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Interrelations of rainfall and morphometric characteristics in generating geological disasters of Kuranji watershed Padang city

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Abstract. The Kuranji watershed is one of the watersheds in the city of Padang, which is currently experiencing development due to rapid population growth. This has resulted in land conversion from areas that have vegetation to built areas such as settlements. This affects the balance of the Kuranji watershed ecosystem and can lead to geological disasters. Therefore an initial analysis is needed in the development of the Kuranji watershed in the future. This study aims to analyse the interrelation of rainfall and morphometric characteristics that have an impact on geological disasters. The data used are data of maximum rainfall and maximum river discharge in the Kuranji watershed from 2009 - 2018. DEM data (30x30) used to calculate morphometric aspects, consisting of linear aspects, area aspects and relief aspects. The calculation of these aspects is done by a Geographic Information System (GIS) approach using ArcGIS 10.6 software. The result shows that the Kuranji watershed has an area of 22469,55 ha with dendritic drainage patterns. The linear aspect reveals that it has 1894 rivers with a total length of 774,6 km. This aspect explains that with the many tributaries, the Kuranji watershed has the potential to cause flooding. Aspects of the area explain that the Kuranji watershed has an elongated shape, steep slope and causes a rapid and large run-off discharge. Drainage density is at medium level with a value of 3,45 (km/km²) which is close to the high category. The higher the drainage density the smaller the chance of water for infiltration and the greater the river discharge. The relief aspect explains that the Kuranji watershed has a height between 0-1860 meters above sea level. Relief ratio and gradient ratio have a value of 0,08. Gradient ratios with high values result in fast and swift flow of surface and river water flow. This has the potential for landslides, channel erosion and river wall erosion. High rainfall, extreme morphometric characteristics, causes the Kuranji watershed to have a great potential for geological disasters.

1. Introduction

Watershed is a landscape separated by altitude and ridge. Each watershed area has a different response to rainfall. The response is influenced by landscapes such as climate, soil, relief and drainage areas. One of the most influential aspects in responding to rainfall is the morphometric aspect. [1] explain that morphometric assessment in watershed areas is very important to do in the assessment of resources and water management in watershed areas. This is because morphometric aspects can



explain the relationship between river networks, reliefs and watershed forms. Also added by [2], [3], [4] that in conducting hydrological investigations as well as the management and development of watershed areas, morphometric analysis is also very important to do. Due to the morphometric characteristics it gives an overview in the form of topography, geology and hydrology which can influence the watershed area process. The Kuranji watershed is located in the city of Padang and has unique characteristics from other watersheds. This watershed has a steep slope reaching more than 50% of the watershed area and has a short upstream to downstream distance. The Kuranji watershed is classified as a small watershed with an area of 22,469.55 Ha.

The Kuranji watershed has a high rainfall of more than 5,000 mm/year. High rainfall will affect water regulation. During the rainy season, the river water level is quite high reaching 2.20 meters with a discharge of 623.50 m³/second. During the dry season the river water debit is 0.50 m³/second. The high difference in river discharge in the rainy season and the dry season presents serious problems for the Kuranji watershed in the future. These problems are related to human needs for land in the watershed area. These needs are like built up land and agriculture.

Reviewed by population, sub-districts in the Kuranji watershed area have high population growth. The sub-districts such as, Koto Tengah sub-district, Kuranji sub-district, Nanggalo sub-district, West Padang sub-district, North Padang sub-district and Pauh sub-district. The population growth rate from 2010-2017 was 8.7 %. The high population growth in the Kuranji watershed will have an impact on land needs. So that proper watershed management is needed to prevent geological disasters in the future. For this reason, researchers are interested in conducting research on how the Interrelation of Rainfall and Morphometric Characteristics in Producing Geological Disasters.

The reason for choosing the Kuranji watershed is that this watershed is the largest watershed in Padang City, which has a fast and large population growth resulting in land conversion. Population growth in the watershed area can cause erosion that can occur more quickly and have an impact on the decline in the quality of the watershed. Land use change in the Kuranji watershed area tends to change from vegetation to developed land. Population pressures and growth have an effect on land use change. [5] The Kuranji watershed is prone to flooding, this is caused by the change in land cover into a residential area.

