The Way Linti watershed area (Figure 1) is administratively located in Gedong Tataan District, Pesawaran Regency, Lampung Province. The research is carried out to find out how the condition of the water system in the area which is also the upstream part of the large Way Sekampung watershed area. The Way Sekampung Watershed is one of the 108 Priority Watersheds to be restored as determined by the Ministry of Environment and Forestry. The materials and tools in this study were laptops with Microsoft Office 19, ArcGIS 10.4, stationery, and recording forms. The data collected in this study are daily rainfall data, daily water level by Automatic Water Level Recorder and water samples obtained throughout 2021. The hydrological data calculation was based on Minister of Forestry Regulation Number 61 of 2014 on the Monitoring and Evaluation of Watershed Performance (KLHK, 2014).

2.1. Discharge Fluctuation Coefficient

Discharge Fluctuation Coefficient (*DFC*) is the ratio between the maximum discharge (Q_{max}) and minimum discharge (Q_{min}) in a watershed area. DFC describes the condition of the soil absorption capacity in a watershed area. The higher the DFC, the greater the runoff is during the rainy season, but during the dry season the water content is very low.

$$DFC = \frac{Q_{max}}{Q_{min}} \tag{1}$$

where *DFC* is the Discharge Fluctuation Coefficient, Q_{max} and Q_{min} is the maximum and minimum discharge (m^3/s), respectively. After obtaining the *DFC* value, then weighting and scoring is carried out as shown in Table 1.

