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Discharge, Sediment, and Dissolved Nutrients in a Conservation Forest of the *Cigumentong* Catchment, Citarum Watershed, Tropical Monsoon Region, Indonesia

Vazão, Sedimentos e Nutrientes Dissolvidos em uma Floresta de Conservação na Bacia de Drenagem de Cigumentong, Bacia Hidrográfica do Citarum, Região de Monções Tropicais, Indonésia

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ABSTRACT

The *Cigumentong* catchment is a conservation forest area that experiences erosion, sedimentation, river flow pollution, and flooding. Research is needed to identify parameters that can gauge the effectiveness of conservation forests, informing policies aimed at preserving their sustainability. The methods used in this study include observing water level height with an AWLR (Automatic Water Level Recorder), measuring rainfall with an ARR (Automatic Rain Recorder), and conducting water sampling using an automatic water sampler, followed by nutrient analysis in the laboratory. The results show that the peak flow discharge occurred 50 minutes after the peak rainfall, on average. Peak sediment and nutrient concentrations occurred after the peak flow discharge with average intervals of 30 minutes for sediment, 155 minutes for total nitrogen, 30 minutes for total phosphorus, and 35 minutes for total potassium. The observation of sediment and nutrient discharge produced a counterclockwise hysteresis pattern. The peak of sediment and nutrient discharge occurring after the peak flow discharge can be one criterion indicating that the hydrological conditions in the *Cigumentong* catchment are still healthy. This study contributes hydrological information as a reference for maximizing the conservation function.

RESUMO

A Bacia de Cigumentong está localizada em uma área de floresta de conservação e enfrenta problemas como erosão, sedimentação, poluição do fluxo dos rios e inundações. Pesquisas são necessárias para identificar parâmetros que possam avaliar a efetividade das florestas de conservação, contribuindo para a formulação de políticas voltadas à preservação de sua sustentabilidade. Os métodos utilizados neste estudo incluem a observação do nível da água com um (Registrador Automático de Nível de Água), a medição da chuva com um ARR (Registrador Automático de Chuva) e a coleta de amostras de água utilizando um amostrador automático, seguida de análise de nutrientes em laboratório. Os resultados indicam que a vazão de pico ocorreu, em média, 50 minutos após o pico de chuva. As concentrações máximas de sedimentos e nutrientes ocorreram após a vazão de pico, com intervalos médios de 30 minutos para sedimentos, 155 minutos para nitrogênio total, 30 minutos para fósforo total e 35 minutos para potássio total. A análise das descargas de sedimentos e nutrientes revelou um padrão de histerese no sentido anti-horário. O fato de os picos de descarga de sedimentos e nutrientes ocorrerem após o pico de vazão pode ser um critério indicativo de que as condições hidrológicas na Bacia de Cigumentong ainda são saudáveis. Este estudo oferece informações hidrológicas valiosas como referência para otimizar a função de conservação.

1. INTRODUCTION

The degradation of land resources is an unavoidable phenomenon. Land resource degradation (soil) can occur in terms of physical, chemical, and biological properties. Factors that cause land degradation can originate from both the environment/nature and human activities. Increased rainfall leads to higher soil loss due to an increase in water velocity, which causes runoff and landslides (Ramos *et al.*, 2019). In recent decades, changes in flow discharge and sediment suspension yield over time in river systems have received increasing attention (Tananda, 2020). Excessive application of pesticides and chemical fertilizers, as well as reduced catchment areas, can also cause erosion, nutrient leaching, eutrophication, and even flooding. Soil erosion can reduce soil productivity because it removes the relatively more fertile topsoil layer (Sutrisno; Heryani, 2013). Based on research conducted by Dai *et al.* (2018), in the South China region, soil nutrients will also be lost. High rainfall is a factor for dissolving N and P, where generally, the loss of N nutrients is higher than P.

Prediction of flow and sediment discharge is needed for better planning and use of land and water resources in various fields such as water supply, flood control, irrigation, water quality, and others. Groundwater, rivers and their floodplains have historically provided significant cultural, economic, environmental, and social benefits, and with proper management (Loucks; Beek; Van, 2017). Accurate evaluation of the volume of sediment transported is a critical issue as it affects the structure and function of water assets and forms the basis for various water-related classifications, such as river morphology, deposited sedimentation, water resource quality modeling, reduced capacity, increased dam maintenance expenditures, and irrigation canal management (Masruhim, 2020). Flow discharges and suspended sediments play important roles in geological, biological, and chemical processes, significantly affecting the geomorphology of land surfaces, river channels, floodplains, and deltas (Darwis, 2018). The dynamics of suspended sediment from slopes to river channels affect aquatic ecosystems, causing reservoir sedimentation and the transport of adhering substances (e.g., pesticides, nutrients, and heavy metals). The transported soil will accumulate in certain areas, potentially triggering siltation and eutrophication (Banuwa, 2013), the threat of eutrophication is also caused by excessive N input (Tanner; Buchmann; Eugster, 2022). Prediction of N and P nutrient loads needs to be done to see the critical status of nutrient concentrations and to determine effective policies in efforts to mitigate eutrophication (Li *et al.*, 2019).

