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# ASSESSING THE DISCHARGE FROM TROPICAL CYCLONE IMPACTS

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**Abstract**

El Niño Tropical Storm From April 2nd to the 6th, 2021, East Nusa Tenggara was hit by one of the biggest storms on record, Seroja. Based on the cyclone's trajectory, Seroja—which originated at 10.5° S and 123° E—traveled westward to Sumba Island and then on to Australia. In addition, the research revealed that the precipitation continued to rise throughout Seroja's development to reach 225 mm, as determined by analysing the rainfall conditions at the Seroja cyclone's centre to the Kambaniru watershed in East Sumba using the Global Precipitation Measurement (GPM) output. Consequently, this research set out to use quantitative analysis on rainfall data from GPM to determine how the storm's rainfall affected the maximum discharge in the Kambaniru watershed. Since there was a lack of field data for the TC Seroja rainfall evaluation, the HSS-SCS Curve Number technique and GPM data were re-used to analyse the flood flow. Based on the data, the Kambaniru watershed's CN value was in the AMC III condition, with a curve number of 88.90. The highest recorded flood during the Seroja storm was 2,987 m3/s, surpassing the flood discharge for the 500-year return period. It was also found that the collapse of the Kambaniru Bridge was caused in part by the narrowing of the river channel on that stretch of the bridge.

*Keywords:* Curve Number; Flash Flood; Rainfall; GPM; AMC.

## 1. Introduction

Tropical cyclones (TC) are storms with great strength, usually formed on large oceans with a sea surface temperature of more than 26.5°C [1]. They are also defined as cyclones occurring in areas with a tropical climate located between 10° to 20° N and 10° to 20° South Latitude. The average radius of a tropical cyclone is 150 to 200 km, while the wind speeds are between 100 and 500 km/hour. It was also reported that the strong winds rotating near the center had a speed of more than 63 km/hour or 34 knots [2, 3]. Moreover, the movement of the wind from the center of high pressure to the center of low pressure turns the center of low-pressure depression into a tropical cyclone. This is due to the fact that lower air pressure makes air masses tend to gather, thereby leading to heavy rains and the potential to cause flash floods. Tropical cyclone formation generally occurs over a warm ocean located within 10° to 20° of the equator but usually fails to form at latitudes less than 4° [4]. It is important to note that it is formed near the equator and then moves further from the equator. However, these disturbances can occur in low latitudes, such as Indonesia, but the possibility of occurrence is rare.

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Tropical cyclone has a very terrible impact on both the area it passes and the surrounding areas. It also has varying durations, which range from a few hours to 14 days, with an average of 6 days. Moreover, the magnitude of the impact depends on the cyclone intensity [5]. It is important to note that the direct effect is through an increment in rainfall intensity [6, 7], wind speed [8], and extreme waves, while the indirect effect can be observed in improved meteorological activity such as the increased flood discharge in the watershed area [9, 10]. The tropical cyclones in Indonesia have been analyzed in previous studies as indicated by the TC Haiyan in Papua [11] as well as TC Cempaka and TC Dahlia in the Southern Ocean of Java [12, 13]. It was discovered that their impacts depend on the type of TC and other factors such as topography, distance from the TC, and global atmospheric conditions in each region. It was also observed that TC Seroja also had a different effect.

The tropical cyclone Seroja, which occurred in East Nusa Tenggara (NTT), was detected in the Sawu ocean of East Nusa Tenggara on the 2nd of April 2021 with the initial code 99S. The air pressure was reported to have started at 1004 hPa and the wind speed was 25 knots [3, 14], after which it increased to 69 knots after three days on April 4, 2021. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) stated that this sacred tropical cyclone caused an increase in rainfall around the cyclone and extreme weather in East Nusa Tenggara [15]. It also had the worst impact on the areas it passes through, such as Alor, East Flores, Lembata, Kupang City, Kupang Regency, Malaka, Belu, Timor Tengah Utara, and East Sumba.

TC Seroja caused several hydrometeorological disasters such as floods, flash floods, landslides, strong winds, waves crashing, fallen trees, and damage to buildings. The flash flood also collapsed some bridges, including the Kambaniru Bridge located in Malumbi village, Kambera, which is 10 km from Waingapu City in the East Sumba Regency, as indicated in Figure 1. There are other infrastructures in East Sumba affected by TC Seroja, and these include the Kambaniru dam damaged by floods and the 5000 local houses destroyed by strong winds on April 4, 2021 [16].

**Figure 1. The collapse of the Kambaniru Bridge due to Tropical Cyclone Seroja**

This study aims to determine the effect of the extreme rainfall intensity during the TC Seroja on the occurrence of flash floods in the Kambaniru watershed. It is important to note that this watershed does not have runoff or rainfall data and this was the reason a rainfall-runoff analysis was conducted using a synthetic hydrograph. The surface runoff was simulated using the SCS CN synthetic unit hydrograph and the Snyder synthetic unit hydrograph. The difference between this study and previous studies is the occurrence of TC Seroja near the equator and its passage through areas classified as semi-arid including the Kambaniru watershed.

## 2. Methods

### 2.1. Study Area and Data

Kambaniru watershed is the largest in the East Sumba Regency with an area of 1,158 km$^2$ and a river length of 207.3 km. It has nine sub-watersheds with a river slope of 0.009 and an average sub-watershed slope of 0.24. Moreover, the annual maximum daily rainfall in the watershed is 29– 126 mm while the annual rainfall ranges from 906.11 to 1,160 mm/year. The rainfall stations located in the area include the Waingapu and Malahar stations.