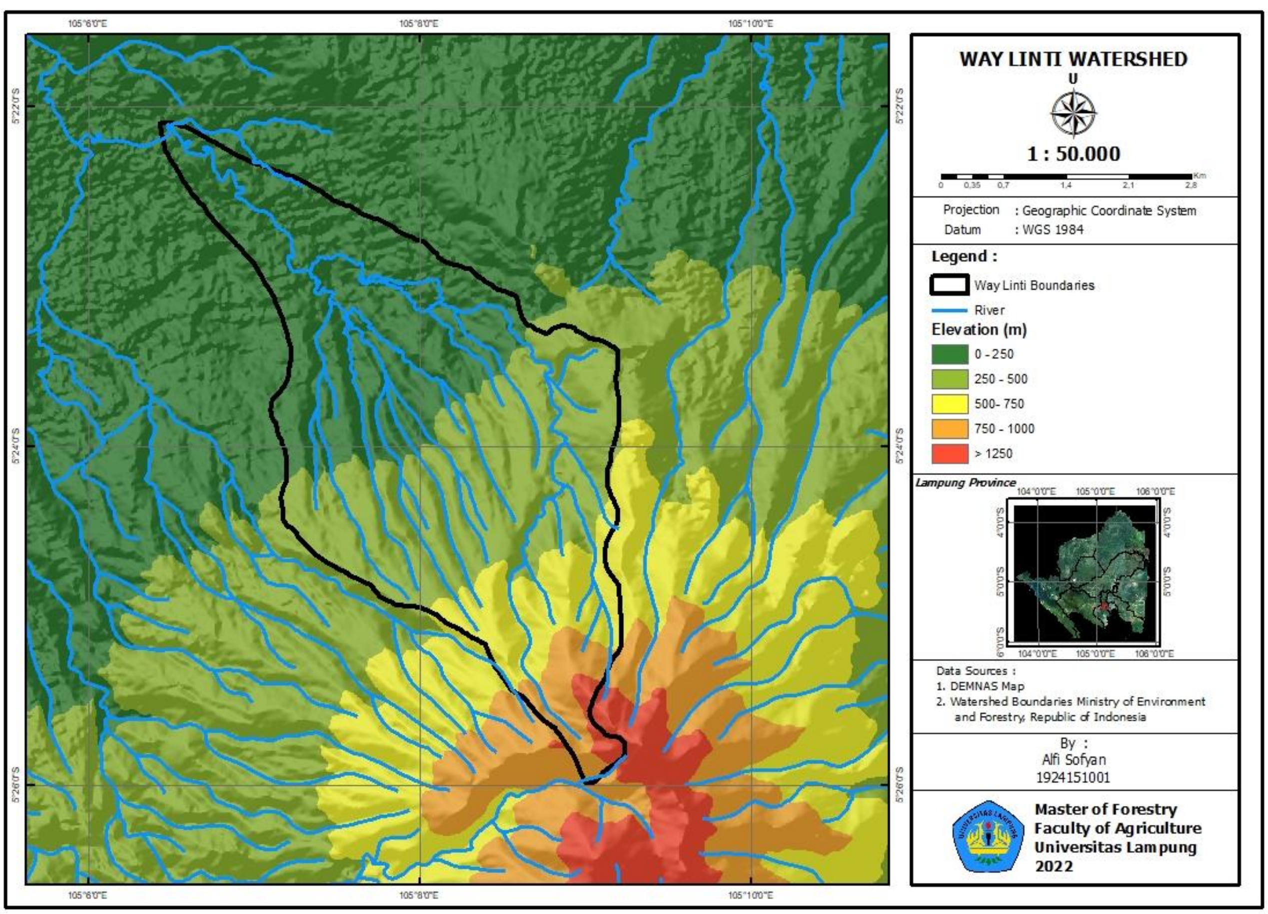

Figure 1. Research location the Way Linti Watershed in the map

Table 1. Score and classification of watershed based on DFC value.

Sub Criteria	Weight	Parameter	*DFC* Value	Class	Score
Discharge Fluctuation Coefficient (DFC)	5	$DFC = \frac{Qmax}{Qmin}$	DFC ≤ 20	Very Good	0.5
			20 < DFC ≤ 50	Good	0.75
			50 < DFC ≤ 80	Medium	1
			80 < DFC ≤ 110	Worst	1.25
			DFC > 110	Very Worst	1.5

Table 2. Score and classification of watershed based on runoff coefficient (RC) value.

Sub Criteria	Weight	Parameter	RC Value	Weight	Score
Runoff coefficient (RC)	5	$CRO = \frac{Q_{annual}}{P_{annual}}$	RC ≤ 0.2	Very Good	0.5
			0.2 < RC ≤ 0.3	Good	0.75
			0.3 < RC ≤ 0.4	Medium	1
			0.4 < RC ≤ 0.5	Worst	1.25
			RC > 0.5	Very Worst	1.5

2.2. Runoff Coefficient

Runoff coefficient (RC) is the ratio between the annual flow thickness (*Q*, mm) and the annual rainfall thickness (*P*, mm) in a watershed. The RC describes the condition of how much rainwater becomes runoff in the watershed. The CRO values obtained are then weighted and scored as shown in the following Table 2.

$$CRO = \frac{Q_{annual}}{P_{annual}} \tag{2}$$

2.3. Sediment Load

Sedimentation refers to the accumulation of soil particles, primarily silt, carried by river flow from upstream erosion processes. These particles settle in downstream areas where the rate at which they deposit is slower than the rate at which they are transported by the water. The occurrence of erosion and sedimentation depends on several factors, namely the characteristics of rain, slope, cover crops and the ability of the soil to absorb and release water into the shallow layers of soil, the impact of soil erosion can cause sedimentation in rivers so as to reduce the carrying capacity of river (Sutrisno, 2002; Aksoy & Kavvas, 2005; Alewell *et al.*, 2019; Bekele & Gemi, 2021). Sediment load (*SL*) was calculated from runoff debit Q (m^3/s), and sediment concentration Cs (mg/L) according to the following equation (Wibisono, 2018), with a conversion factor $k = 0.0864$.

$$SL = k \times Cs \times Q \tag{3}$$

Sedimentation concentration was obtained through laboratory tests from water samples collected throughout 2021. After laboratory tests were carried out, weighting and scoring were carried out as shown in the following Table 3.