The *Cigumentong* catchment is located in a conservation forest within a tropical monsoon climate zone, and it is part of the *Citarik* sub-watershed, upstream of the *Citarum* watershed. The *Cigumentong* river (upstream of the catchment) is a perennial river, with water flowing continuously throughout the year, even during the dry season. This indicates that the groundwater and aquifer conditions in the area remain in good condition. However, some problems can be found in the middle part of this catchment. The area has experienced a decline in environmental conditions, particularly in land and water resources, due to soil physical factors, high rainfall, and steep slopes (Mauludin, 2016). The problem that often occurs in the *Citarum* watershed is the problem of the reservoir and river sedimentation. The runoff of surface runoff in upper *Citarum* is 3,632.50 million m/year, while sedimentation in the upper *Citarum* is 7,898.59 tons ha^{-1} (Imansyah, 2012). This issue relates to the groundwater aquifer in the *Citarik* sub-watershed. According to Suryadi *et al.* (2020), the *Jatinangor* and *Rancaekek* subdistricts which are located within the *Citarik* sub-watershed, are high risk of land-use changes, which was driven by rapid development into educational and industrial zones. The increasing population in these areas has led to excessive groundwater extraction, resulting in a significant decline in groundwater levels. As watershed areas become more developed, the infiltration of surface water into groundwater is increasingly disrupted (Suryanta *et al.*, 2022). Other research by Ginkel (2015) stated that surface water and groundwater interact within the basin, particularly in the case of unconfined shallow aquifers—located just a few meters to approximately 40 meters below the surface—which are heavily utilized through well extraction. They may indicate the groundwater condition in the middle to the downstream of *Citarum* watershed is not good enough. Not only the erosion and sedimentation problems, the rivers in the *Citarum* sub-watershed, from upstream to downstream, are heavily polluted (Rahman; Purwanto; Suprihatin, 2014). Sloping agricultural land triggers erosion, and the burden of nitrogen loss focuses on non-upstream pollution (Bah *et al.*, 2020). Based on the content of nitrogen (N) and phosphate (P) compounds present, the waters of the *Cirata* reservoir located in West Bandung are included in the eutrophic category or heavy pollution (Jubaedah; Sudinno; Anas, 2014).

The impact of changes in water discharge and sediment load in the river system on the ecological environment of a basin is significant. Sediment fluxes affect many important features of the basin, such as ecology and environment, resource provision, and various sectors including industrial production, residential life, cultivation and agriculture, and estuarine delta development (Mulyaningsih, 2018). The increase in population drives the need for greater food production and stimulates economic growth and urbanization, which in turn produce household waste and agricultural runoff. Excessive use of nitrogen (N) and phosphorus (P) to boost food production without proper management eventually leads to a new problem: water pollution (Yang *et al.*, 2019).

The relationship between suspended sediment dynamics, rainfall, and flow discharge provides valuable information for identifying factors and processes influencing sediment response—specifically, the physical principles driving changes in suspended sediment concentration and discharge. This understanding helps researchers interpret the spatial distribution of sediment sources at the catchment scale (Manuhana, 2017). Basically, the amplitude of variations in the frequency and intensity of extreme hydrological events is much greater than the average hydrological factor (Mulyaningsih, 2018). Likewise, nutrient concentrations showed greater fluctuations in extreme hydrological events (Du *et al.*, 2014). Therefore, some experts have begun to focus on the flooding process during extreme events or single maximum discharge and sediment transport values, as well as event-based observations to investigate nutrient dynamics under different conditions (Du *et al.*, 2014) in several basins (Mulyaningsih, 2018). A quantitative assessment of flow discharge, suspended sediment dynamics, and dissolved nutrients is crucial for supporting the management of the Upper Citarum River. Analyzing these factors in the upstream area, which is also a conservation forest, has been rarely conducted, making it an intriguing endeavor. These findings can offer valuable insights to the public and relevant agencies regarding the hydrological conditions and ecosystem health of the upstream area. This information can serve as a reference for enhancing the conservation efforts within the watershed.

2. METHOD

2.1. Research area

The research was conducted in the *Cigumentong* catchment, which is the upstream of the *Citarik* sub-watershed, *Citarum* Watershed, Indonesia (Chaidar *et al.*, 2017). Geographically, it is located at coordinates 6^o 56'– 6^o 57' S and 107^0 55'– 107^0 56' E, while administratively, this area is divided into two regions, namely Garut and Sumedang regencies. The *Cigumentong* catchment has an area of 363 hectares, which is spread over the *Cigumentong* Village area and the conservation area *Masigit Kareumbi Buru* park (Withaningsih; Parikesit; Fadilah, 2022). This river flow is a river flow that comes from the springs of Mount *Kareumbi*. From the primary data analysis, this area is located at an altitude of 1,000-1,400 meters above sea level. The topography of this area is diverse but is dominated with steep slopes. It consists of a flat area (0-8%) covering an area of 20 hectares, sloping (8-15%) covering an area of 49 hectares, rather steep (15-25%) covering an area of 95 hectares, steep (25-45%) covering an area of 160 hectares, and very steep (> 45%) covering 39 ha. The administration map of the *Cigumentong* catchment can be seen in Figure 1.

