Peak discharge estimation to evaluate and monitor the Gumbasa Watershed performance, Central Sulawesi, Indonesia

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Abstract: One of the appropriate strategies to evaluate watershed health is by determining peak discharge. The influence of frequent floods and landslides due to forest destruction, and land degradation, especially the upstream, can affect watershed health and the carrying capacity. This study aims to determine the estimated peak discharge the Gumbasa Watershed performance, Central Sulawesi, Indonesia to monitor and evaluate the performance of the main watershed. This was conducted using a rational method with a combined and average flow coefficient approach. The rainfall intensity was calculated based on the concentration-time, which is highly dependent on the characteristics of the flow area. The results showed the flow coefficient in the Palolo and Gumbasa downstream areas was 0.45 and 0.57, which means that 45% (Palolo) and 57% (Gumbasa) of the falling rain will become surface runoff classified as high. Conversely, flow coefficient was low (0.12) for Lindu, meaning that some of the rainwater is flowing on the land surface, thereby causing high peak discharge, especially in the downstream, whereas in the upstream part of the sub watershed Lindu has a high land cover density, which causes a small runoff coefficient. Therefore, it is necessary to conserve and restore land through reforestation and rehabilitation to minimize the flow coefficient and peak discharge.

Keywords: conserve, hydrology, land degradation, runoff coefficient

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[*] 1 Introduction

Floods or peak discharge and erosion are recognized globally as a serious problem in the world, especially in the tropics, and is a fundamental problem in the global climate system (Li et al., 2020; Mohanty et al., 2020; Seddon et al., 2020) since they can damage the ecosystem arrangement and land productivity (Naharuddin et al., 2020).

The determination of peak discharge with other hydrological indicators is very important to evaluate watershed health and also to generate important data for sustainable watershed management (Fercher et al., 2018; Volpi et al., 2018). It has also been reported to be very useful in flood frequency analysis and plays an important role in the hydrological cycle and climate change (Prakash

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et al., 2014). The main factors affecting peak discharge include rainfall characteristics such as duration, amount, intensity and pattern (Adib et al., 2018; Wei et al., 2019) as well as the attributes of the watershed such as size, shape, topography, soil type, geology, land degradation and land use (Rashid et al., 2015; Pramono et al., 2010). Flood discharge is generally influenced by the surface runoff, climate change (Milly et al., 2002; Yang et al., 2013), and environmentally unfriendly land usage (Chaeruddin and Hardwinarto, 2011). The changes in land use from primary and secondary forests to cultivation areas have the ability to cause high surface runoff and increased frequency of flooding (Li and Wang, 2009; Adnan and Atkinson, 2011). This further affects the nature and components of ecosystems, thereby causing environmental problems, especially where the principles of soil and water conservation are not heeded (Bai et al., 2017; Devianti, 2018; Khan et al., 2019).

The main challenges to the environmental management in Central Sulawesi Province, Indonesia, in 2019 were floods and landslides, which were recorded to have been increasing over the years by 41%, 54%, 60%, and 59% for 2015, 2016, 2017, and 2018, respectively. This was found to be higher compared to other natural disasters such as drought, coastal abrasion, tornado, forest and land fires in this region (Akhbar, 2019; Central Sulawesi Environmental Service, 2019).

The Gumbasa watershed has strategic value because it is located in the Palu River upstream, observed to be flowing throughout the year. It also has protective and preservative functions by regulating the water system for all other watershed parts, especially the Palu River. It is important to monitor its performance because ecologically it affects the health of the watershed.

The hydrological cycle is related to many processes namely rainfall, surface runoff including peak discharge (Adamala et al., 2019). Prediction of peak discharge with a rational method based on rainfall, watershed area, and watershed characteristics has been introduced by several authors (Fang et al., 2013; Ploum et al., 2019; Debnath et al., 2019), who pointed out that peak discharge is directly proportional to rainfall intensity. However, a rational method for assessing peak discharge has not been widely developed in some watersheds in the tropics. The rational method for estimating the peak discharge has advantages because the factors that affect the runoff discharge are considered in more detail and has simplicity (Baiamonte, 2020), and also has been applied by Ayalew et al. (2014) for studying the effect of hillside dynamics and the nature of rainfall on the estimated peak discharge.