Table 3. Score and classification of watershed based on the sediment loads (*SL*)

Sub Criteria	Weight	Parameter	SL Value	Class	Score
Sediment Load (SL) (mg/l)	4	$SL = k \times Cs \times Q$	SL < 5	Very Good	0.5
			5 < SL ≤ 10	Good	0.75
			10 < SL ≤ 15	Medium	1
			15 < SL ≤ 20	Worst	1.25
			SL>20	Very Worst	1.5

3. RESULTS AND DISCUSSION

3.1. Rainfall Analysis

Rain comes from water vapor in the atmosphere, so its form and amount are influenced by climatological factors such as wind, temperature and atmospheric pressure. The water vapor rises into the atmosphere so that it cools and condenses to form water droplets and ice crystals which eventually fall as rain (Triatmodjo, 2008; Lenvain, 1975; Bols, 1978). Rainfall on the earth's surface is measured as a water depth, typically in millimeters (mm), and is assumed to be uniformly spread over the catchment area. Rainfall intensity refers to the amount of rain received per unit of time, commonly expressed in mm per hour, mm per day, mm/day, mm/week mm/month, mm/year, etc., which are successively often called hourly, daily, weekly, monthly, yearly rain, and soon. The intensity of rainfall greatly influences the amount of erosion that occurs, both on agricultural land and forest land (Triatmodjo, 2008; Bols, 1978; Lenvain, 1975; Wischmeier & Smith, 1978). Rainfall data was obtained from collecting rain data for 2021 from River Flow Observation Station (RFOS) in the Way Linti watershed. The Way Linti Watershed has an average wet month (> 100 mm/month) of 8 months and a dry month (< 100 mm/month) of 4 months. Comparison of wet months and dry months in the Way Linti watershed shows that the area has a moderate climate type (Table 4 and Figure 2).

Table 4. Rainfall summary of Way Linti Watershed

Precipitation	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Rainfall (mm)	485	230	456	341	162	252	143	69	71	38	78	213	2538.0
Average rainfall (mm)	15.65	7.93	14.71	11.37	16.20	18.00	11.00	13.80	2.37	1.27	2.79	6.87	9.0
Maximum rainfall (mm)	77	75	146	124	49	36	27	33	43	16	31	73	146.0
Minimum rainfall (mm)	4	4	5	4	5	5	3	4	4	4	4	4	3.0
Rainy days (day)	13.00	18.00	14.00	15.00	10.00	14.00	5.00	4.00	4.00	4.00	7.00	14.00	122.0

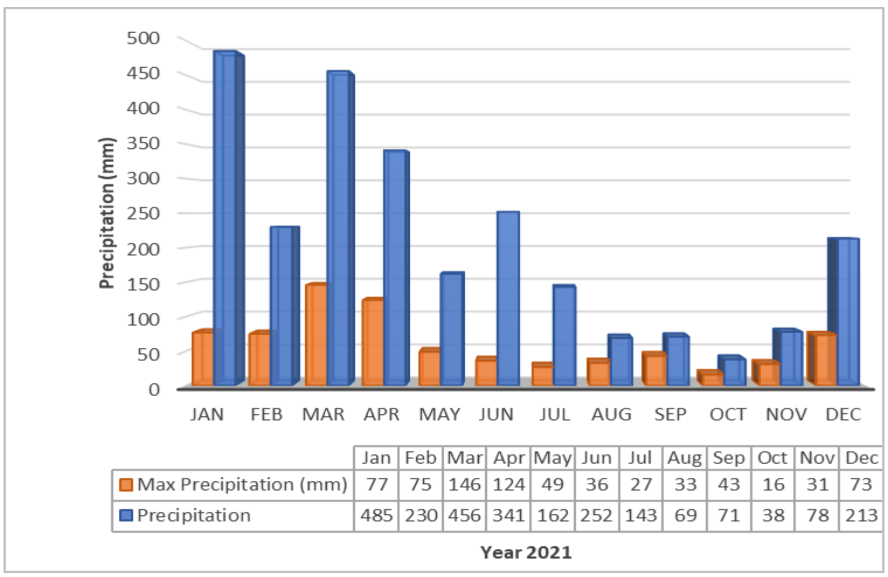

Figure 2. Monthly rainfall at Way Linti Watershed for 2021 (mm)

3.2. Topography

The topographical condition of the Way Linti Watershed is generally divided into two categories, namely the flat-sloping topography covering an area of 685.19 ha (52.71%), the remaining 776.09 ha (47.29%) fall into the rather steep to very steep category. Such conditions will greatly affect the response of the watershed to the rainfall that falls on it. If the land cover is dominated by dry land agriculture, it will certainly increase the surface runoff rate, which in turn will increase river discharge fluctuations (Pandey *et al.*, 2007). This is in accordance with the research of Yustika *et al.* (2019a) which states that the runoff rate is not only influenced by rainfall intensity, it is also strongly influenced by the condition of the vegetation cover and the condition of the slope. In detail, the topographic conditions and slope maps of the Way Linti watershed are presented in Table 5 and Figures 3.