The Kambaniru area is dominated by marl, limestone, and tuff with very low aquifer productivity of 0.1 lit/sec while the underground rivers or karst springs in some places have a discharge of approximately 5 lit/sec [17]. The watershed has several water potentials considering the fact that the catchment area is dominated by impermeable rocks. Furthermore, the geological structure is in the form of faults and fractures with the fault observed to be forming the springs that supply surface water, especially rivers while the fractures become underground rivers due to the

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dissolution process (limestone). In addition to the radial shape and local rock lithology, the watershed is vulnerable to flooding during the rainy season because rainfall reaches 239 mm/day upstream as recorded on 22 December 2013. It is important to note that the worst impact of flash floods in the Kambaniru River was the collapse of the connecting bridge between Karera and Pinupahar Districts.

Global Precipitation Measurement data from April 2-5, 2021 which consists of initial data and boundary map conditions of the model were obtained from *https://giovanni.gsfc.nasa.gov/giovanni/* [18]. Moreover, the Kambaniru watershed located between 9°40’ S - 10°10’ S and 119°55’ E - 120°43’ E as indicated in Figure 2 was the focus of this study. The GPM data downloaded were calibrated with ground station data to ensure a correlation coefficient before they were applied.

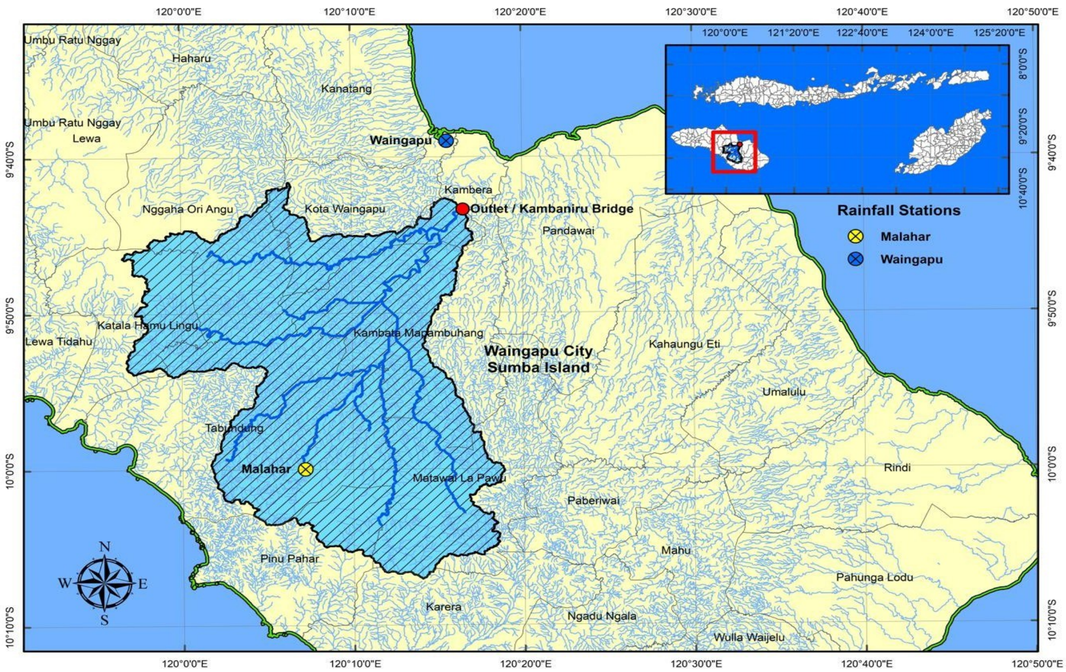


**Figure 2. Location map of Kambaniru Watershed**

The rainfall data were analyzed using the Soil Conservation Service Curve Number (SCS-SN) Unit Hydrograph method to obtain the runoff. This method was also applied to determine the curve number value in the Kambaniru watershed through the overlying (intersection) of the hydrological soil group map and land use map [19] to produce a new polygon representing the curve number value. Moreover, the flow chart for the research methodology is described as follows (Figure 3):

### 2.2. Study Framework

The design flood discharge can be analyzed using different methods including the SCS-CN synthetic unit hydrograph which is advantageous due to its possible application to areas without flood hydrograph data from observations and reservoir water levels but with rain data. It is based on the Curve Number (CN) value which is the index value to determine the amount of rainfall flowing into and entering the river network system [20]. The empirical formula normally used is stated as follows:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \tag{1}$$

The initial abstraction is a sensitive parameter in hydrological models because its value directly determines the amount of runoff [21]. This is due to its ability to show the amount of precipitation required to fall to have an excess yield on the soil surface. It was discovered from previous studies that initial abstraction (Ia) is closely related to the antecedent watershed conditions and can be calculated using the following equation:

$$Ia = 0.2 \times S \tag{2}$$

where, Ia is the initial abstraction and S is the potential maximum retention (mm) which can be generally determined as follows [22]:

$$S = 25400 / CN - 254 \tag{3}$$

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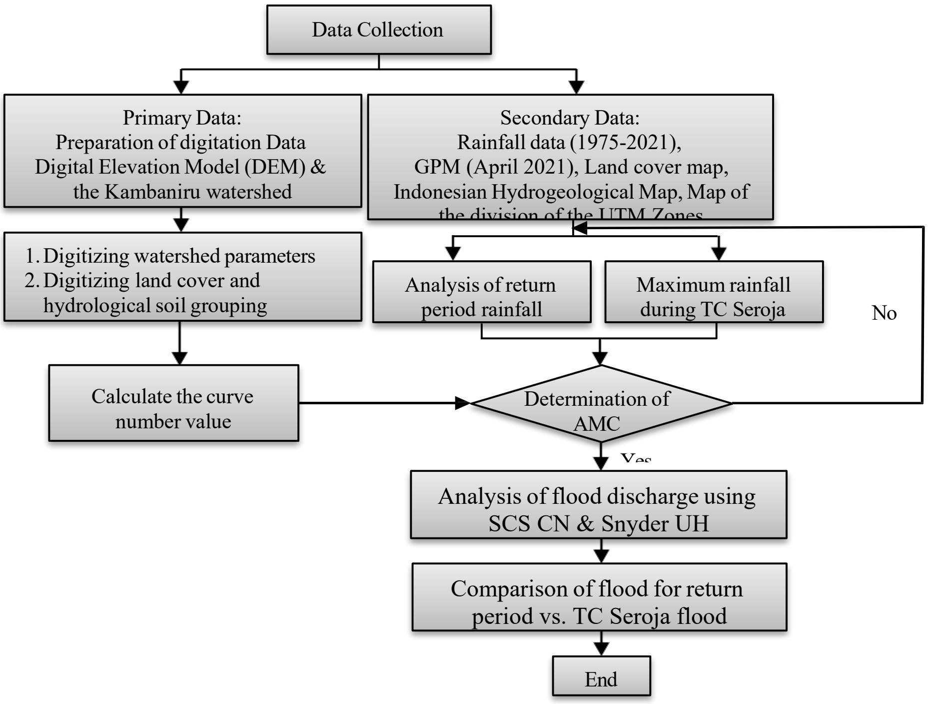


**Figure 3. Flow Chart of Research Methodology**

The potential maximum retention (S) of water by the soil occurs due to infiltration or after the initiation of the runoff [23]. Therefore, Equations 1 and 2 can be rewritten as follows:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (4)$$

where, Q is the direct runoff (mm) and P is the precipitation or rainfall (mm).

The curve number (CN) value is a function of watershed characteristics such as land cover, watershed slope, rock lithology, soil moisture, and soil working methods. It is a non-dimensional quantity which varies between 0 to 100. The relationship between S and CN is a purely mathematical transformation usually implemented due to the convenience in the portrayal of the coefficient and ease of understanding [24].

For the CN value, the normal antecedent moisture conditions also apply such that it can be converted into Equations 5 and 6 For dry conditions (AMC I) or wet conditions (AMC III). The classification for each AMC condition is, therefore, provided in the following Table 1.

$$CN(I) = \frac{4.2\ CN\ (II)}{10 - 0.058\ CN(II)} \quad (5)$$

And;

$$CN(III) = \frac{23\ CN\ (II)}{10 + 0.13\ CN(II)} \quad (6)$$

**Table 1. AMC determination for curve number (CN)**

| AMC | Precipitation of previous 5 days (mm) | |
|---|---|---|
| | **Dormant season** | **Growing season** |
| I (Dry soil) | Less than 12.7 mm | Less than 35.56 mm |
| II (Normal soil) | 12.7 mm – 27.94 mm | 35.56 mm – 53.34 mm |
| III (Saturated soil) | More than 27.94 mm | Less than 53.34 mm |

Snyder [25] presented a method to derive synthetic unit graphs empirically. This Snyder synthetic UH has two main parameters which are the lag factor ($C_t$) and the peak flow factor ($C_p$). These parameters are topographically dependent and should be estimated for each particular case. This method was selected for this study because it is a part of HEC-HMS software. Meanwhile, the catchment time lag formula is presented as follows [26]:

$$T_{lag} = C_t\,(L.L_c)^{0.2} \quad (7)$$

where, $C_t$ is the coefficient explaining the catchment gradient and it is related to catchment storage, L is the mainstream length (km), and $L_c$ is the mainstream length from the outlet to the closet point to the catchment centroid (km). Moreover, Snyder's formula for peak discharge is as follows:

$$Q_p = \frac{2.78 \times C_p \times A}{T_{lag}} \quad (8)$$

where, A is the catchment area and $C_p$ is the empirical coefficient connected to the triangular base time to time lag.

## 3. Results

One of the impacts of the TC Seroja in East Sumba Regency is the occurrence of extreme rainfall and strong winds for a few days from April 2 – 6, 2021. It is, therefore, necessary to study this rainfall using the ground station and satellite data.

### 3.1. Maximum Daily Rainfall Analysis

The annual maximum daily rainfall data for a period of 41 years (1975-2021) were obtained from the Malahar rainfall station and analyzed using the point rainfall method. The results are presented in the graph as shown in Figure 4.