The variations in Gumbasa watershed carrying capacity are associated with frequent floods and landslides caused by uncontrolled land use without regard to the principles of soil and water conservation as well as the accelerated forest and land degradation due to encroachment, especially in the upstream. This means it is very important to monitor and evaluate the Gumbasa watershed performance, especially the peak discharge, to ensure it is managed in line with appropriate land standard as well as social-economic and institutional criteria.

This study aimed to estimate peak discharge of the Gumbasa watershed in the three sub-watersheds including Lindu, Palolo, and Gumbasa towards monitoring and evaluating the performance and plan for the sustainable management of the watershed.

2 Materials and Methods

2.1 The study area

The study was conducted in 2018 at Gumbasa watershed with coordinates between latitudes 1˚01’04”-1˚30’01” S and 119˚55’44”-120˚18’47” E, administratively included in Sigi Regency, Central Sulawesi (Figure 1). Three sub-watersheds including Lindu located with coordinates between latitudes 01˚19’34’’ S and 120˚18’35’’ E, Palolo with coordinates 01˚ 18’16.23” S and 120˚32’47,19’’ E, and Gumbasa on 01˚17’55’’ S and 119˚58’32’’ E were used in this research to represent the upstream, middle, and downstream areas observed to be experiencing frequent floods and landslides annually. The peak discharge was estimated in three sub-watersheds, including Lindu, Palolo, and Gumbasa with 57.675 ha, 45.664 ha, and 23.389 ha, respectively.

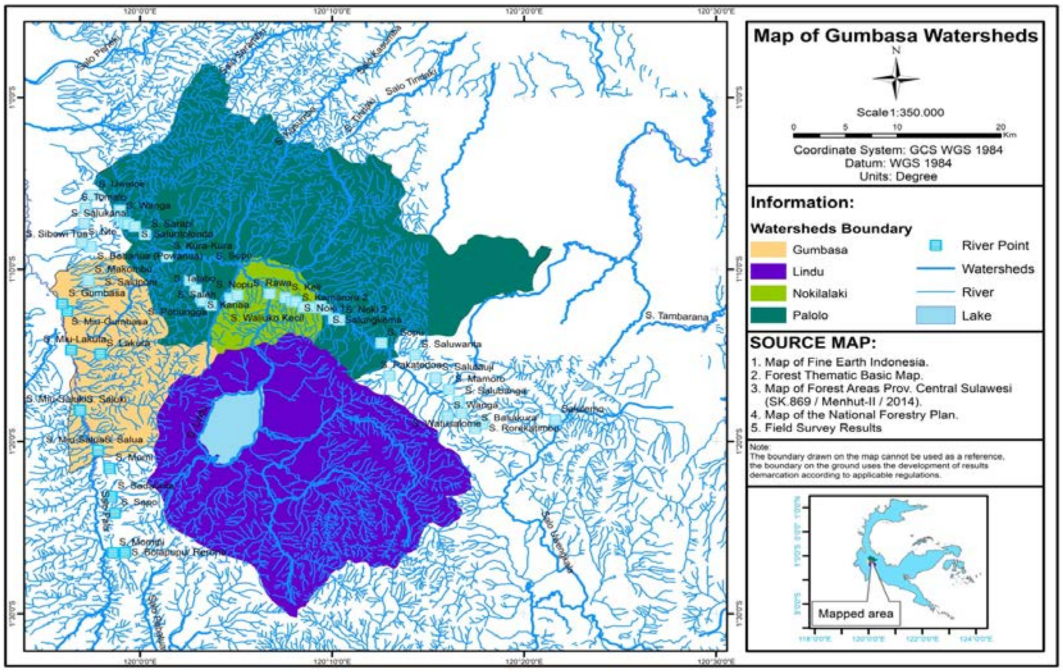

Figure 1 Location of the study area

2.2 Research method

A rational method of evaluation is usually implemented in watersheds/sub-watersheds with an area less than 5,000 ha, while those with more surface require breaking down the flow coefficient according to land use and area, because of the larger watershed area. The rational method was conducted using combined or average flow coefficient values, while the rainfall intensity is calculated based on the longest concentration time (i.e. a certain return period obtained from the intensity duration frequency curve which can be used in calculating flood discharge for planning soil and water conservation buildings), which is highly dependent on the characteristics of the flow area.

