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QUANTITATIVE GEOMORPHOLOGY OF CIPANCAR WATERSHED AND THE IMPLICATION FOR FLOOD RISK

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ABSTRACT: Cipancar watershed is located in Sumedang, West Java, Indonesia. The purpose of this research was to determine the flood risk of the Cipancar watershed in Sumedang area through quantitative geomorphology approach, namely watershed morphometry. Elevation and stream network data used were obtained from a digital elevation model and topographic map using Map Info and Global Mapper software. The morphometric parameters used in this research consist of drainage density, drainage texture, Form factor, ratio of elongation, and ratio of circularity. The research area consists of hills, elongated hills, volcanic cone, and plains. It also consists of radial, subdendritic, and subparallel drainage pattern with the dominance of quaternary volcanic rocks. Cipancar watershed has 15 subwatersheds with predominantly very coarse-intermediate texture and very elongated-elongated basin shape. Only the Cpc_09 and Cpc_10 watersheds have oval-circular basin shape. Rainfall conditions that are not too high do not have a significant effect on the potential for flooding. The research area can be classified into very low to moderate flood risk. The very low-low flood risk is located in the upstream of the Cipancar watershed such as Leles, Cikandung, Leuwigoong, Cicalengka, and South Sumedang districts; and some areas of Kadungora, Cibiuk, Balubur Limbangan, and Selaawi districts. The low-moderate flood risk is located in the middle to downstream of the Cipancar watershed such as some areas of Kadungora, Cibiuk, Balubur Limbangan, and Selaawi districts. The results indicate that the quantitative geomorphology can be used to determine the flood risk in a particular area.

Keywords: Cipancar :atershed, Floods, Morphometry, Sumedang, Quantitative *eomorphology

1. INTRODUCTION

Population growth in a particular area results in unavoidable land use changes. The land use change has dynamic and spatial characteristic. Also, it can increase the runoff rate and flood frequency [1]. Floods occur when water on the surface is stagnant for a long time. This happens when the subsurface conditions are saturated with water due to the infiltration capacity that has reached its limit so that the water on the surface can not infiltrate into the subsurface and become surface runoff. Hence, the potential for flooding is closely related to the infiltration capacity in a particular area.

Several researchers studied the infiltration capacity and flood potential through a quantitative approach. The higher the steepness of the slope, the easier erosion occurs resulting in a greater amount of surface water or runoff [2]. If the surface conditions are saturated with water then more amount of water will stagnate on the gentle slopes resulting in flooding. In addition, watershed characteristics reflected through quantitative geomorphology parameters also play an important role in estimating flood potential [3], [4]. Flood potential that has been identified will certainly facilitate flood management in the future.

Research on quantitative geomorphology in the Cipancar watershed has not been widely carried out. In fact, quantitative research on the characteristics of a watershed is able to show the ability of the watershed to respond the natural phenomenon such as floods. Cimanuk watershed is one of the large watersheds in West Java which has been studied regarding its geological and geomorphological conditions and the implications for natural phenomenon [4], [5]. However, the Cipancar watershed, which is part of the Cimanuk watershed, has not been studied much even though the area has undergone many physical changes.

Cipancar watershed is one of the watersheds located in Sumedang, West Java, Indonesia (Fig.1). It consists of several districts such as Cikandung, Cicalengka, Cibiuk, Leuwigoong, Kadungora, Balubur Limbangan, Leles, Selaawi, and South Sumedang districts (Fig.2). Administratively, the Cipancar watershed consists of several developing areas which will certainly continue to experience physical changes. These physical changes can have both good and bad impacts on the surrounding area. Therefore, it is important to comprehensively study the physical characteristics of the Cipancar watershed.

Watershed or surface water catchment is a natural hydrologic entity that associated with geological features [6]. Just like other watersheds, the Cipancar watershed is associated with related geological conditions such as rock types, slopes, geological structures, and others. The Cipancar watershed has the potential for environmental change due to several factors such as its strategic location, population growth, and changes in land use. If this area is not managed properly then environmental degradation can occur, for example flooding. This research is important to do as an effort to determine flood risk of Cipancar watershed in Sumedang area through quantitative geomorphology approach.

Source: https://en.wikipedia.org/wiki/West_Java

Fig. 1 The research location at Sumedang, West Java Province, Indonesia

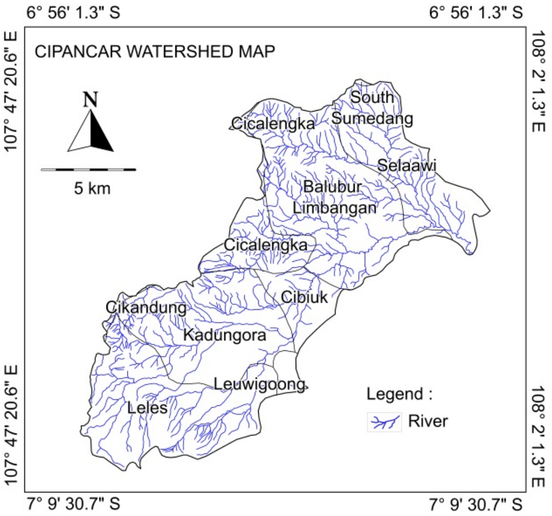

Fig. 2 Cipancar watershed map

2. RESEARCH SIGNIFICANCE

The quantitative geomorphological research should be carried out as an effort to prevent the risk of flooding that may occur in areas such as Kadungora, Cibiuk, Balubur Limbangan, Selaawi, Cicalengka districts, etc in Sumedang area. The morphometric characteristics of the watershed can be determined measurably by this research. This research can also provide significant benefits for other studies in various areas. Moreover, the results of this research can be used to trace flood prone areas so that the regional development can be managed properly and sustainably in the future.