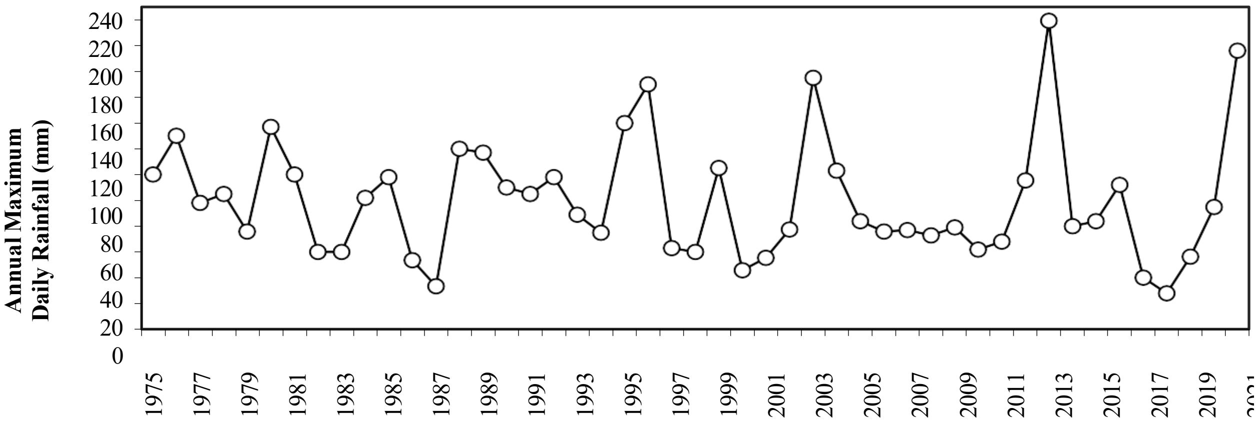


**Figure 4. The annual maximum daily rainfall in Kambaniru Watershed**

Figure 4 shows that the highest rainfall in Malahar occurred in 2013 and 2021. It is important to note that there was TC Rusty in 2013 which triggered strong wind at 25-40 km/hour and extreme rainfall for three days [27]. This implies that the East Sumba area is very vulnerable to tropical cyclone storms because there have been 2 TCs in the area in the past decade. The distribution of extreme rainfall heights from April 1 to 6, 2021 at the Malahar rainfall station and from GPM data is presented in Figure 5 and the peak was recorded to be 216 mm for the Malahar station and 225 mm for the Global Precipitation Measurement data. Meanwhile, rainfall with a height above 200 mm/day is categorized as very high with flood susceptibility, especially for the semi-arid area such as East Sumba Regency.

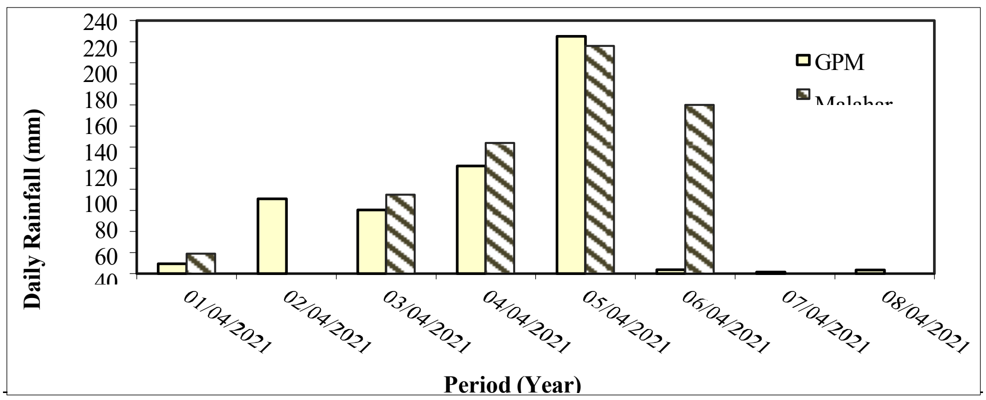


**Figure 5. The maximum daily rainfall from April 01, 2021, to April 8, 2021, in Kambaniru Watershed**

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The Global Precipitation Measurement (GPM) was used to compare the existing ground station rainfall data due to the need for accurate spatial and temporal resolution information of extreme rainfall in flood forecasting and disaster mitigation. The GPM produces half-hour grid data through the Integrated Multi-Satellite Retrieval for GPM (IMERG) system and it evaluates the performance of IMERG data to measure extreme precipitation indices over Indonesia such as TC Seroja in East Nusa Tenggara. It is pertinent to note that several studies have been conducted on the calibration or evaluation of GPM satellite data [28, 29].

The information presented in Figure 5 showed that the daily rainfall value from GPM data is much higher than the ground station's maximum daily rainfall. Furthermore, the accuracy of the rainfall data from the two sources was analyzed using a correlation coefficient for the initial test, hence a value more than 0.60 indicates the GPM data represent the ground station data and the result is presented in Figure 6.