2.3 Peak discharge estimation

The peak discharge estimate is calculated using rational methods based on the value of the runoff coefficient (*C*), the time of concentration (*Tc*), and the watershed area (*A*) has been obtained. The peak discharge (*Qp*) was calculated based on the rational formula (Russo, 2009; Budianto et al., 2017) as follows:

$$Qp = 0.278 \times C \times I \times A \quad (1)$$

where: Qp is the peak discharge ($m^3\ s^{-1}$), C is the runoff coefficient based on factors of the drainage area, such as soil type, slope, and vegetation cover condition (dimensionless), I is the rainfall intensity ($mm\ h^{-1}$), A is the watershed area (km^2).

2.3.1 Determination of the runoff coefficient (*C*)

Runoff coefficient value analysis is based on land cover and conditions of Gumbasa watershed. Runoff coefficient value was referenced according to Pramono et al. (2010).

Table 1 Runoff coefficients (*C*) considered according to Pramono et al. (2010)

Watershed condition	Runoff coefficient
Sandy and gravely soil for agriculture	0.20
Sandy and gravely soil for grass	0.25
Sandy and gravely soil for forests	0.10
Dusty soil without impending horizon for agriculture	0.40
Dusty soil without impending horizon for grass	0.35
Dusty land without impending horizon for forests	0.30
Heavy clay soil for agriculture	0.50
Heavy clay soil for grass	0.45
Heavy clay soil for the forest	0.40

The value of the runoff coefficient in the three sub-watersheds was obtained by analyzing the soil structure of each type of land cover. Runoff coefficient value was determined based on the state of the drainage area as shown in Table 1.

2.3.2 Determination of the rainfall intensity (*I*)

The rainfall intensity was calculated using the Mononobe formula (Auliyani and Nugrahanto, 2020) as follows:

$$I = \frac{R\,24}{24\left(\frac{24}{Tc}\right)2/3} \quad (2)$$

Where: I is the rainfall intensity (mm h^{-1}), R_{24} is the daily rainfall (mm), Tc is the time of concentration (h)

2.3.2.1 Time of concentration (*Tc*)

The concentration-time was obtained using the following equation (Budianto et al., 2017):

$$Tc = L^{1.15}/7700\,H^{0.385} \quad (3)$$

where: Tc is the time of concentration (h), $L$is the length of the main river (km), $H$is the difference between the watershed's highest and lowest points (m).

The estimated peak discharge data of the three sub-watersheds were compared with the direct water discharge measured during 30 occurrences of rain using the floating method (Figure 2) and analyzed using the following equation (Norhadi et al., 2015).

$$Q = V \times A \times K \quad (4)$$

where: Q is the river discharge (m^3 s^{-1}), V is thebuoy speed (s), A is the river cross-sectional area (m^2), and K is the buoy coefficient (dimensionless).

$$K = 1 - 0.116\,\{\sqrt{1-\alpha-0.1}\,\} \quad (5)$$

$$\alpha = \frac{depth\ of\ the\ stalk\ (h)}{the\ depth\ of\ the\ river\ (d)}$$

Figure 2 Measurement of water discharge and soil sampling

3 Results and discussion

3.1 Rainfall

The results showed the overall average annual rainfall in the downstream ranged 1,400-1,600 mm $year^{-1}$ and upstream ranged between 2,200-2,400 mm $year^{-1}$. This is due that the upstream was associated with the dominant primary dryland forest vegetation in the conservation area of Lore Lindu National Park. According to Brümmer et al. (2012) the effect of rainfall on the presence of forest vegetation has a strong correlation. At high rainfall intensity and short period, does not cause flooding, but at low intensity and a long period, there is usually a large surface runoff and severe erosion (Wei et al., 2019).