The rapid increase in population in the Kuranji watershed encourages researchers to find solutions to provide an initial picture of the Kuranji watershed. So that in future development will be avoided from adverse geological disasters. This research has 2 approaches. First, look at the relationship between rainfall and river discharge in the Kuranji watershed. Second, how rainfall and morphometric aspects can produce geological disasters in the Kuranji watershed.

2. Material and method

2.1. Description of the study area

The Kuranji watershed is located in the Padang city, West Sumatra and has an area of 22,469.55 hectare. The Kuranji watershed is located between 100°21'18.84" – 100°33'52.87" E dan 0°47'23.36" – 0°56'13.71" S, with a maximum height of 1,860 meters above mean sea level. This watershed has an annual rainfall of 5,054 mm [6]. This research was conducted in November 2018 - March 2019. The research location can be seen in Figure 1.

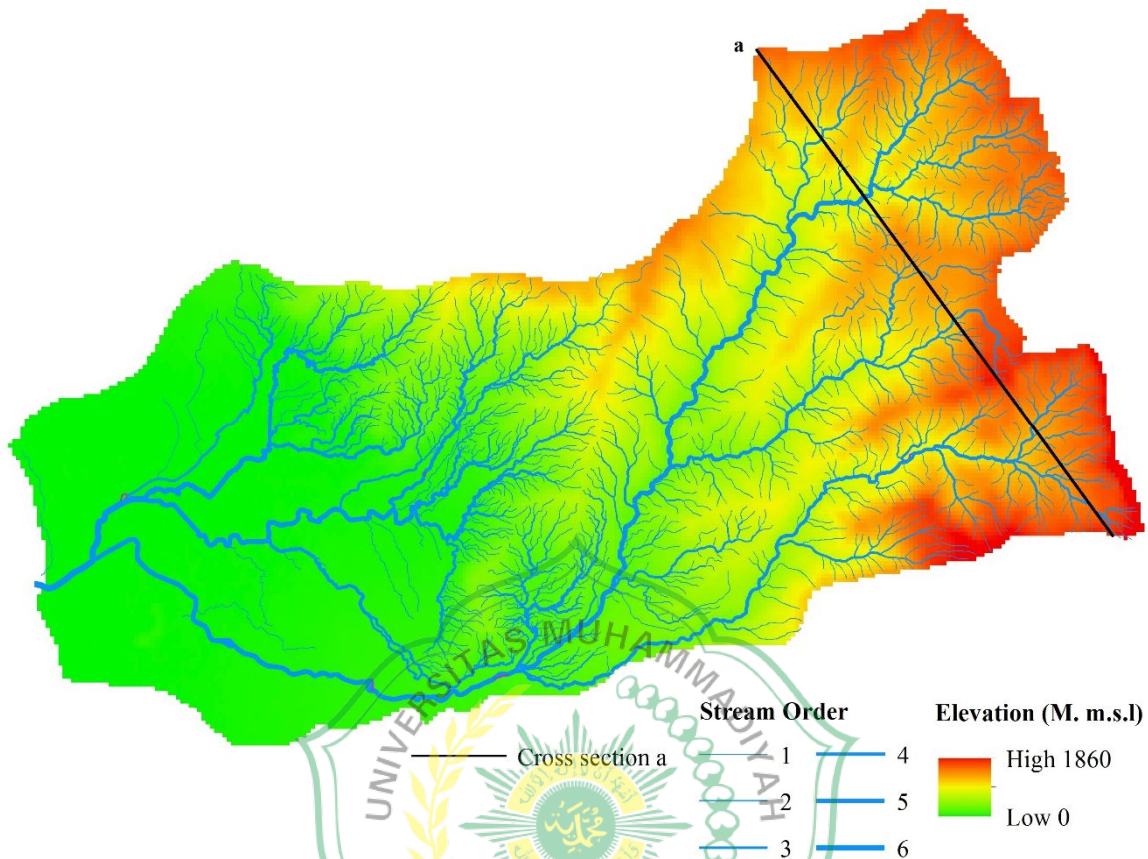


Figure 1. Map of the Kuranji watershed research location

2.2 Data sources and processing

The data in this study are the first, the rainfall data uses secondary data of the average maximum rainfall in one month for one year from 2009-2018. The data used is sourced from Department of Water Resources management of West Sumatera. Second, river discharge data uses secondary data of the average maximum river flow in one month for one year from 2009-2018. The data used are sourced from Department of Public Works and spatial planning of Padang City. Rainfall and river discharge data to see the comparison of the amount of rainfall with the resulting river discharge. The three Digital Elevation Model (DEM) data with a resolution of 30 meters were taken from the United State Geological Survey (USGS) website. DEM data in this study were used to calculate morphometric aspects which consisted of linear aspects, area aspects and relief aspects. The calculation of these aspects is done by a Geographic Information System (GIS) approach using ArcGIS 10.6 software. In determining the river order using the method proposed by Horton. For cross-section profile extending the main river and cross-profile watershed using 3D analyst interpolate line. The methods used in assessing morphometric aspects can be seen in Table 1.

Table 1. Morphometric Characteristic Method

Aspects	Parameters (P)	Methods
Linier aspects	Stream order (u)	Hirarchical ordering
	Stream length (Lu)	Length of the stream
	Mean stream length (Lm)	$Lm = Lu/Nu$