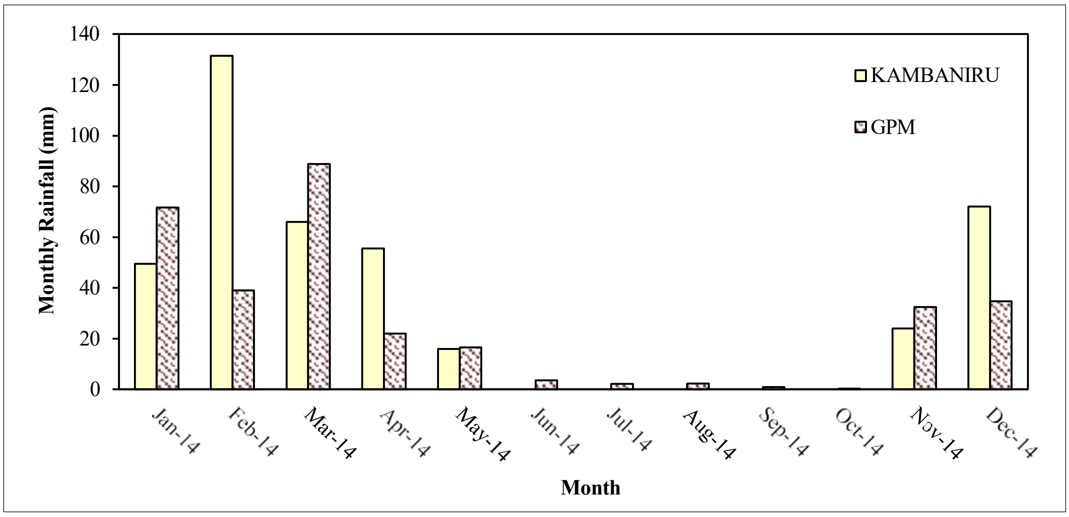


**Figure 6. The monthly rainfall recorded from the ground station and GPM data in Kambaniru Watershed**

Figure 6 shows that the comparison of the two monthly rainfall data produced a correlation coefficient value of 0.6352 and this indicates the GPM data is good enough to be used as an initial reference in case the data from the earth station is not yet available. The satellite products and field data have also been previously compared using correlation coefficients in the Himalayan region [30] and the results showed that the medium to heavy as well as light to medium rainfall estimates is close to the field data.

### 3.2. Wind Speed

TC Seroja started from the closed circulation on wind gradient in the southern sea of NTT, triggering a wind bend which then causes a slowdown in air mass flow that occurs on 2 to 3 April 2021. This slowing condition resulted in an increase in the mass of water vapor in the area around the wind bend, which is in the southern ocean of NTT and continues to move towards the southern part of the East Sumba ocean, thus having an impact on a very significant increase in the growth of convective clouds is presented in Figure 7.

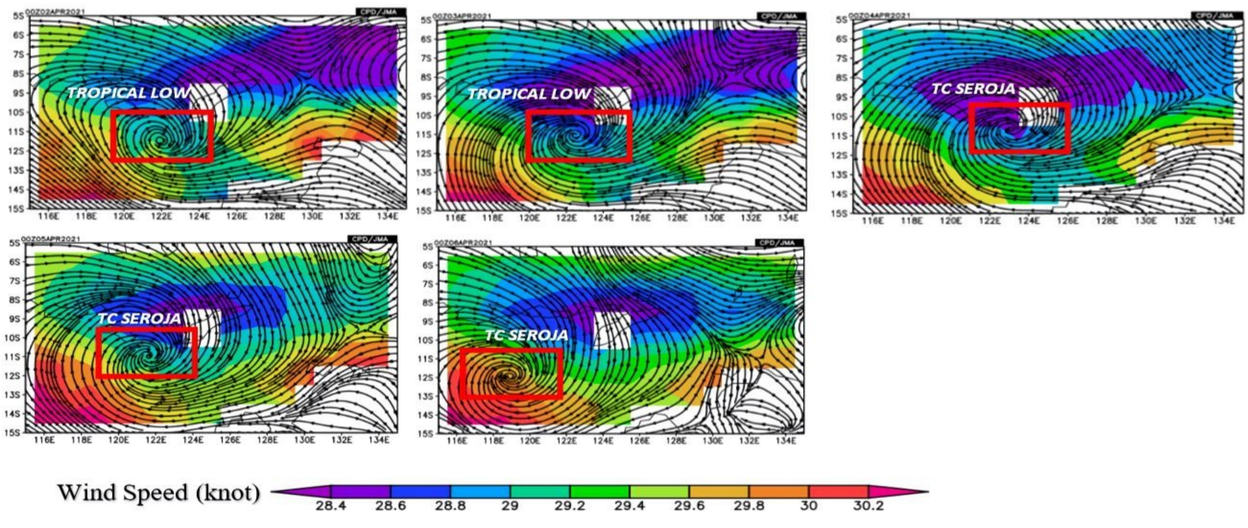


**Figure 7. The circulation of wind on 2nd to 6th April 2021 [31]**

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The change in form from seed cyclone to tropical cyclone Seroja occurred on April 4 to 6, 2021, when the movement of tropical cyclone Seroja from the West Timor Sea to the south of Rote Island moved towards the southern ocean of East Sumba. Maximum wind speed occurs evenly in most areas of NTT. During the period from March 29 to April 10, 2021, the highest wind speeds occurred on April 5 to 6, 2021, ranging from 45-69 knots or 81–124 km/hour as shown in Figure 8.