3.2 Climate in the study area

According to the RFOS (River Flow Observation Station) and WMC (Watershed Management Center) data from Palu Poso for the 2014-2018 period, the highest average monthly rainfall was recorded in April with 375.28 mm h^{-1} while the lowest was in July with 56.49 mm h^{-1}. Meanwhile, the average annual was 1,468.75 mm h^{-1} at average 127.32 h on rainy days. Moreover, the monthly distribution data also showed there were 6 wet months and 1 dry month at a Q value (Q value is obtained from dividing the number of dry months divided by the number of wet months) of 16.84% which according to Smith and Ferguson's classification is climate B. The temperature was recorded to range between 24-36 °C while average humidity was 88% and average wind speed was 3.8 km h^{-1}. According to Suripin and Kurniani (2016) climate change affects peak discharge, due to climate change (rainfall characteristics), flood discharge will increase in the range of 15.10 m^3 s^{-1} (31.5%) for a 2-year return period to 32.28 m^3 s^{-1} (25.5%) for the period 200-year payback.

3.3 Runoff coefficient (*C*)

C values for Lindu, Palolo, and Gumbasa sub-watersheds were determined using a land cover overlay, slope, and soil type maps database, and the results are presented in Table 3.

C is an important factor in determining the level of peak discharge and, according to the data in Table 3, downstream Gumbasa and Palolo have higher values compared to Lindu located in the upstream. This is associated with the primary dryland forest land use dominant as well as the National Park conservation area situated in Lindu.

The *C* values of Palolo and the Gumbasa mean that 45% (Palolo) and 57% (Gumbasa) of the falling rain will become surface runoff classified as high, therefore, conservation and restoration efforts are required to ensure proper infiltration. This is in line with the findings of Budinetro et al. (2012) that surface runoff can be minimized by using vegetative soil conservation techniques.

3.4 Rainfall intensity (*I*)

The rainfall data obtained during the study period and the information provided by Pramono et al. (2010) led to the classification of rain as low with 30-40 mm, moderate at 50-80 mm, and high with rainfall > 80 mm. The rainfall intensities in the three sub-watersheds are presented in Table 2.

The results (Table 2) show that generally the classification of rainfall in all areas in the three sub-watersheds was generally evenly distributed. This is because land cover was still good since primary forest is still dominant.

Table 2 Rainfall characteristics in the study sites

Sub-watershed	Classification	Rainfall in 24 h (mm)	Rainfall intensity (mm h^{-1})
Lindu (Upstream)	Low	31	21
	Moderate	58	27
	High	98	18
Palolo (Middle)	Low	35	13
	Moderate	72	10
	High	94	16
Gumbasa (Downstream)	Low	38	17
	Moderate	68	24
	High	89	22

3.5 Peak discharge

The rainfall data, intensity, flow coefficient, and area were used to determine the peak discharges of the three sub-watersheds and the results are presented in Table 3.

Figure 3 Plantations land

Table 3 shows that average peak discharge is high, especially in the downstream area (Gumbasa sub-watershed). This was observed to be influenced by rain intensity, area, changes in land use from forest land to plantations (Figure 3), encroachment, and critical lands. This is in agreement with the findings of Handayani et al. (2005) and Jain et al. (2017) that an increase in peak discharge/flow from runoff volume is caused by changes in land use as well as Budinetro et al. (2012) report that land-use variations lead to a reduction in the absorption area and surface runoff rate.

The most dominant land use in the research location, especially the river border, is for plantation as shown in Figure 3 and Figure 4 without attention to the principles of soil and water conservation. According to Saraswati et al. (2017), this process has the ability to decrease water absorption, increase flow coefficient, and subsequently, the peak discharge in the watershed.