Table 5. Topography of Way Linti Watershed

No.	Topography	Slope	Area (Ha)	%
1	Flat	0 – 8 %	403.84	24.61
2	Sloping	8 – 15 %	461.35	28.11
3	Rather Steep	15 – 25 %	368.05	22.42
4	Steep	25 – 45 %	279.62	17.04
5	Very Steep	> 45 %	128.42	7.82
	TOTAL		1,641.28	100.00

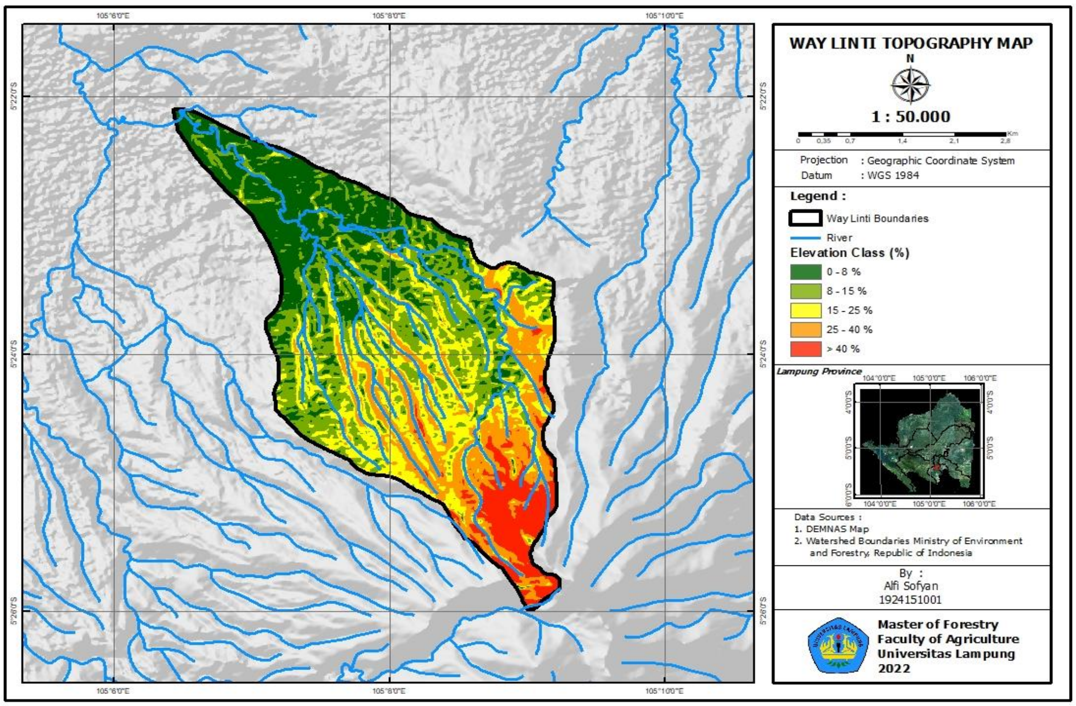

Figure 3. Topographical class of Way Linti watershed

3.3. Land Use of Way Linti Watershed

Way Linti watershed has an area of 1641.28 ha with land cover dominated by dry land agriculture covering an area of 986.10 ha (60.08%), the rest successively being land cover in the form of forest 10%, plantations 17.64%, rice fields 6 .13% and settlements 5.67%. Such conditions will affect the hydrological response of the watershed, this is partly due to the fact that the mixed dry land agricultural area is not covered by permanent vegetation throughout the year. When the land is not covered with permanent vegetation and high-intensity rain occurs, it will cause an increase in surface runoff. In detail, the condition of land cover is presented in Table 6 and Figure 4.