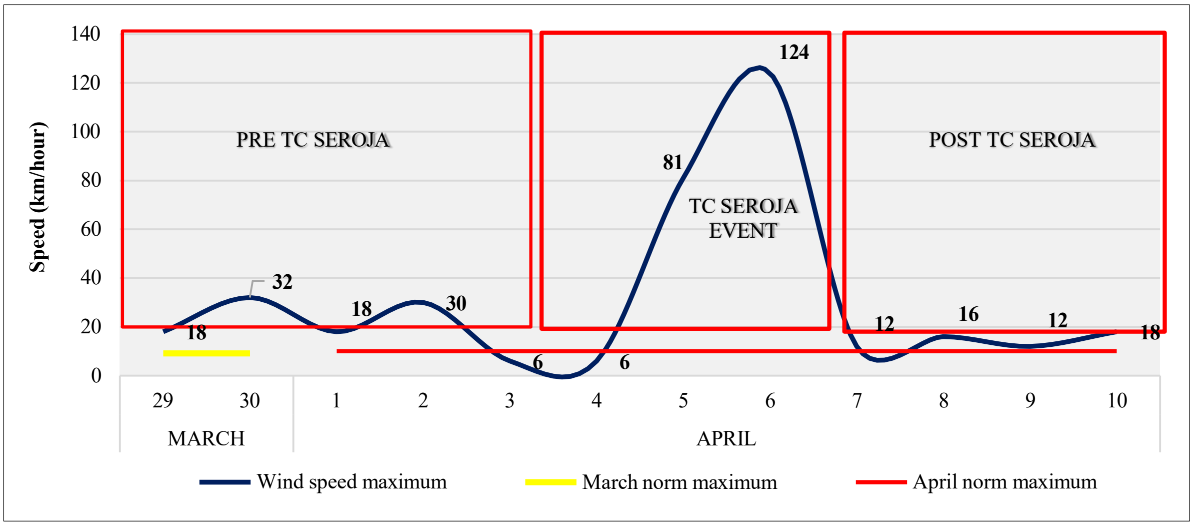


**Figure 8. Maximum wind speed event TC Seroja in East Sumba**

### 3.3. Flood Discharge during Tropical Cyclone Seroja

Flood analysis was conducted in the Kambaniru watershed using HSS SCS-CN with the help of HEC HMS software. The result showed that the curve number value was 77.03 and the rock lithology is dominated by marl limestone, limestone, and tuff with low to moderate graduations. The conversion of these findings into a hydrologic soil group (HSG) indicates the Kambaniru watershed has a value of C to D.

The CN value obtained is also for the antecedent moisture conditions (AMC) II condition which is believed to be normal. It was discovered from Figure 9 that the soil condition in the Kambaniru watershed when the tropical cyclone Seroja was AMC III conditions and the CN value was 88.90.

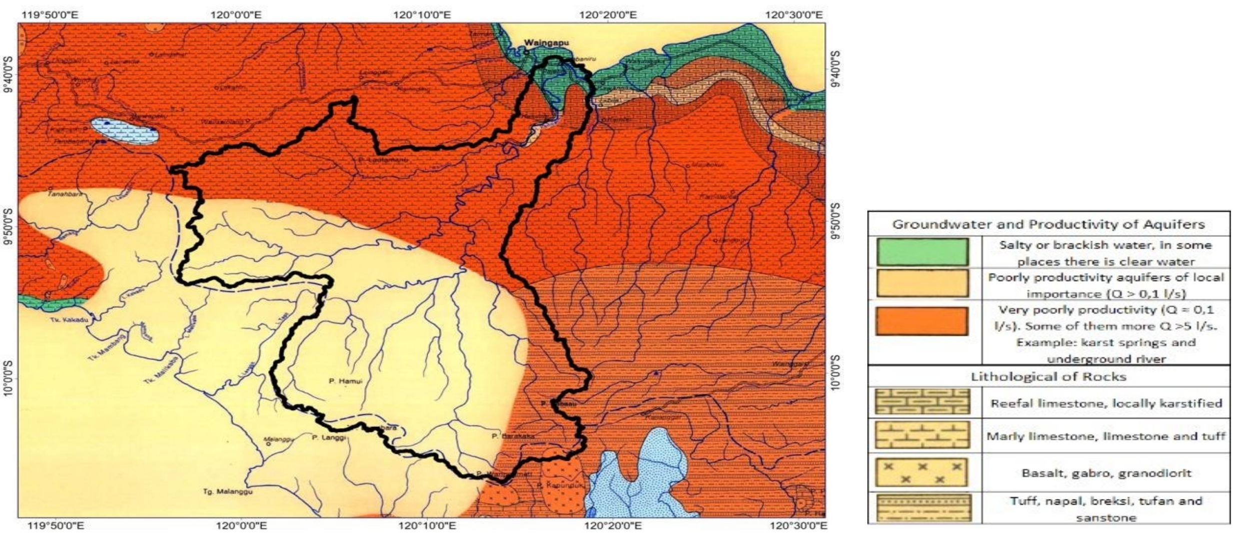


**Figure 9. The hydrogeology map of Kambaniru Watershed**

The flood discharge was simulated at a rainfall height of 225 mm from GPM during the tropical cyclone Seroja through the SCS-CN unit hydrograph and the result is presented in Figure 10 while the discharge values for the Kambaniru watershed are presented in Table 2.