	Stream length ratio (RI)	$RI = Lu/Lu-1$
	Bifurcation ratio (Rb)	$Rb = Nu/Nu+1$
Areal aspects	Drainage density (Dd)	$Dd = Lu/A$
	Stream frequency (Fs)	$Fs = N/A$
	Drainage texture (Dt)	$Dt = Dd * Fs$
	Length of overland flow (Lg)	$Lg = 1/2 * Dd$
	Form factor (Ff)	$Ff = A/Lb^2$
	Circularity ratio (Rc)	$Rc = 4\pi A/P^2$
	Elongation ratio (Re)	$Re = \sqrt{(4A/\pi)} L^{^2}$
Relief aspects	Basin relief (R)	$R = H-h$
	Relief ratio (Rr)	$Rr = (R/lb)$
	Ruggedness number (Rn)	$Rn = R * Dd / 1000$
	Gradient ratio (Rg)	$Rg = Es - Em / Lb$
	Melton ruggedness number (MRn)	$MRn = R / A^{1/2}$
	Basin slope (Sb)	$Sb = H / Lb$

3. Results

3.1. Comparison of rainfall with river discharge

Rainfall is one factor in determining the size of the river discharge. The greater the rainfall, the river discharge generated will also be even greater. In general, this is evident from the analysis of rainfall and river discharge conducted on the Kuranji watershed. Complete comparison of rainfall and river discharge can be seen in Figure 2.

Figure 2 is a comparison of rainfall and river discharge in the last 10 years. The figure explains that rainfall is directly proportional to river discharge. The greater the rainfall, the river discharge generated will also be even greater.

3.2 Morphometric characteristics

River drainage patterns in the Kuranji watershed are based on Figure 1 including the dendritic flow pattern. Has a flow sequence with six levels based on the Strahler method. Dendritic flow patterns are flow patterns with branches of a river resembling a tree structure. [7] dendritic flow patterns indicate that the watershed area is composed of resistant and homogeneous rocks. The dendritic pattern of tributary branching that is irregular and almost all river angles are less than 90^0 . This pattern develops on rocks with equal resistance and the control of the structural layers less influences the flow pattern. The dendritic pattern was less influenced by the structure of the folds and faults in the formation of river channels. The dendritic pattern produces a large river flow because it is influenced by the shape of the river channel branching spread in all parts of the watershed.

The Kuranji watershed has a high river gradient level. This can be seen in Figure 3. Within a distance of 5 km to downstream, the Kuranji watershed has decreased by 890 meters above mean sea level. This results in the faster and faster river currents and increased erosion of canals and sediment transport.