Table 3 Estimation of peak discharge using rational methods

Sub-watershed	Rainfall (mm)	Runoff coefficient	Rainfall intensity (mm h^{-1})	Area (km^2)	Peak discharge ($m^3\ s^{-1}$)
Lindu (Upstream)	31	0.12	21	576.75	404.05
	58	0.12	27	576.75	519.49
	34	0.12	18	576.75	346.33
Palolo (Middle)	35	0.45	13	456.64	742.63
	72	0.45	10	456.64	571.26
	84	0.45	16	456.64	914.01
Gumbasa (Downstream)	38	0.57	17	233.89	630.06
	68	0.57	24	233.89	889.49
	89	0.57	22	233.89	815.37

The plantation land with pure cacao, which is a non-agroforestry species also has a considerable influence on high surface runoff and peak discharge. This is in line with Naharuddin et al. (2018), who showed the occurrence of high surface runoff at 72.67 l ha^{-1} in non-agroforestry, pure cocoa, aged 10 years compared to the 45.98 l ha^{-1} recorded for candlenut-cocoa agroforestry.

The condition of pure cocoa plantations in Palolo and the Gumbasa sub-watershed in downstream which are more than 10 years old tends to cause high surface runoff and contribute to higher peak discharge. This is in line with Monde (2010) opinion that the maturity level of cocoa plants impacts on surface flow with 5, 8, and 12 years recorded to have produced a total surface flow of 201.88, 224.83, and 247.48 m^3 ha^{-1}, respectively, despite being treated with rorak and mulch.