Table 6. Land coverage of Way Linti watershed

No.	Landcoverage	Area (Ha)	%
1	Secondary Forest	171.88	10.47
2	Mixed Dryland Agriculture	447.68	27.28
3	Plantation	289.57	17.64
4	Dryland Agriculture	538.42	32.80
5	Rice Field	100.66	6.13
6	Settlement	93.07	5.67
	TOTAL	1,641.28	100.00

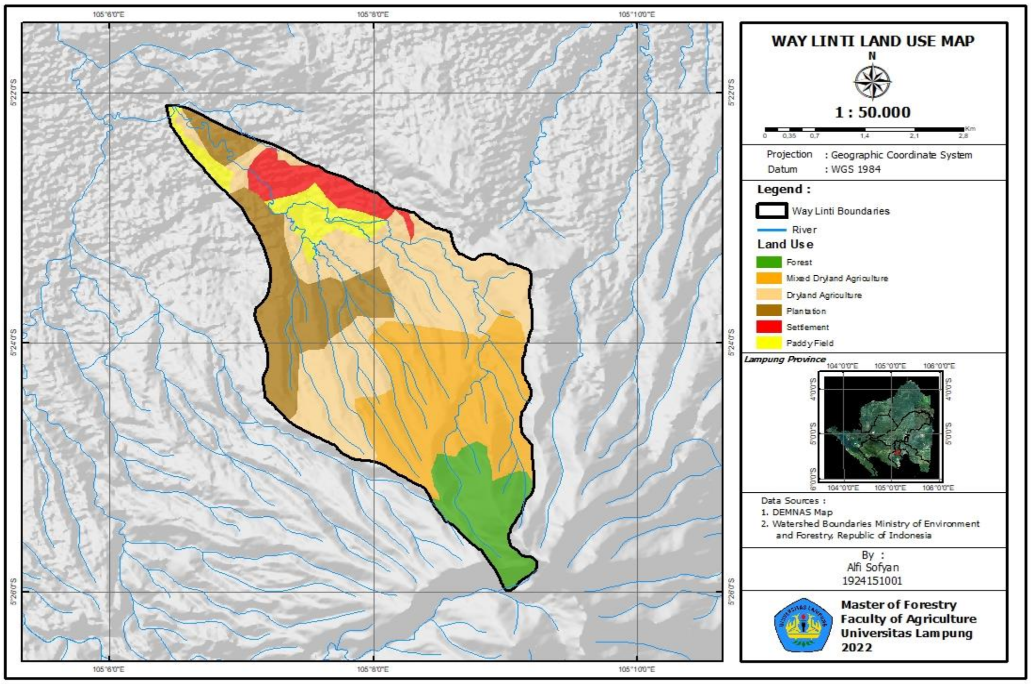

Figure 4. Land Use of Way Linti Watershed

3.4. River Discharge Analysis of Way Linti

The flow rate describes the response of the watershed system to rainfall input in a systematic way whole. The amount of flow discharge is strongly influenced by soil conditions and the area covered vegetation, topography, and rainfall that occurs (Watershed Agency, 2008). Field data measurements were carried out by automatic water level recorder (AWLR) in the Way Linti watershed which was recorded every day at 07:00, 12:00 and 17:00. The measurement point is located at the Way Linti Watershed River Flow Observation Station (RFOS). To get the river discharge flow value, there are two basic data, namely the wet cross-sectional area of the river (m^2) and the flow velocity data (meter/s). The wet cross-sectional area is obtained from measuring the entire wet part of the river body. While the flow velocity is obtained from sampling the water velocity in each segment of the river depth for a certain period of time (Table 7 and Figure 5). Apart from topographic conditions and the amount of rainfall, the condition of land cover in the form of agricultural land, plantations or forests will influence river discharge in the watershed concerned (Borreli *et al.*, 2021).

Table 7. Daily river discharge of Way Linti (2021)

No.	Month	Daily Discharge (m^3/s)			
		Discharge Volume	Discharge Average	Maximum Discharge	Minimum Discharge
1	January	36.11	1.16	5.75	0.25
2	February	24.31	0.84	5.51	0.21
3	March	34.71	1.12	4.66	0.21
4	April	22.87	0.76	1.96	0.30
5	May	19.77	0.64	1.56	0.31
6	June	25.92	0.86	3.08	0.40
7	July	16.42	0.53	1.27	0.21
8	August	12.98	0.42	1.07	0.21
9	September	6.73	0.22	0.97	0.07
10	October	1.68	005	0.30	0.02
11	November	1.21	0.04	0.26	0.02
12	December	2.04	0.07	0.24	0.02
		204.76	0.56	5.75	0.02