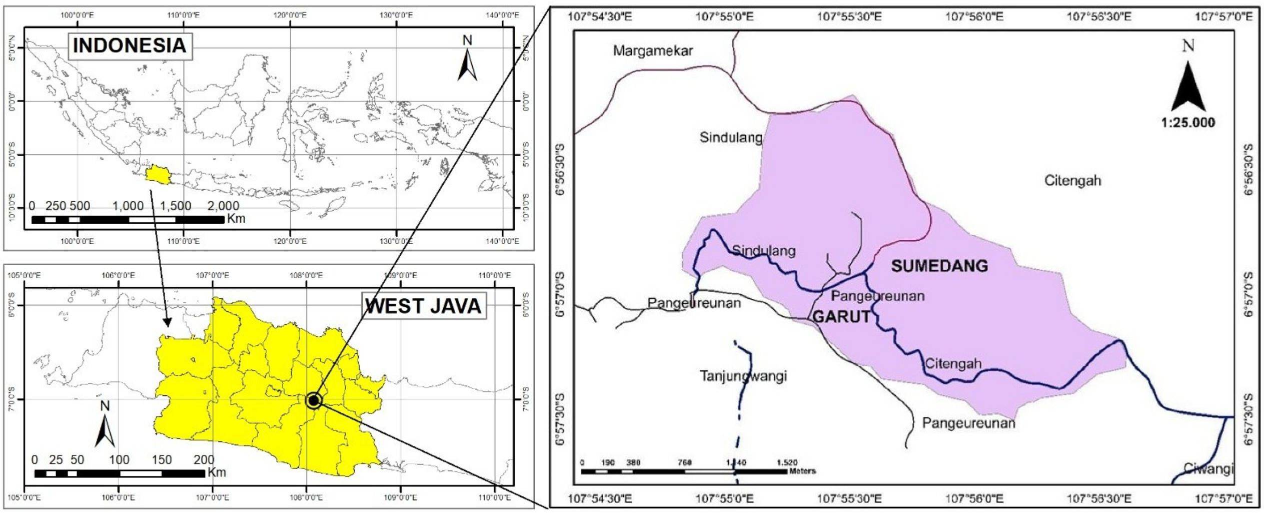


Figure 1. Administration map of research site, *Cigumentong* catchment area in Indonesia

The research site consists of two types of soil, namely Ultisol soil (*Typic Paledults*) and Inceptisol soil (*Typic Dystrudepts*). Based on the results of the analysis in the laboratory, Ultisol soil has the following characteristics: sandy loam texture with a sand fraction of 17,18 %; clay fraction of 47.05%; and dust fraction of 35.78%, the permeability of 8.73 cm/hour which is categorized as rather fast, pH 5.57 (acidic), moisture content of 18.37%, and nutrient content in the form of soil organic C content of 6 .12% which is classified as very high, N-total soil is 0.12% which is classified as low, P-total soil is 12.66 mg/100 gr, and K-total soil is 28.31 mg/100 gr. Inceptisol soil characteristics are as follows: clayey clay texture with a sand fraction of 20.6%; clay fraction of 47.08%; and dust fraction of 32.31%, the permeability of 11.89 cm/hour which is categorized as rather fast, pH 5.69 (slightly sour), moisture content of 15.22%, and nutrient content in the form of soil organic C content. by 6.64% which is classified as very high, N-total soil is 0.12% which is classified as low, P-total soil is 11.34 mg/100 gr, and K-total soil is 22.91 mg/100 gr. The soil type map can be seen in Figure 2.