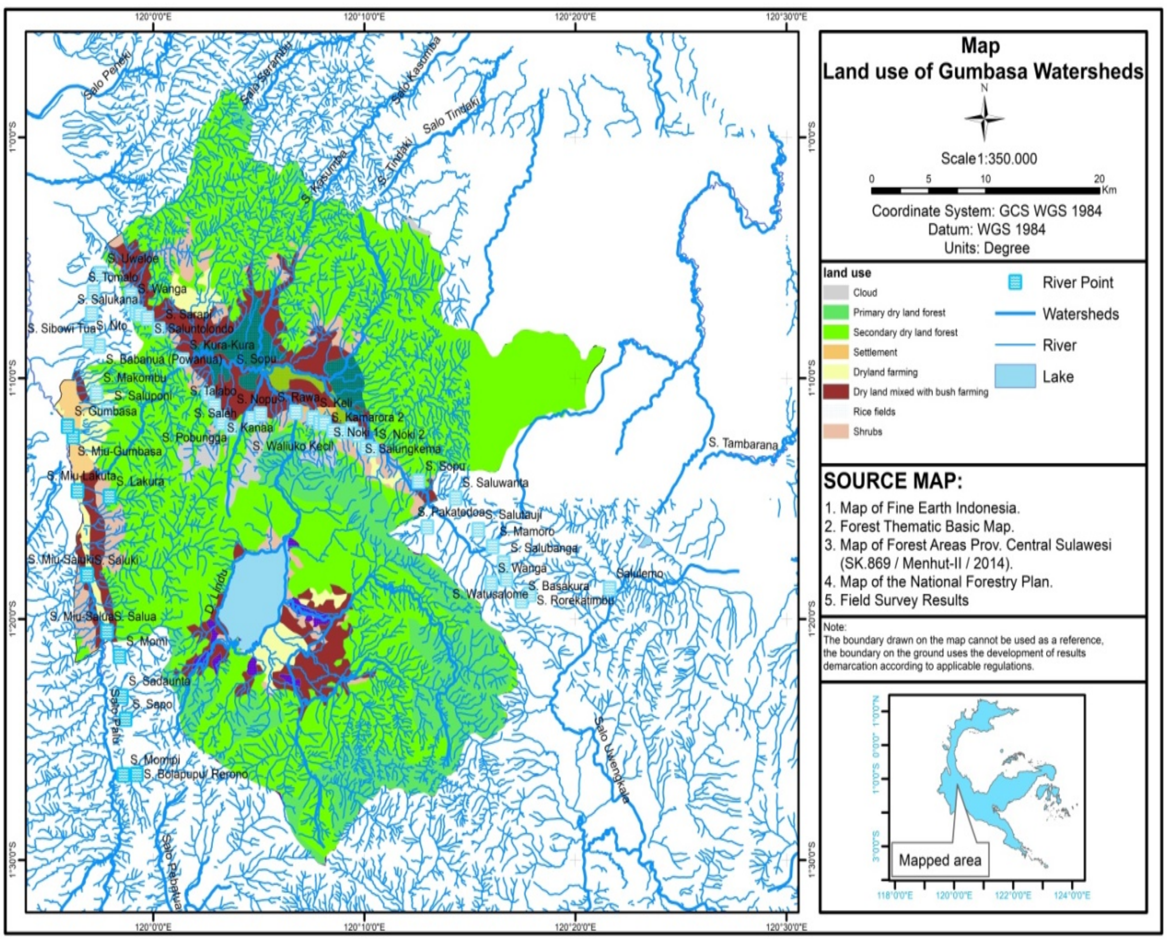

Figure 4 Land use map

The comparison of the estimated peak discharge based on rainfall classification for the three sub-watersheds is presented in the Figure 5.

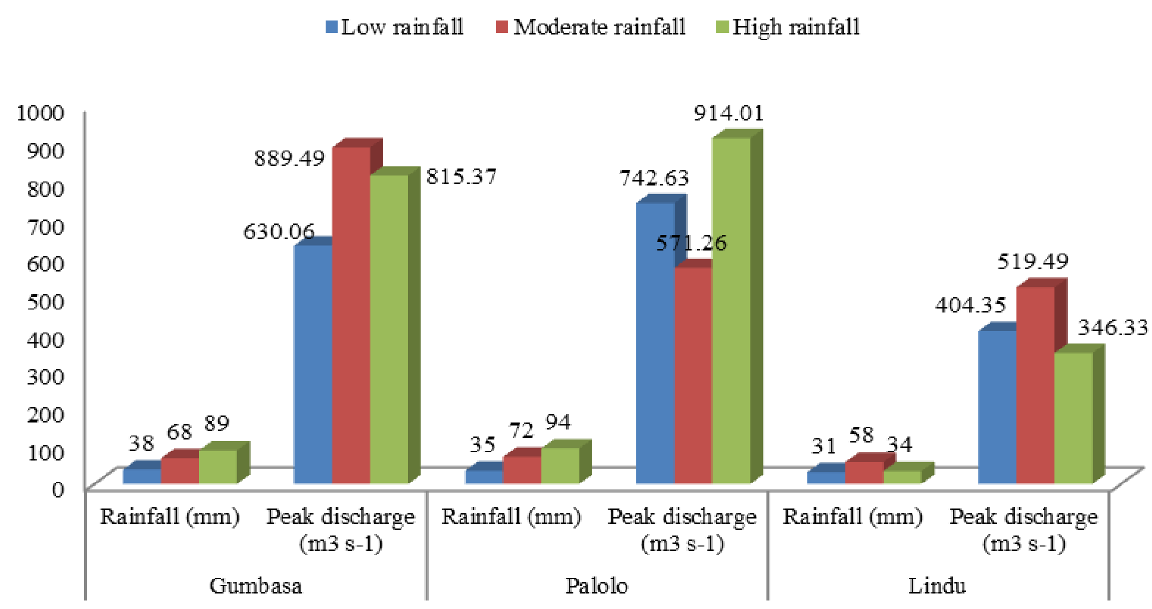

Figure 5 Estimation of peak discharge towards the rainfall classification in the Gumbasa, Palolo and Lindu sub-watershed

Figure 5 show the changes in rainfall caused variations in the estimated peak discharge in the three sub-watersheds. This is supported by Jain et al. (2017), who stated that changes in rainfall and other relevant climate variables such as land use and coverage cause variations in peak discharge. Moreover, the surface flow in the watershed was due to the integration of climate input, topography, land use/cover.

Water flow was also measured using the floating method to compare the peak discharge with direct measurements on the study site and the results are presented in Figures 6, 7 and 8.