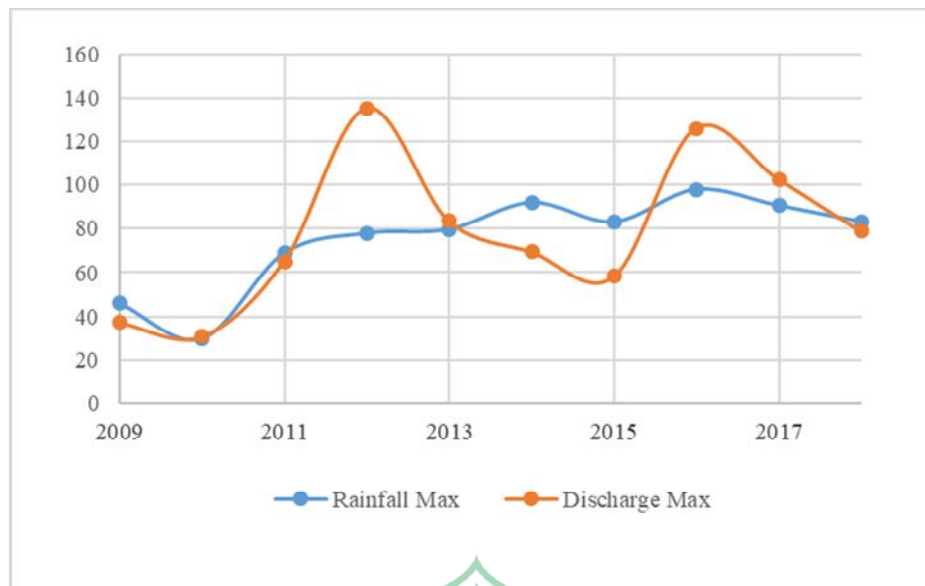


Figure 2. Comparison of Rainfall and River Discharge in The Kuranji Watershed

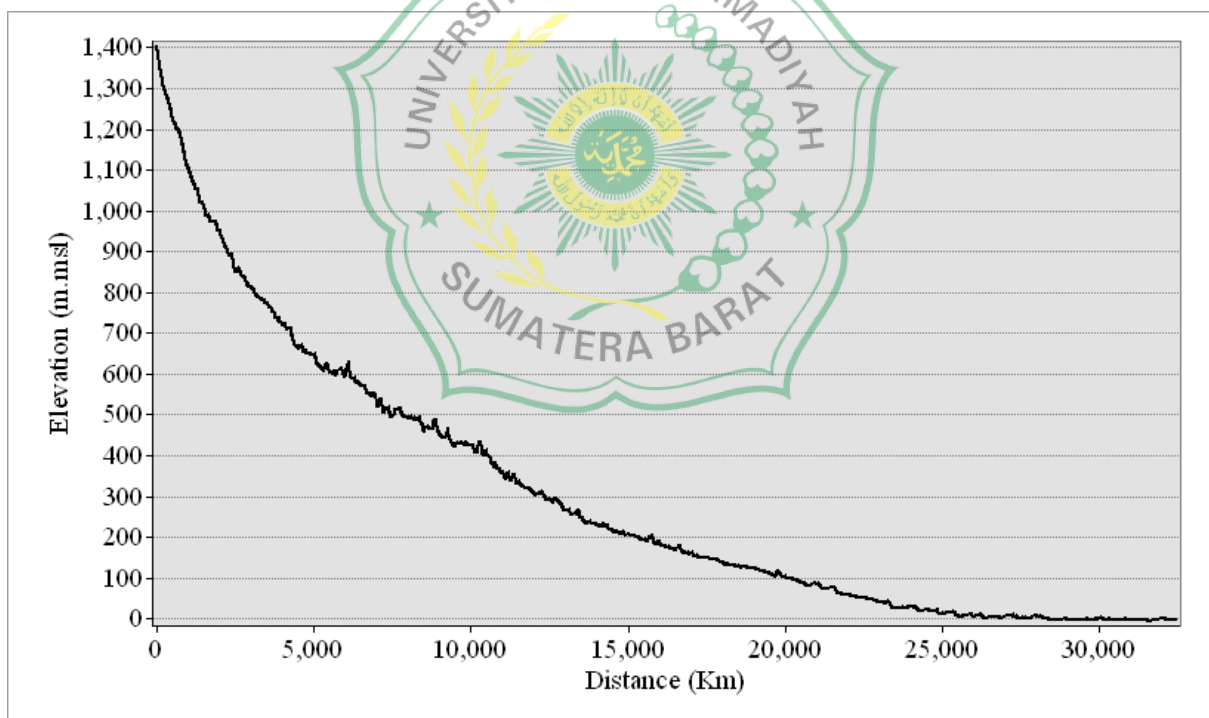


Figure 3. The longitudinal section of the main river in the Kuranji watershed from upstream to downstream.