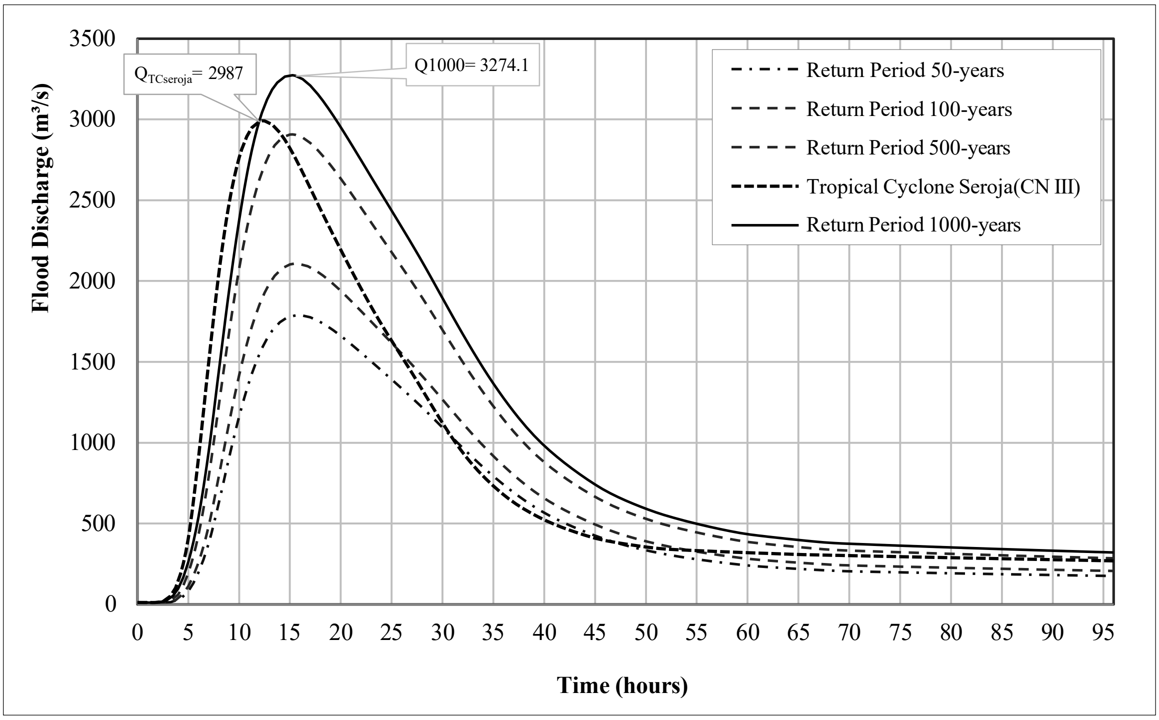


**Figure 10. Estimation of flood discharge due to TC Seroja for the discharge return period design in Kambaniru Watershed**

**Table 2. Flood discharge for different return periods in Kambaniru Watershed**

| No. | Return Period (years) | Rainfall (mm) | Flood discharge (m³/s) |
|---|---|---|---|
| 1 | 2 | 93.156 | 466.3 |
| 2 | 5 | 131.84 | 832.4 |
| 3 | 10 | 158.78 | 1106.5 |
| 4 | 25 | 194.41 | 1487.9 |
| 5 | 50 | 222.04 | 1789.3 |
| 6 | 100 | 250.51 | 2107.1 |
| 7 | 500 | 320.56 | 2906.9 |
| 9 | 1000 | 352.59 | 3274.1 |

The 1000-year return period flood discharge was observed to be almost close to the calculation done by JICA (1996) with a discharge value of 3,320 $m^3$ /second [32].

The maximum floods during the tropical cyclone Seroja for normal conditions with AMC II were discovered to have discharges above the 500-year return period and below the 1000-year return period. Meanwhile, for growing conditions, the maximum flood value was 2,987 $m^3$/second because there had been continuous high rainfall above 50 mm/day for the previous 5 days and this exceeds the 500-year return period of 2900.6 $m^3$/second but below the 1000-year return period value of 3,274.10 $m^3$/s (see Figure 11).

The SCS hydrograph was further calibrated with Snyder's hydrograph model to obtain the non-physical parameters. It was discovered that the soil in the Kambaniru watershed is divided into two types based on FAO HWSD data and these include the Chromic Luvisols and Lithosols. The Chromic Luvisols dominate by covering an area of 900.92 $km^2$ (77.8%) and spread predominantly in the upstream part of the watershed while Lithosols cover 257.08 $km^2$ and spread dominantly in the downstream part.

Model 1 and model 2 comparation were observed to have some similarities in the shape of their hydrograph or volume and some of the non-physical parameters obtained close to the peak coefficient of 0.60 from the Snyder Hydrograph are presented in Table 3.

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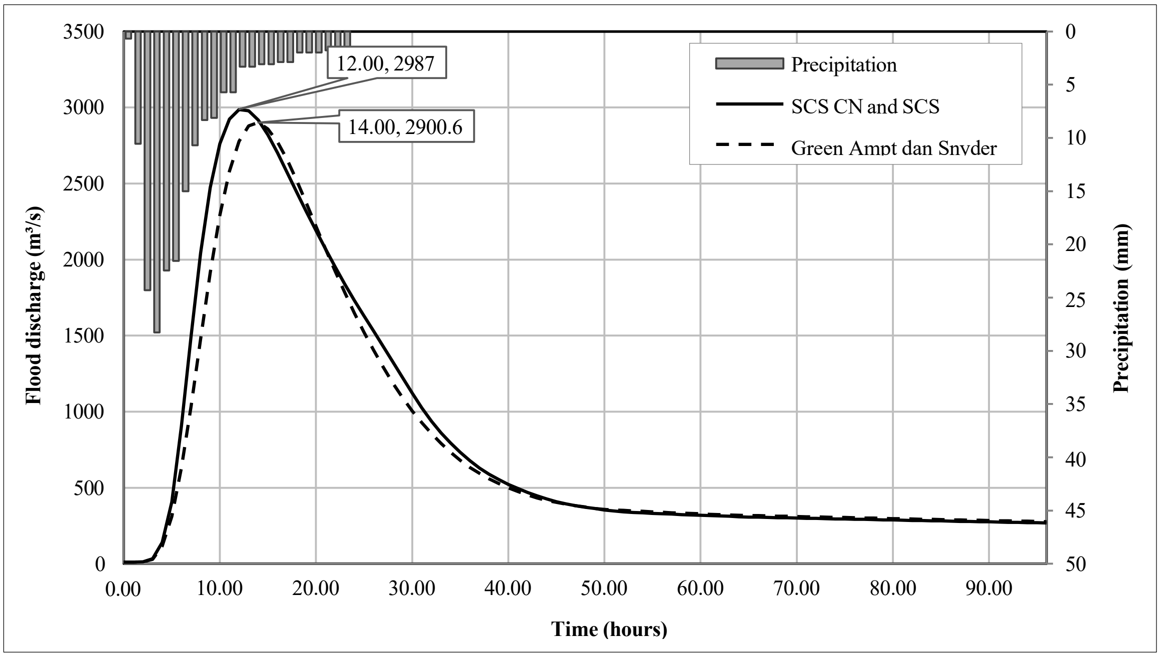