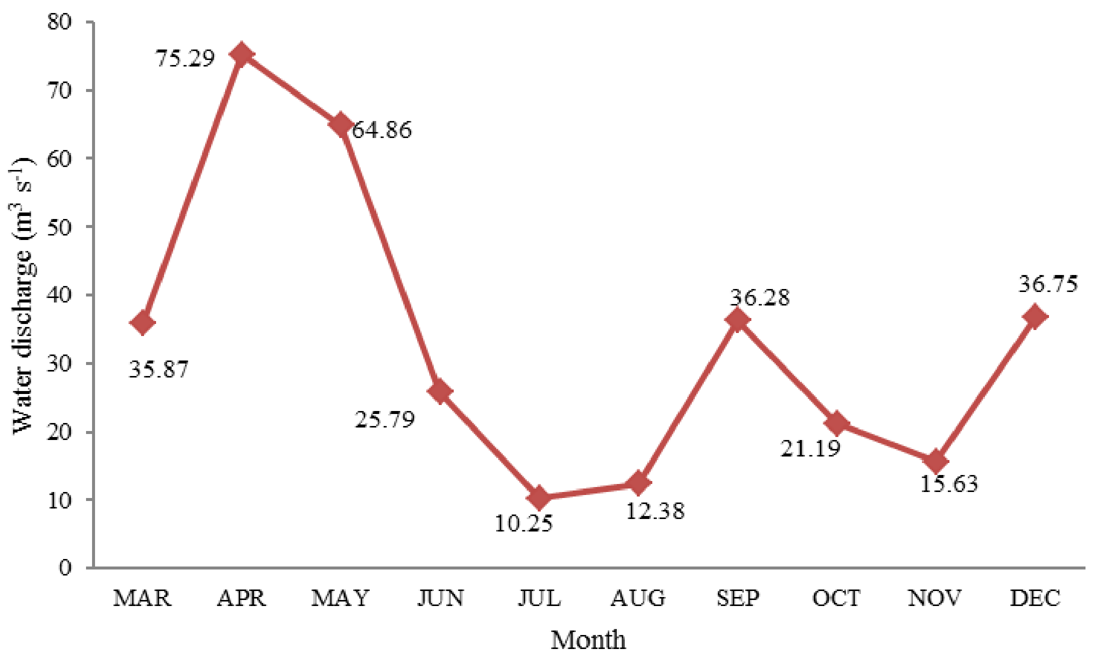

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Figure 6 Water discharge in the Lndu sub-watershed