The slope upstream of the Kuranji watershed is very steep, this can be seen in Figure 4. The slope of the upstream can cause a large surface run-off which results in erosion. Not only the large slope of the Kuranji watershed, high annual rainfall (5.54 mm) also increases river discharge and surface run-off resulting in soil erosion. [8] the intensity of rain and slope causes soil erosion. The higher the intensity of rainfall and the slope, the greater the erosion will be. The impact of rainfall intensity is greater on the amount of soil erosion than on slope.

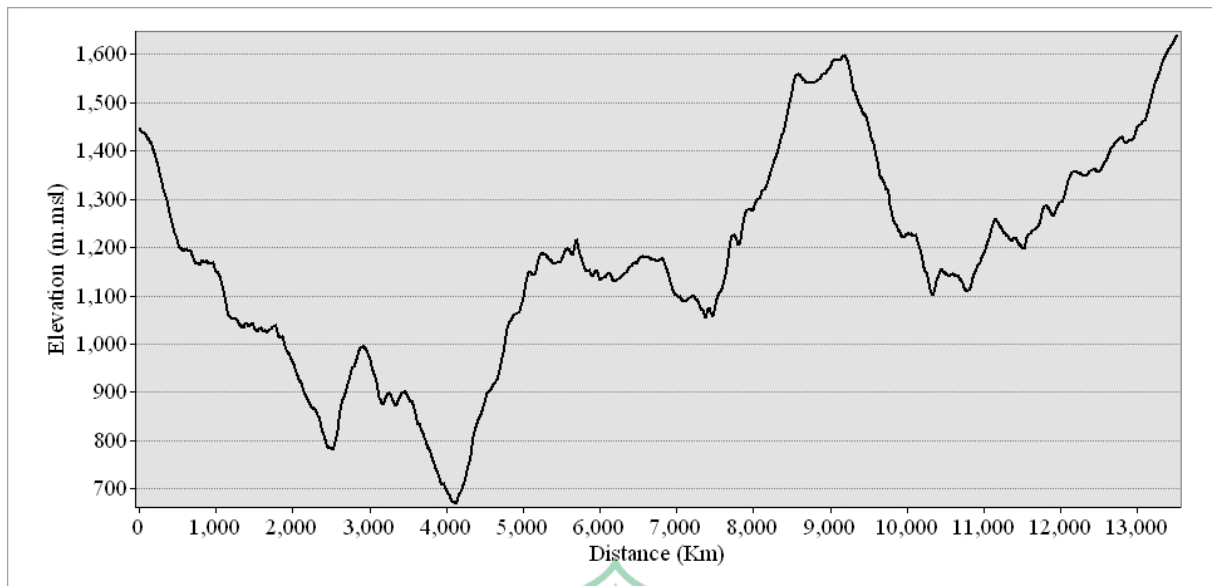


Figure 4. The cross-section of the upstream Kuranji watershed

The form of the Kuranji watershed as seen from the hydrological function explains that, most of the rain that falls into the watershed area quickly enters the river. This is because the Kuranji watershed has a dendritic pattern and has many river branches. Steep slope upstream of the watershed, resulting in rapid run-off, large erosion and impact on decreasing infiltration. [9] if infiltration decreases resulting in the amount of surface run-off and soil erosion. It can be concluded that the Kuranji watershed has a large rainfall, high river gradient and a steep slope upstream. This has an impact on the amount of river discharge and the rapid river flow and run-off.

3.2.1 Linear aspects The linear parameters studied in this study are Stream order (u), Stream length (L_u), Mean stream length (L_m), Stream length ratio (RI), Bifurcation ratio (R_b). More can be seen in Table 2.

Table 2. Linear aspects of Kuranji watershed

No	P	Stream Orders					
		1	2	3	4	5	6
1	u	975	462	253	131	70	3
2	L_u	457.75	140.35	82.67	49.51	40.77	3.55
3	L_m	0.47	0.30	0.33	0.38	0.58	1.18
4	RI	0.00	0.31	0.59	0.61	0.84	0.09
5	R_b	2.11	1.82	1.92	1.85	17.50	0.00

Table 2 explains that, the number of Stream order for the first order is 975 tributaries and the stream length is 457.75 km. the smallest number of orders was found in the sixth order, totalling 3 tributaries and a stream length 3.55 km. Stream length increases in the first order and decreases in the last order. This means that the first order has a large number of rivers but the river length is short. The last order was small but each river had a long flow. The shorter flow of the river indicates that the area is on a steep slope. The longer the river flow indicates the flat area.