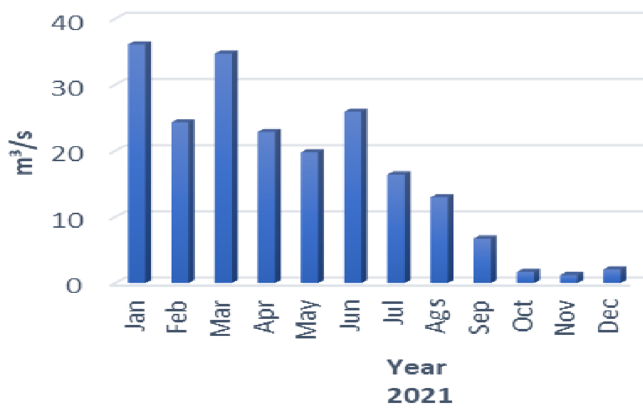

Figure 5. Monthly discharge at Way Linti watershed in 2021.

3.5. Discharge Fluctuation Coefficient (DFC)

The results of the analysis of the Way Linti watershed debit data throughout 2021 obtained a maximum discharge value (Q_{max}) of 5.754 m^3/s and a minimum discharge value (Q_{min}) of 0.016 m^3/s. The *DFC* value from the ratio of the maximum discharge and minimum discharge is 367.94. Based on the classification and scoring, the *DFC* of Way Linti watershed is in the very high class (*DFC* > 110) with a score of 1.5 (Table 8).

A high *DFC* value suggests a significant difference between Q_{max} and Q_{min}, meaning runoff is considerably higher in the rainy season while water flow in the dry season is minimal, potentially indicating drought conditions. This implies that the land's capacity to absorb and retain rainwater is low, resulting in much of the runoff flowing directly into rivers and eventually reaching the sea. Consequently, water availability in the watershed during the dry season is limited (KLHK, 2014).

The research results in the Way Linti watershed show the maximum discharge value (Q_{max}) ofof 5.754 m^3/second and a minimum discharge value (Q_{min}) of 0.016 m^3/second and a *DFC* value of 367.94. The Discharge Fluctuation Coefficient (*DFC*) value illustrates that the runoff value that occurs during the rainy season is high so that runoff water. Whereas during the dry season there is a very small runoff value and results in drought. Discharge fluctuation coefficient (*DFC*) often referred to as runoff coefficient (*RC*) is a watershed hydrological characteristic parameter obtained from the comparison between maximum discharge (Q_{max}) and minimum discharge (Q_{min}) or often abbreviated as Q_{max}/Q_{min} parameter, which is an indicator of hydrological quantities to express whether watershed functions as a good processor or not, can be viewed from the point of view of the comparison value (Sunardi, 2016).

Table 8. The *DFC* classification of Way Linti watershed (2021)

Sub Criteria	Weight	Actual Value	Score	Class	Score
Discharge fluctuation coefficient (*DFC*)	5	367.94	*DFC* > 110	Very Worst	1.5

Table 9. Runoff coefficient classification of Way Linti watershed (2021)

Sub Criteria	Weight	Actual Value	Score	Class	Score
Runoff coefficient (RC)	5	0.193	CRO ≤ 0.5	Very Good	0.5

3.6. Runoff Coefficient

The results of the analysis of rainfall and river discharge data for 2021 obtained a rainfall volume value of 2,538.00 mm and a river discharge of 488.74 mm. The *RC* value from the ratio of rain thickness and river flow thickness during 2021 is 0.193. Based on the classification and scoring the Way Linti watershed *RC* value is included in the very low class (*RC* ≤ 0.2) with a score of 0.5 (Table 9).

The actual *RC* value of the Way Linti watershed is 0.193 which illustrates that 19.3% of the total rainfall that falls in the Way Linti watershed area becomes direct runoff and the rest is base flow. This is in line with Asdak (2007) stating that the greater the change in land use, for example the change from forest to agricultural fields, the greater the change that occurs in surface runoff. Run off that occurs in large quantities will trigger flooding and erosion, which can damage the watershed. The movement of run off generally follows the movement of rainfall. When rainfall increases, run off also increases. According to Haryanto *et al.* (2017) there is a gap between the rainy season and the dry season, then the influence of the infiltration coefficient and the runoff coefficient affects the total direct runoff in an area.