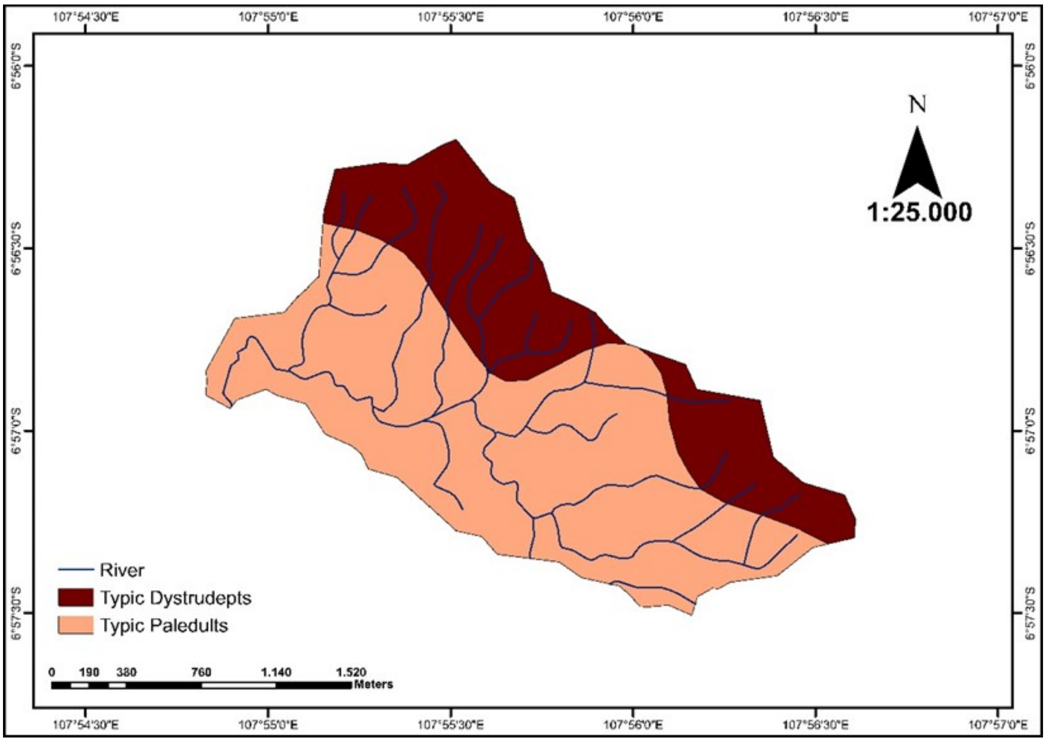


Figure 2. Soil types map of *Cigumentong* catchment

Cigumentong catchment with an area of 363 Ha is divided into three types of land use, which are dominated by plantation forest land use of as much as 59%, primary dryland forest 28%, and mixed dryland agriculture 13%. The climatic conditions of this region have an average temperature of 22 - 24.9 degrees Celsius and humidity of 67-88%. This region has a clear difference in rainfall patterns between the rainy and dry seasons. Based on the data for the last 10 years, the total rainfall is 23,134.7 mm with an average annual rainfall of 2103,15 mm. Land use map and rainfall data for the last 10 years can be seen in Figures 3 and Table 1.

2.2. Data collection

The data used in the research are Landsat satellite imagery, DEM maps, land use maps, slope maps, and soil type maps sourced from the Bandung land cover map in 2019 and the *Bandung* area administration map in 2017, water level data (TMA) obtained from AWRL, rainfall data obtained from ARR. Water sampling was carried out using an automatic water sampler (ISCO 3700 C Portable Automatic Sampler) every 15 minutes during rain events. Samples were collected into 600 ml bottles. The collected samples were stored in a refrigerator at 4 degrees Celsius. The method used in this study is a quantitative analysis method by analyzing rainfall, water flow, and analysis of suspended sediment and dissolved nutrients (N, P, and K) from samples of the Cigumentong river water. Laboratory analysis was carried out at the Chemistry and Soil Fertility Laboratory and the Gifu University Laboratory, Faculty of Agriculture, Universitas Sebelas Maret, Surakarta, with the guidance and method from Indonesia Agriculture Ministry (BalitBang, 2006; Balittan, 2009).

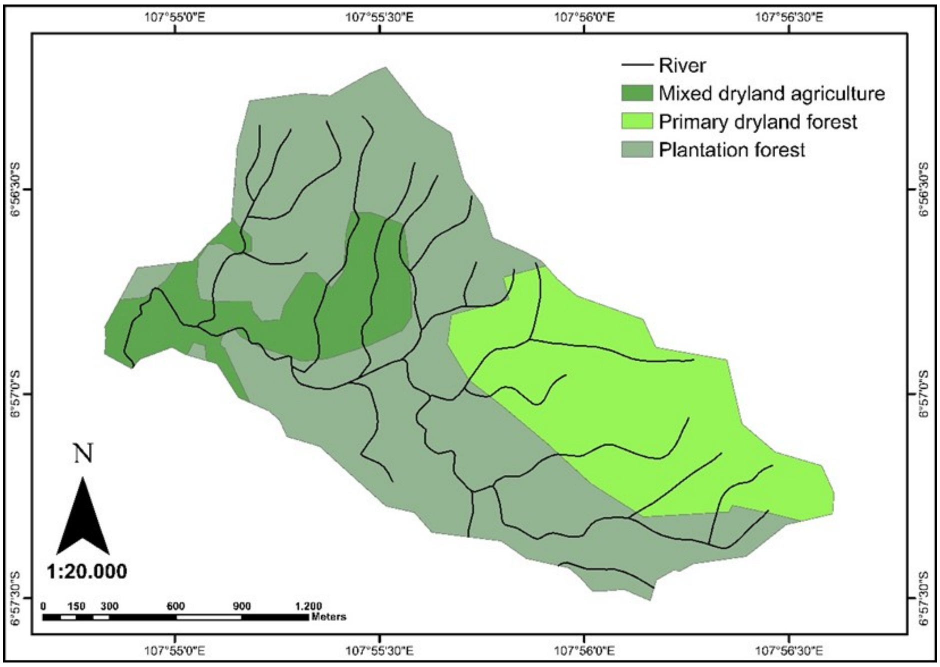


Figure 3. Land use map of the Cigumentong catchment

2.3. Data Analysis

Analysis of sediment concentration using evaporation and filtration methods, pH using the electrometric method, total nitrogen (TKN) using the Kjeldahl method, total phosphate using the Vanadomolybdophosphoric Acid Colorimetric method, and total potassium using the Absorption Spectrophotometry (AAS) method (Balittan, 2009). Statistical analysis, the regression method was used to determine the relationship between water level and flow rate, which was determined based on the water level of the *Cigumentong* river using the equation according to (Hansen; Israelsen; Stringham, 1979).

$$Q = 0.0184\ LH3/2 \quad (1)$$

where: Q is the flow rate (liter/second), L is the length of the weir threshold (cm), and H is the water level (cm).

Flow discharge data, sediment, and nutrient concentrations during several rainfall events are the main data used in this analysis. The correlation between flow rate and sediment and nutrient concentrations was determined based on regression analysis with a coefficient of determination (R2) of 0.5. The relationship between flow rate and sediment and nutrient concentrations is also described by means of a hysteresis pattern. This data was analyzed with the cumulative sum method. The hysteresis pattern can vary, such as clockwise or counterclockwise. A clockwise hysteresis pattern occurs when the sediment/nutrient concentration reaches its peak before the peak of flow discharge. While the counterclockwise pattern occurs when the sediment/nutrient concentration reaches its peak after the peak of the flow discharge (Jarsjö et al., 2015).