Mean stream length is the ratio between the numbers of stream order in one level with the total stream length in that level. This parameter explains that the mean stream length in one order depends on the number of river branches in that order. The more branching rivers indicate that the faster surface flow enters the river and potentially has a large discharge.

Stream length ratio is the ratio between the total stream lengths in one order to a lower order. The higher the stream length ratio, the greater the stream flow which is accommodated by the higher stream order. The more short the stream flow, indicating a steeper slope.

Bifurcation ratio (R_b) is an index of river branching levels. Which explains the ratio between the numbers of rivers for a particular order to a higher order. The higher the value of R_b , the more the number of tributaries in the order. The more number of tributaries, the less chance of water to enter the ground. The average R_b value is 4.2. [10] The Kuranji watershed often floods due to low infiltration. [11] Explains that if a R_b value greater than 5 indicates that structural control influences drainage patterns.

3.2.2 Areal aspects The parameters of the area or area studied in this study area perimeter, watershed area, watershed length, drainage density, stream frequency, length of overland flow, form factor, circularity ratio and elongation ratio in the form of a watershed. More can be seen in Table 3.

Table 3. Areal aspects of Kuranji watershed

No	Parameters	Kuranji watershed
1	Watershed area (Km^2)	224.69
2	Watershed length (km)	24.33
3	Drainage density (D_d)	3.38
4	Stream frequency (F_s)	8.34
5	Length of overland flow (L_g)	1.69
6	Form factor (F_f)	0.38
7	Circularity ratio (R_c)	0.51
8	Elongation ratio (R_e)	0.70

The Kuranji watershed has an area of 224.69 km^2 with a circumference of 74.32 km. This watershed has a length of 24.33 km measured by the main river. River level explains the large number of tributaries in a watershed. The higher the level of the Drainage density (D_d), the more water that can be accommodated in river bodies and the faster it increases river flow.

D_d value indicates the proximity of the river network. Low D_d causes rough drainage texture, high drainage density causes fine drainage texture. The D_d value is $3.45 \text{ (km / km}^2\text{)}$, according to [12] very high river density results in low groundwater potential.

The D_d value explains that the Kuranji watershed has a large amount of erosion and sediment potential. This value explains that the infiltration volume is small and run-off quickly enters the river, thus resulting in an increase in river discharge. [13] Added that the higher the value of D_d , the opportunity for infiltration of land is smaller and increases river discharge. Low DD is usually found in areas that are resistant to erosion, close vegetation cover and have low relief.

Stream frequency (F_s) is a comparison of the number of rivers with a watershed area. The value of F_s has a relationship with the value of D_d . The F_s value in this study was 8.43, the value is high. This F_s value explains that the Kuranji watershed has a high relief and a low infiltration capacity. This has the potential to influence surface run-off and erosion. According to [14] high F_s have an impact on the magnitude of peak currents and [12] high F_s results in high erosion.

Length of overland flow (L_g) explains that the length of the flow is equal to half of the drainage density, the shorter the flow length, the faster the run-off surface enters the river. L_g is the length of the slope which explains the extent of water flowing above the ground before entering the drainage

channel [15]. The general Lg value is 1.72 km/km^2 and in the upstream of the Kuranji watershed is 0.50 km/km^2 . The Lg value describes the surface run-off rather long time entering the drainage channel. This affects the amount of infiltration opportunity and reduced surface run-off. In line with the opinion [16] that the Lg value $> 0.30 \text{ km/km}^2$ represents a long run-off, large infiltration and small surface run-off.

Form factor (Ff), Circularity ratio (Rc) and Elongation ratio (Re) are watershed form factors with values 0.38, 0.51, 0.70. These parameters have a strong relationship with one another that is used to describe the watershed configuration [1]. Based on these values it can be explained that the Kuranji watershed has an elongated shape, indicating that the peak flow is high and the decline is fast. Erosion and discharge are very high in the upper reaches because the Re value is quite high at 0.70. The shape of the Kuranji watershed is getting closer to the circle so the run-off debit is getting bigger. Re value less than 0.80 indicates that the watershed has an elongated shape and has high relief and steep slope. Values close to 1 illustrate very low relief, while values of 0.60 to 0.80 are associated with steep slopes [17].