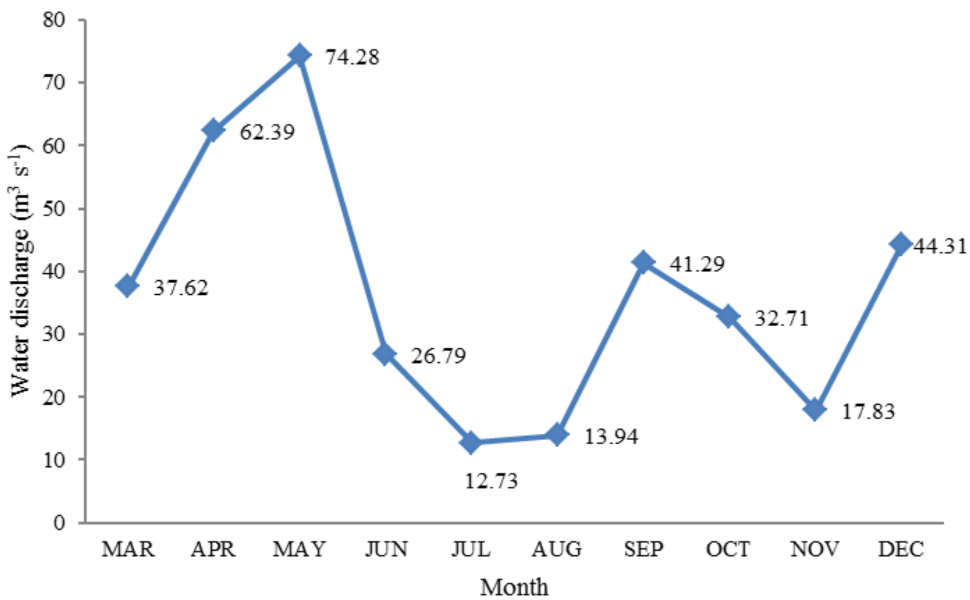

Figure 7 Water discharge in the Palolo sub-watershed

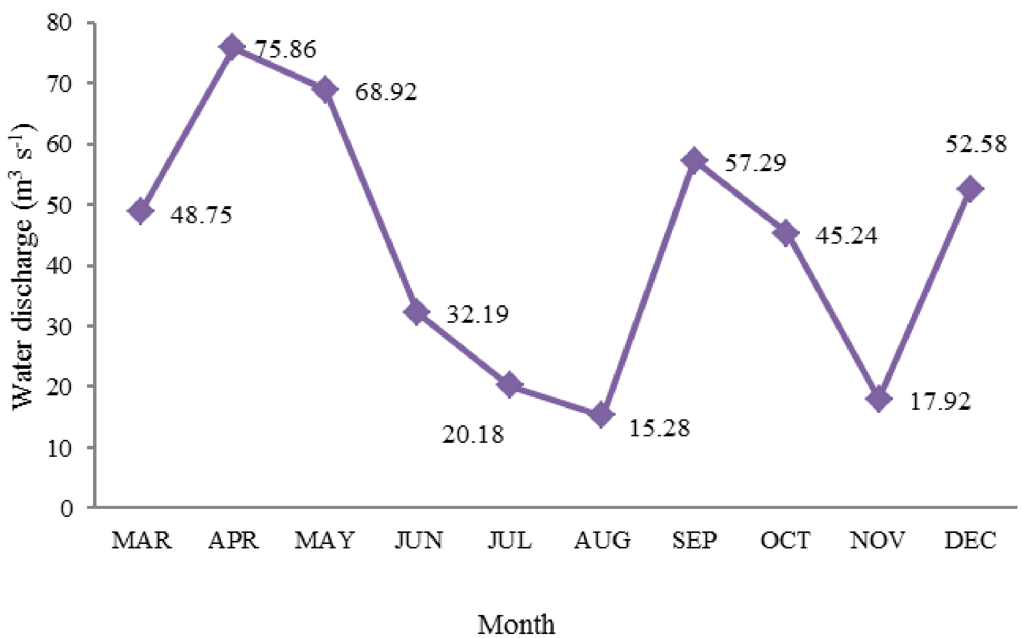

Figure 8 Water discharge in the Gumbasa sub-watershed

The peak discharge data in Table 3 were compared using the measurements for 10 months study period as presented in Figures 6, 7, and 8. An almost the same fluctuating trend was observed for the sub-watersheds, even though the values are different. This was caused by the uneven rainfall due to the relatively large area of the watersheds, which agrees with Pramono et al. (2010) findings that uneven rainfall with a relatively large watershed area influences the level of water discharge.

Gumbasa watershed generally has slopes very steep at 71.43%, this has a significant contribution to the high peak discharge. These conditions are very prone to surface runoff and have the possibility of occurring simultaneously unless the lands are managed to focus on conservation principles, especially on slightly to very steep sloped land.

4 Conclusion

The runoff coefficient (*C*) in the Palolo and Gumbasa downstream areas was 0.45 and 0.57, which shows that 45% (Palolo) and 57% (Gumbasa) the falling rain will become surface runoff classified as high. This was followed by an increase in peak discharge due to the influence of the area and the conversion of forests to the plantation, encroached, and critical lands, especially in the river areas of the three sub-river basins that have experienced land use disturbances that are not in accordance with the principles of soil and water conservation.

The slope of the Gumbasa watershed was recorded to be 71.4% with class ranging from slightly to very steep and this means it is very vulnerable to surface flow thereby leading to high flow coefficient and peak discharge. Therefore, it is necessary to conserve and restore land through reforestation and rehabilitation to minimize the flow coefficient and peak discharge.

The results of this study become input for the district government in the Gumbasa watershed area, in order to mitigate floods. In the framework of the management of the Gumbasa watershed in a sustainable way, it requires the environmental management aspects of the watershed ecosystem, especially the arrangement of forests towards other land uses, in accordance with the principles of soil and water conservation with forest and land rehabilitation patterns

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