3. RESULTS AND DISCUSSION

3.1. General description of the observed events

Table 2 summarizes the characteristics or temporal components of rainfall, flow discharge, sediment concentration, and dissolved nutrient concentrations (total Nitrogen, total Phosphorus, and total Potassium) from three flood events observed during the rainy season, specifically in December to February. From these results, it is evident that the peak flow discharge occurs after the peak rainfall, with an average delay of 40 minutes. This finding is consistent with the research of Trinugroho, (2018) conducted in the Ping River, Thailand, where peak flow discharge followed the peak rainfall in five observed rain events. Similarly, Staddal, Haridjaja and Hidayat, (2016) noted that as rainfall intensity increased, so did the flow discharge, with the peak discharge occurring sometime after the peak rainfall. The time interval between peak rainfall and peak flow discharge is influenced by various factors, including land cover and catchment shape.

The relatively elongated shape of the *Cigumentong* catchment results in a smaller flood discharge, as indicated by Handayani *et al.*, (2018). This is because the flow time from tributaries to the main river varies, preventing accumulation in the main river. Additionally, the main river flow in the *Cigumentong* catchment is positioned relatively to the left of the catchment boundary, leading to longer flow times from tributaries to the main river. Moreover, the time interval between peak rainfall and peak flow discharge is influenced by rain characteristics and initial soil moisture conditions. Soil moisture affects the time required to reach peak discharge, while rain characteristics impact the magnitude of the discharge value (Nining; Sutarno; Komariah, 2017).

Table 1 – Rainfall Data 2011-2021

Year	Month												Total	Mean
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec		
2011	30.5	75.5	249	137	133.5	72.5	33	0	0.5	71.5	240	-	1043	94.82
2012	446	280.5	404.5	579.5	224	193.5	189	3.5	7	16	194	414	2951.5	245.96
2013	446	280.5	404.5	579.5	224	193.5	189	3.5	7	16	194	414	2951.5	245.96
2014	254	201	404.5	239	29	103	45	23.5	-	12	166.5	562	2039.5	185.41
2015	219	304.5	303	167.5	49	81	-	-	-	4.5	237.5	335.5	1701.5	189.06
2016	266.5	551.5	605.5	210	50.5	109	194	35.5	168.4	359.5	257.5	203.5	3011.4	250.95
2017	153.5	134.5	382.9	-	-	109	194	35.5	168.4	359.5	490.5	233	2260.8	226.08
2018	111	274.5	375	196	38.5	9	8	15	4.5	38	303.5	379	1752	146.00
2019	50	329	252	401.5	101	0	-	-	23	17	48.5	193.5	1415.5	141.55
2020	234	414	376.5	237	188	34	16	19.5	5.5	-	210	288.5	2023	183.91
Total	2210.5	2845.5	3757.4	2747	1037.5	904.5	868	136	384.3	894	2342	3023	21149.7	1909.69
Mean	221.1	284.6	375.7	305.2	115.3	90.5	108.5	17	48	99.3	234.2	335.9	2115	190.97

Table 2 – Summary of the time components of rainfall, flow discharge, sediment concentration, and dissolved nutrient concentration of 3 flood event.

Component	Discharge			Sediment			Nitrogen			Phosphorus			Potassium		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Duration of rainfall events (min)	345	420	395	345	420	395	345	420	395	345	420	395	345	420	395
Time to peak	30	75	50	45	105	70	120	345	205	60	90	75	60	120	85
Lag Time	30	45	40	45	75	60	120	315	195	60	75	70	60	120	85
Falling limb time (min)	300	390	355	285	375	335	105	300	200	270	360	330	270	360	310
Time different from peak discharge to peak sediment	-	-	-	15	45	30	90	270	155	30	30	30	30	45	35

Based on Table 2, it is evident that the peak sediment concentration occurs after the peak flow discharge, with an average delay of 60 minutes. This finding is consistent with research conducted in the US Virgin Islands, which found that suspended sediment concentration increases rapidly at discharges with low runoff rates, resulting in a non-linear relationship between suspended sediment concentration and flow discharge (Ramos-Scharron; MacDonald, 2007). The peak flow discharge in the Cigumentong catchment typically occurs shortly after the peak rainfall, meaning that maximum rainfall does not necessarily coincide with maximum flow and sediment discharge. Cigumentong catchment is predominantly covered by forest land with abundant natural vegetation. During rainfall, water infiltrates into the ground, reducing erosion and surface runoff that would otherwise carry sediment into river flow, resulting in lower sediment concentration.

This observation aligns with research conducted on the Qin River and Nanliu River, north of Beibu Bay, South China, by Tang et al. (2021), when rainfall is less than the effective or peak levels, the discharge resulting from rain events is adequate to mobilize sediment. Additionally, as rainfall increases, sediment levels can decrease because rainfall promotes vegetation growth, which helps prevent surface runoff and soil erosion. This finding is consistent with research conducted in the Ngatabaru sub-watershed of Central Sulawesi, Indonesia by Handayani and Indrajaya (2011), when it rains, the kinetic energy of rainwater can disrupt soil aggregates and induce erosion. However, the sediment resulting from erosion is transported by river flows, which takes time. Therefore, a higher rainfall intensity does not necessarily equate to a larger measured sediment discharge.