**Figure 11. Comparison of simulated SUH hydrographs (P – precipitation, Q – discharge) in Kambaniru Watershed**

**Table 3. Non-Parameter Physical using losses GA and Snyder Hydrograph in Kambaniru Watershed**

| **Green and Ampt (GA)** | |
|---|---|
| Initial content | 0.010 |
| Saturated content | 0.385 |
| Suction (mm) | 316.3 |
| Conductivity (mm/hr) | 0.300 |
| Impervious (%) | 0.000 |
| **Snyder** | |
| Peaking Coefficient | 0.600 |

The total difference in the maximum flood volume between the Snyder hydrograph and SCS-CN hydrograph was found to be 2.89%. The findings also showed that the lag time, $T_{lag}$, model parameter had an optimal value of 14 hours with a peaking coefficient ($C_p$) of 0.600 for the Snyder hydrograph after calibration while SCS-CN had 12 hours. This simply shows the maximum flood that exceeds the flood discharge at the 500-year return period cannot pass through the narrowed cross-sectional capacity of the river.

The collapse of the Kambaniru Bridge during the tropical cyclone Seroja was found to be due to the continuous high-intensity rainfall and an increase in the volume of surface runoff in the Kambaniru River. Meanwhile, the narrow channel of the river was observed to be due to a weir structure and the collapse of the pedestrian bridge connecting the 2 villages because of the increase in runoff volume. Therefore, it is necessary to normalize and study the construction of structures in the Kambaniru river channel.

## 4. Discussion

The tropical cyclone Seroja has the worst effect on flood discharge in the Kambaniru watershed for several reasons, such as the shape of the watershed, river flow patterns, curve number value, and high daily rainfall intensity for 5 days. It was observed that the shape of the Kambaniru watershed is radial, and this implies it tends to overflow downstream due to the tributaries meeting at one outlet. The high rainfall intensity in one area allows the movement of runoff downstream by the tributaries and its collection at one outlet point, thereby leading to massive flooding downstream of the watershed.

The flow pattern of the Kambaniru watershed is dendritic, and this signifies its tributary flow resembles a leaf segment and empties directly into the Sawu Sea as observed in Puslitbang [17]. Moreover, the valleys in the area have a mature morphological level and the river slope of 0.9% indicates its tendency to be flat, thereby allowing the surface runoff to last quite a long time in reaching the downstream compared to a steep slope. This further causes an increase in river volume when the tributaries meet at the outlet point.

The curve number value of the Kambaniru watershed was recorded to be 77.03, with predominantly marl limestone, limestone, and tuff with low to moderate graduations. This type of rock is present in 64.30% of the total area of the watershed with the inclusion of tuff, and this led to poor porosity and permeability due to the inability of the rock to store water and its impermeability. This contributed to the massive floods experienced in the Kambaniru watershed during tropical cyclone Seroja.

There was heavy rainfall at an average of 52.20 mm/day for 5 days during the cyclone and the wind speed until 69 km/hours from April 5 to 6, 2021. The rainfall is included in the very high rain category and the initial humidity soil value is categorized as AMC III. The growing condition soil value of AMC can affect the value of flood discharge under normal conditions, while heavy intensity and continuous rainfall affect the soil's ability to absorb water. Moreover, the soil saturation supported by rock lithology, which tends to be an impermeable layer, causes the volume of surface runoff to increase and multiply. It was also discovered that the soil moisture condition calculated using the value of accumulated rainfall in the previous 5 days increased the CN value by 14.20%, as indicated by the increment from 77.03 under normal conditions to 88.90. These factors led to a very high volume of surface runoff downstream of the Kambaniru River, and the flood discharge exceeded the value for a 500-year return period. It was also observed that the narrowing of the river channel on the Kambaniru bridge segment was one of the reasons the bridge collapsed.

## 5. Conclusion

From April 4–6, 2021, TC Seroja affected the rate and severity of high rainfall and wind speeds in East Nusa Tenggara, particularly in the East Sumba region. Wind speeds in the cyclonic zone reached 81 to 124 km/h (45 to 69 knots). The collapse of the Kambaniru Bridge was caused by floods caused by this high rainfall, which exceeded 200 mm/day. There was an increase in the soil moisture value from AMC II to AMC III, with the change from CN(II) = 77.03 to CN(III) = 88.90. In addition, 366.3, 832.4, 1106.5, 1487.9, 1789.3, 2107.1, 2906.9, and 3274.1 m3/s were consecutively recorded for the flood discharge during a return time of 2 to 1000 years. During the flood on April 4, 2021, the value was 2987 m3/s, which is the same as the figure for the 500-year return period. Results also demonstrated that watershed features, such as heavy rainfall over several days and river channel constriction at the bridge section, contributed to flooding in the Kambaniru watershed during TC Seroja. Another element that impacts the overflow downstream of the Kambaniru River is the dendritic river flow pattern, which is caused by the radial form of the watershed. The watershed's tuff rock lithology, which is both impermeable and has low porosity, increased the river's ability to store water. Extreme flooding occurred downstream of Kambaniru as a result of tropical cyclone Seroja's peak and the rivers' incapacity to handle surface runoff from upstream, as well as heavy rainfall in the days leading up to the storm's peak.

## 6. Declarations

### 6.1. Acknowledgements

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