3.2.3 Relief aspects The relief parameters examined in this study are basin relief (R), relief ratio (Rr), ruggedness number (Rn), gradient ratio (Rg), melton ruggedness number (MRn). More can be seen in Table 4.

Table 4. Relief aspects of Kuranji watershed

No	P	Kuranji watershed
1	R	1,865
2	Rr	0.08
3	Rn	6.43
4	Rg	0.08
5	MRn	3.90

The average height of the Kuranji River Basin is 1,865 meters above sea level. With a very steep slope upstream. Relief ratio is the ratio between height and length of the watershed area. The higher the relief of an area, the greater the ratio value. The longer the watershed area, the smaller the ratio will be. The relief ratio in the Kuranji watershed is 0.08. This means that the river flows in a steep area with a short forecasting time. High relief in the upstream area of the watershed illustrates the high level of slope. This results in rapid surface run-off and the ability to wash away soil particles. Impacts on reduced infiltration. [18] added that the higher relief ratio indicates steep slope and high relief. The higher the watershed relief, the surface flow and erosion is increasing. Ruggedness number (Rn) is a comparison between area relief and drainage density. The Rn number in the Kuranji watershed is 6.43. This value means that this area has high relief in the upstream and has a dense drainage density. Added by [19] that the value of $Rn > 2$ explains that the area has high morphology, vulnerability to soil erosion, high landslides and has a high response to peak discharge. The more branching rivers, the higher the Rn value. This explains that the watershed has the potential to experience drought, because rainwater flows quickly into the river.

The melton roughness (MRn) is 3.90. This figure is a comparison between relief and area. The higher relief of an area, the melton roughness rate will be higher. In the Kuranji value watershed (MRn) is included in the high category means this watershed has a high slope and high erosion and fast run-off. Roughness value (< 0.83) indicates a gentle slope and a low level of erosion.

The gradient ratio (Rg) illustrates the relationship of height to watershed length. The Kuranji watershed Rg value is 0.08, including the high enough category. The higher the relief of a watershed, the greater the gradient produced. The higher the steepness of the river, the faster and swift water flowing in the watershed area. The faster the water flows in the river body, the more energy to erode

the river bed and walls. This results in the amount of sediment that will be transported in the downstream watershed.

4. Interrelation of rainfall to morphometric in producing geological disasters

Annual rainfall in the Kuranji watershed is quite high, reaching 4,500–6,500 mm. High rainfall has the potential to produce geological disasters such as soil erosion, landslides, floods and flash floods. This potential will become greater because the Kuranji watershed > 50% of the area has steep relief.

Morphometric characteristics such as linear aspects explain that the Kuranji watershed has a fairly high level of river branching. This explains that the greater the number of tributaries, the smaller the chance of infiltration, and the surface run-off will quickly enter the river body. The surface run-off has the potential to bring soil particles into the river body. Surface run-off that quickly enters the river body will produce a large river discharge and has the potential to cause flooding. Supported by relatively steep slopes and high rainfall, surface run-off flows more quickly with large volumes so that the potential for more erosion, landslides and flash floods.

Morphometric characteristics such as the area aspect explained that the Kuranji watershed has a high river density in the upstream and low in the downstream. The high density of this river explains that surface run-off will quickly enter the river body and the volume of infiltration is small. So the Kuranji watershed is vulnerable to groundwater shortages. This can be proven by looking at the annual flow coefficient by calculating the ratio of maximum and minimum discharge. More can be seen in the following figure 5.