According to Li et al. (2014), erosion can elevate sediment concentration by enhancing the flow, which increases frictional force on the riverbed based on Table 2 and Figure 5, it is evident that the dynamics of nutrient concentrations (total Nitrogen, total Phosphorus, and total Potassium) are highly variable. The peak concentrations of these nutrients occur after the peak flow discharge. Fluctuations in total Nitrogen and total Phosphorus concentrations do not mirror fluctuations in flow rate. This finding aligns with the results of a study conducted by Han et al. (2010) in the Yangtze River, China, dissolved ammonium and phosphate concentrations fluctuated substantially without a significant trend in each flood event. This indicates that total dissolved Nitrogen discharge cannot be predicted by flow rate alone, as other factors affect the solubility of Nitrogen in water.

In addition to eroded soil, nitrogen sources in water come from the metabolism of living organisms and the decomposition of dead organisms. A significant contribution of Nitrogen also comes from agriculture, industry, forestry, and organic materials such as litter (Sulistyorini; Edwin; Arung, 2017). The presence of nitrogen and phosphate in water is related to the decomposition process by microorganisms and is highly dependent on pH and oxygen availability (Maslukah; Indrayanti; Rifai, 2014).

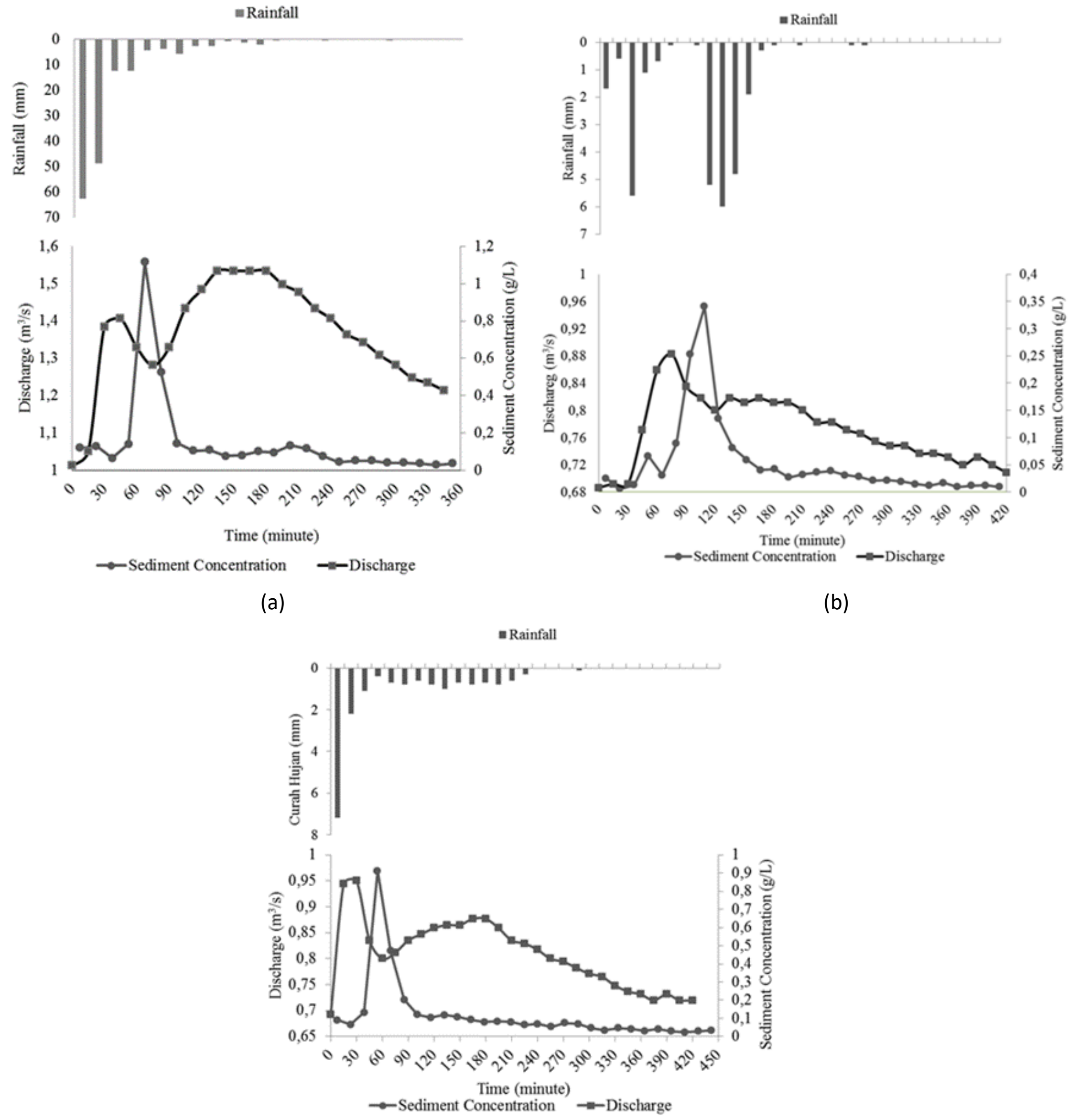
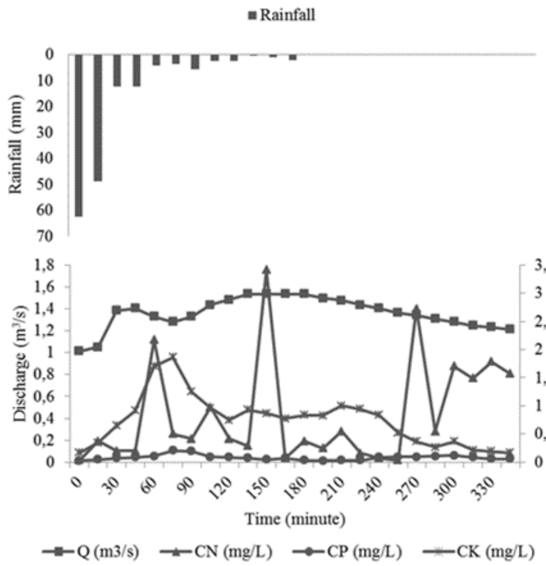
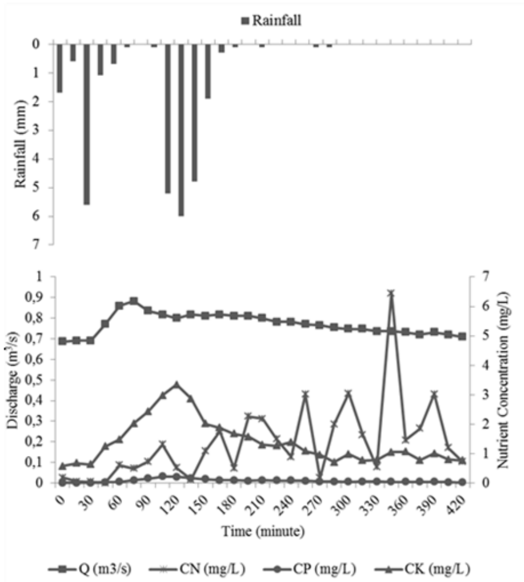