Surface flow is the amount of rainfall that is not infiltrated by the ground surface. This is largely determined by the condition of the land cover which is described by the curve number value, where the better the land cover condition, the smaller the curve number value, the surface flow that occurs will also be smaller (Mahapatra *et al.*, 2018; Panagos *et al.*, 2007). According to Abdullah & Muchtar (2007), the factors that affect the amount of river discharge are: (1) Rain, rain intensity and duration of rain greatly affect the amount of infiltration, groundwater flow and surface runoff. The length of time it rains is very important in relation to the length of time it takes for rainwater to flow into the river. (2) Topography, especially the shape and slope of the slopes affect the length of time rainwater flows through the ground surface to the river and the intensity of the flood. (3) Soil type and structure greatly affect the shape and density of drainage. (4) The state of the plants will affect the amount of interception, transpiration, infiltration, and percolation. (5) Human activities by constructing buildings, clearing agricultural land, urbanization can change the nature of the watershed.

3.7. Sediment Load (SL)

According to Kodoatie & Sjarief (2008), sediment is material that comes from the headwaters of the river and is then carried away by the flow when erosion occurs in the river. According to Kodoatie & Sjarief (2008), the sediment load in each river depends on the number of correlated variables. In all river conditions, there is no one equation that can represent all of them to be applied. Asdak (2007) translates sediment as the result of erosion processes, both surface erosion, trench erosion, or other types of soil erosion. Sedimentation that occurs in the river will indirectly reduce the river discharge. The amount of sedimentation that occurs in rivers is greatly influenced by the amount of erosion on the land. Land erosion can be reduced by the condition of dense and good plant roots (Gyssel *et al.*, 2005; Kinnel, 2010). Sedimentation values were obtained from water samples taken throughout 2021. Then laboratory tests were carried out on these water samples. Based on laboratory test results, a sediment load value of 58.78 tons/ha/year was obtained (Table 10).

Table 10. Classification of Sediment Load in the Way Linti Watershed in 2021(mg/l)

Sub Criteria	Weight	Actual Value	Score	Class	Score
Sediment Load (SL)	4	58.78	SL > 20	Very Worst	1.5

Sediment rate is the amount of soil and parts of soil that are transported by water from a place that is eroded in a river basin and enters rivers or water bodies (Arsyad, 2006). Laboratory test results from water samples taken in the Way Linti watershed obtained a sediment load of 58.78 ton/ha/year. Sediment yield depends on the amount of total erosion that occurs in a watershed or sub-watershed and depends on the transport of eroded soil particles. Sediment production refers to the rate at which sediment flows past one observation point in a watershed/sub-watershed. The amount of sediment yield depends on the physical characteristics of a watershed or sub-watershed and is expressed as the volume or weight of sediment per unit area of the catchment area per unit time (Asriadi & Pristianto, 2018). This high sedimentation value can be caused by the type of soil that is easily eroded and also the high rainfall which causes the beginning of erosion of the soil aggregate (Wibisono, 2021). Aji (2014) states that one of the most influential hydrological factors on erosion and sedimentation is rainfall. Rain intensity as a product of rainfall will determine the amount of flooding that occurs. The greater the rainfall, the greater the flood which has implications for the large amount of soil that is washed away into the stream and later undergoes a process of sedimentation downstream.

4. CONCLUSION AND SUGGESTIONS

Research on water has been performed based on the assessment of Minister of Forestry Regulation Number 61 of 2014 concerning Monitoring and Evaluation of Watershed Performance. Based on field analysis, it is revealed that water management system in the Way Linti Watershed is characterized by the discharge fluctuation coefficient (*DFC*) of 367.94, which is very high category or very worst. Even though management system in the Way Linti Watershed has very low runoff coefficient (*RC*) of 0.193, but the sediment load (*SL*) based on laboratory test resulted a value of 58.78 mg/l, which is included in the very high category. To upgrade the hydrological performance of Way Linti Watershed, it is recommended to make rehabilitations on the watershed especially enrichment the land coverage by permanent vegetation like agroforestry.

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