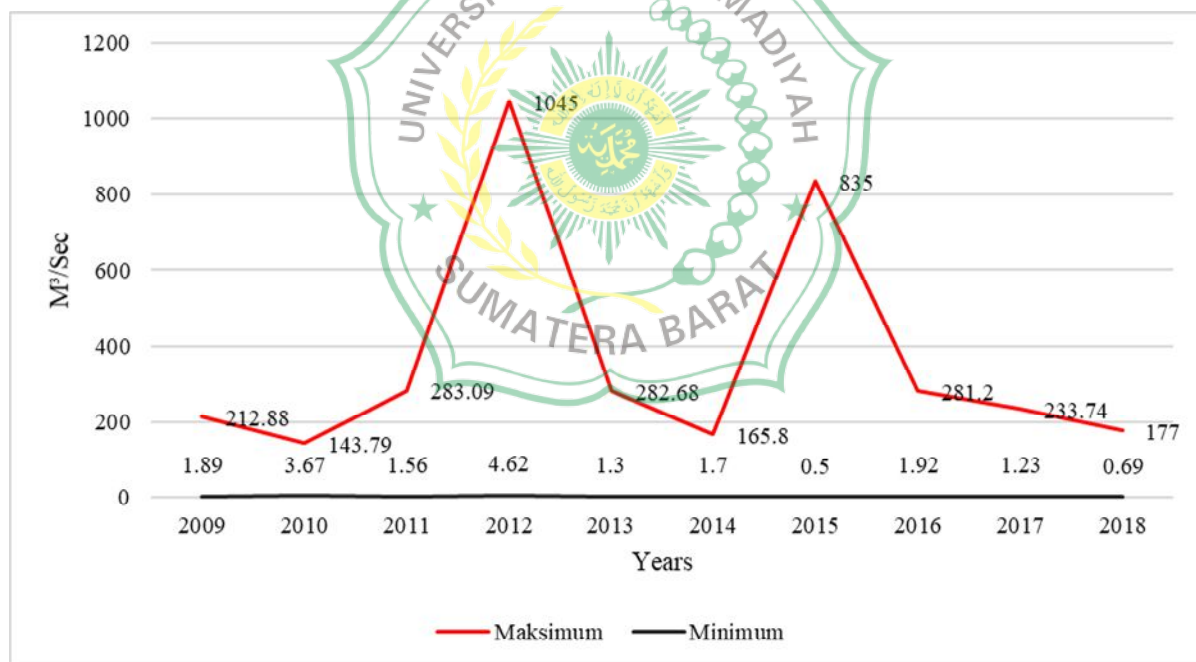


Figure 5. Comparison of maximum discharge with minimum discharge in the Kuranji watershed

The picture above explains that when it rains, the river discharge increases. When there is no rain, the river will discharge. Indirectly, this condition explains that the land in the Kuranji watershed is less able to hold and store rainwater. This results in large surface run-off, resulting in large erosion and the potential for landslides and flash floods. The inability of the land in the Kuranji watershed to store water, has resulted in the dry season of the Kuranji watershed.

The picture above explains that when it rains, the river discharge increases. When there is no rain, the river will discharge. Indirectly, this condition explains that the land in the Kuranji watershed is less able to hold and store rainwater. This results in large surface run-off, resulting in large erosion and the

potential for landslides and flash floods. The inability of the land in the Kuranji watershed to store water, has resulted in the dry season of the Kuranji watershed.

The shape of the Kuranji watershed is rounded at the upstream part and extends downstream. This form can be explained that, in the upstream part of the Kuranji watershed, it has the ability to accommodate extensive rainwater and in the downstream increasingly narrowed. The wider the watershed's capacity to rain water, the greater the potential water available in the Kuranji watershed and the greater the river discharge generated.

Morphometric characteristics such as the relief aspect explained that the Kuranji watershed has a high relief in the upstream part. This means that high relief also produces steep slopes, high river gradients and high flow speeds. The more steep the slope the faster the surface flow and the higher the level of erosion and landslides. Simultaneously the impact of the occurrence of flash floods and the higher scouring in the river body.

The conclusion of the interrelation of rainfall to morphometric in producing geological disasters is that the Kuranji watershed has high rainfall, the shape of the watershed is rounded upstream, the number of tributaries and more than 50% of the land in the Kuranji watershed has steep slopes. This situation makes the Kuranji watershed have a high potential for soil erosion, landslides, floods and flash floods.

5. Conclusion

Based on the linear aspect, it is explained that the Kuranji watershed has the potential to cause flooding. The flooding was influenced by a lot of river orders in the upper watershed and steep slopes. The area aspect explains that the Kuranji watershed has a high river density. This results in small infiltration, large run-off and large erosion. High relief causes rapid surface run-off to enter the river body and quickly reaches the watershed outlet. This causes the Kuranji watershed to potentially flood. The relief aspect explains that the Kuranji watershed has high relief, steep slopes and large river gradients. This causes high erosion, high run-off and large peak discharge, so that the potential for floods and landslides occur. Kuranji watershed with a high river order produces high run-off, erosion and river discharge and is also influenced by steep topography and high gradients. Kuranji watershed has the potential to cause geological disasters such as floods and landslides that cause flash floods.

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