Figure 4. Hydrograph of rainfall units, flow discharge and sediment concentration in flood events (a) Flood on December 30, 2021 (b) Flood on February 4, 2022 (c) Flood on February 14, 2022

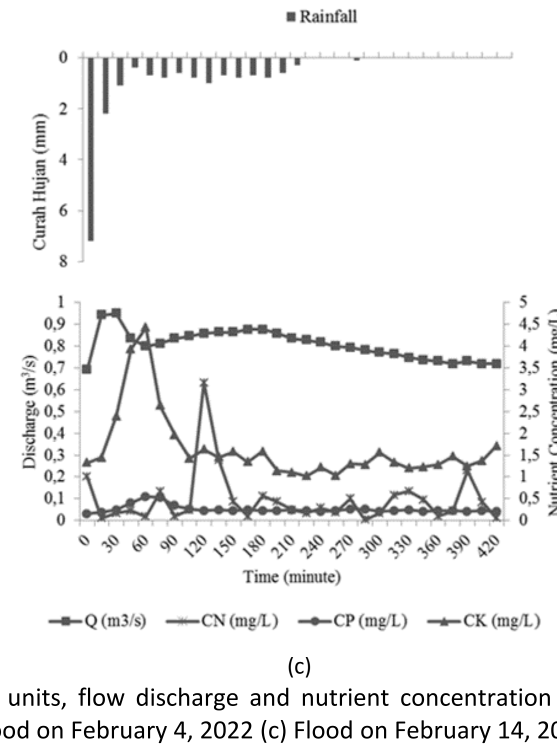
A high volume of water also causes dilution of ammonia, resulting in a lower concentration (Purmaningtyas, 2014). The natural environment is typically characterized by a limited flow of dissolved phosphorus (Kroiss; Rechberger; Egle, 2008). According to research conducted by Pratiwi and Andi (2013) in Themas Mico Saputra, Rauf and Sabrina (2019), in soil colloids, phosphorus nutrients have the ability to bind quite tightly, so that if there is a surface runoff, this phosphorus element is difficult to dissolve. According to research conducted by (Patty; Arfah; Abdul, 2015), high or low phosphate nutrient levels may be influenced by the process of phosphate diffusion from sediment.



(a)



(b)



(c)

Figure 5. Hydrograph of rainfall units, flow discharge and nutrient concentration in flood events (a) Flood events on December 30, 2021 (b) Flood on February 4, 2022 (c) Flood on February 14, 2022

Sediment serves as the primary storage location for phosphorus in marine cycles, typically in the form of particulates bound to hydroxide compounds and iron oxides. Phosphorus compounds bound in sediments can decompose with the assistance of bacteria or through abiotic processes, releasing phosphate compounds. The dynamics of increasing potassium nutrient concentration occur following the flow rate. This is in accordance with research conducted by (Yang *et al.*, 2015), which states that the concentration of potassium in river flows increases due to the high intensity of rainfall, which causes rainwater to dislodge topsoil particles, leading to runoff that transports potassium.

Additionally, the cohesive forces of soil aggregates contribute to saturated soil conditions. Soils with higher water content experience increased surface runoff, resulting in higher flow rates that further transport potassium during increased flow conditions. This is in accordance with the research of Harahap (2019) who found surface runoff contributes to the erosion process, leading to the displacement of soil material and the transfer of nutrients, chemicals, and organic substances from the soil into the river.

3.2. Hysteresis pattern

Figure 6 displays a hysteresis pattern depicting the relationship between flow discharge and sediment concentration, as well as nutrient concentrations of nitrogen, phosphorus, and potassium during multiple flood events. The relationship between flow rate and sediment concentration exhibits a counterclockwise hysteresis pattern. According to Nadal-romero, Regüés and Latron (2008), a counterclockwise hysteresis pattern usually occurs in flood events with an average short duration of 400 minutes. The results from several flood events in the *Cigumentong* catchment indicate that they are all short duration, averaging 395 minutes, with rainfall not being excessively high. This is also in line with research by Relau and Pinang (2013) that a rainfall duration that is relatively short can lead to a counterclockwise hysteresis pattern, as the transported material is depleted earlier due to the shorter distance traveled. This is also in line with According to research by Billi and Spalevic (2022) who found as the duration of the flood event increases, the sediment concentration also tends to increase. However, due to the long channel length from upstream to downstream, this typically results in an anticlockwise hysteresis pattern.

The anticlockwise hysteresis pattern observed in all flood events occurred because sediment and nutrient concentrations peaked after the flow discharge had already peaked. According to Jarsjö et al. (2015), the average time difference between the peak sediment concentration and peak flow discharge is approximately 30 minutes. Similarly, the average time differences between the peak nitrogen concentration and peak flow rate, and between phosphorus and potassium concentrations and peak flow rate, are approximately 155 minutes, 30 minutes, and 35 minutes, respectively. According to Rodríguez-Blanco *et al.* (2018), the delay in the peak time of sediment and nutrient concentrations in river flow is attributed to the delayed input from the upstream area to the observation outlet area, caused by erosion of slopes and hills during rainfall. The average rainfall in several flood events in the *Cigumentong* catchment is 69.1 mm. According to, Counterclockwise hysteresis patterns are produced by relatively low rainfall, which leads to a low hydrological response from the catchment, resulting in low sediment concentrations. This is also in line with research conducted in the California watershed by Aguilera and Diego (2020), where the rotation pattern of phosphate and nitrate hysteresis shows a counterclockwise pattern. This may be due to rapid runoff in the impermeable areas, causing a delay in the process of transporting nutrients from the source to the monitoring point.

3.3. Watershed health

The watershed management approach involves regulating water and flood management from the upstream to the downstream areas of a catchment (Setyawan *et al.*, 2018). Indicators used in determining watershed health include hydrology, soil and water quality, land cover, and population. River flow discharge during flood events can serve as an indicator of the watershed's (DAS) ability to respond to rainfall. According to Ichwana and Nasution (2014), several criteria good watershed conditions, including a constant flow rate, good water quality, small fluctuations between maximum and minimum discharges, and a stable water level from year to year. In the *Cigumentong* catchment, forest areas dominate the land cover. According to Jones *et al.* (2022), forests play an important role in hydrological processes involving rainfall; they convert rainfall into evapotranspiration and surface runoff, and absorb and store water in the soil. The soil in the *Cigumentong* catchment contains more than 30% silt and more than 40% clay. According to Du *et al.* (2022) in their research that soils with fine textures (silt and clay) are characterized by relatively low infiltration rates, resulting in high surface runoff. These soils tend to be more problematic than coarse-textured soils (sand), as they are prone to compaction and puddles, making them more susceptible to erosion. The condition of the soil and land cover in the *Cigumentong* catchment indicates that it is still in a healthy (good) state.

The health of the watershed can also be assessed by examining the hysteresis pattern and graphs of flow, sediment, and nutrient discharge from flood events. In the Cigumentong catchment, the counterclockwise hysteresis pattern observed during flood events indicates that the peaks of sediment and nutrient concentrations occur after the peak discharge, as shown in the attached graph.

This delayed peak suggests that the hydrological conditions in the catchment are still good (moderate). This is evidenced by the relatively insignificant transport of sediment at the beginning of rainfall, where rainwater is well absorbed by the soil, resulting in low discharge. Additionally, the river does not dry up during the dry season, further indicating healthy watershed conditions. The increase in surface water volume in the context of watershed hydrology indicates that the health of the watershed tends to deteriorate (Miardini, 2015). Rainfall can affect sediment concentration (Cs) and sediment discharge (Qs). Rainfall is a factor that affects runoff and soil erosion in a watershed. The higher sediment buildup can potentially reduce the river's capacity to handle large-intensity rainwater, especially during the rainy season (Ahmad; Nathan; Lias, 2019). The average suspended sediment concentration from the three flood events is 103.04 mg/L. This falls within the range of 100 – 250 mg/L, which is considered moderate health criteria for suspended sediment. Despite this moderate classification, the area has steep slopes, emphasizing the urgent need for conservation efforts. The steepness of the slopes significantly affects nitrogen presence through erosion and surface runoff (Yang *et al.*, 2020). This study has several shortcomings and limitations during its implementation. A longer observation and sampling period is recommended for future research.

4. CONCLUSIONS

The characteristics of time components including rainfall, flow rate, sediment concentration, and dissolved nutrient concentrations (N-total, P-total, and K-total) from three flood events in the *Cigumentong* catchment reveal several patterns: the peak flow discharge occurs, on average, 40 minutes after the peak rainfall, while the peak sediment concentration follows the peak flow discharge by an average of 60 minutes. Additionally, peak nutrient concentrations (N-total, P-total, and K-total) in the *Cigumentong* catchment occurred after the peak flow. The hysteresis pattern observed between flow discharge and sediment concentration, as well as the concentrations of nitrogen, phosphorus, and potassium from these flood events, displays a counterclockwise hysteresis pattern. Based on the hydrological response to rainfall, the health condition of the *Cigumentong* catchment is categorized as moderate.

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