3. METHODOLOGY

This research is carried out through studio analysis using Geographic Information System (GIS) method. Map Info and Global Mapper software are used in this research. The data used in this research are data that can be calculated and measured, namely the stream network and elevation. Stream network and elevation data can be obtained by extracting Digital Elevation Model (DEM) and digitizing topographic maps. According to [3], [7], [8], remote sensing and Geographic Information System (GIS) method can be used to extract stream network and geological surface features.

The Digital Elevation Model (DEM) is the main data source in this research which can be used in many other quantitative researches [3], [4]. It can be used to determine the amount of slope and morphology characteristics in a particular area [4], [9]. Hence, both the slopes and watershed conditions as reflected in the morphometry of the watershed were examined in this research.

This quantitative geomorphological research involves the morphometric aspects of watershed. Watershed morphometry consists of several parameters that can be calculated or measured. The morphomemetric parameters were used in this research namely drainage density (Dd), drainage texture (Dt), Form factor (Rf), ratio of elongation (Re), and ratio of circularity (Rc).

3.1 Drainage Density and Drainage Texture

The total length of all streams in a drainage basin or watershed is known as the drainage density [10]. The high value of drainage density is associated with high sediment yield value [11]. Some conditions such as steep slope, elongated watershed shape, high-moderate relief, and young stage of erosion are associated with lower drainage density while gentle slope, circular watershed shape, low relief, and old stage of erosion are associated with higher drainage density [12]. Drainage density (Dd) value can be calculated using Eq. (1) [10], [13] whereas the classification of drainage density can be seen in Table 1.

$$D_d = \frac{L}{A} \tag{1}$$

Where L is the total length of all streams (km) and A is the area of drainage basin (km^2).

Table 1 Classification of drainage density [14]

D_d	Class
<2	Very coarse
2-4	Coarse
4-6	Moderate
6-8	Fine
>8	Very fine

The total of all stream segments in the perimeter of a drainage basin or watershed is known as drainage texture [13]. Coarse drainage texture is characterized by lower drainage density while fine drainage texture is characterized by higher drainage density [10]. Both drainage density and drainage texture are closely related. Drainage texture (Dt) value can be calculated using Eq. (2) [13] whereas the classification of drainage texture can be seen in Table 2.

$$D_t = \frac{N_u}{P} \tag{2}$$

Where Nu is the total of all stream segments and P is the perimeter of drainage basin (km).

Table 2 Classification of drainage texture [14]

D_t	Class
<4	Coarse
4-10	Intermediate
10-15	Fine
>15	Very Fine

3.2 Form Factor, Ratio of Elongation, and Ratio of Circularity

Several morphometric parameters are used to determine the shape of watershed, namely form factor, ratio of elongation, and ratio of circularity. These three parameters are generally used to determine whether the shape of a watershed is elongated or circular. These parameters also have provisions regarding the shape of the watershed.

The ratio between the area of a watershed to the square of the length of the watershed is known as form factor [13]. Form factor (Rf) is related to the ratio of elongation (Re) and ratio of circularity (Rc) which will be discussed next. Small Form factor (Rf) values tend to indicated the elongated shape of a drainage basin or watershed. The Form factor (Rf) value can be calculalated using Eq. (3) [13].

$$R_f = \frac{A}{(L_b)^2} \tag{3}$$

Where A is the area of drainage basin (km^2) and Lb is the length of drainage basin (km)

The ratio between the area of a drainage basin or watershed to the length of a drainage basin or watershed is known as ratio of elongation [15]. High ratio of elongation (Re) values indicate that the shape of drainage basin tends to be circular so that the infiltration rate is high and the runoff rate is low while low ratio of elongation (Re) values indicate that the shape of drainage basin tends to be elongate so that the infiltration rate is low and the runoff rate is high [11]. The elongated watershed shows a young stage of erosion while the circular watershed shows a old stage of erosion [12]. Ratio of elongation (Re) value can be calculated using Eq. (4) [15] whereas the shape of drainage basin based on ratio of elongation (Re) can be seen in Table 3.

$$R_e = 2\frac{\sqrt{A/\pi}}{L_b} \tag{4}$$

Where A is area of drainage basin (km^2) and Lb is length of river basin (km)

Table 3 Classification of ratio of elongation [10]

Re	Class
<0.5	Very elongated
0.5-0.7	Elongated
0.7-0.8	Less elongated
0.8-0.9	Oval
0.9-1.0	Circular

The ratio between the area of a drainage basin or watershed to the perimeter of a drainage basin or watershed is known as ratio of circularity [10]. It indicates whether a drainage basin is has an elongated shape marked by a ratio of circularity (Rc) value of less than 0.5 or a circular shape marked by a ratio of circularity (Rc) value of more than 0.5 [21]. The lower the ratio of circularity (Rc) value, the lower the risk of flash flooding while the higher the ratio of circularity (Rc) value, the higher the risk of flash flooding [17]. In addition, the stage of a drainage basin or watershed can be indicated by its ratio of circularity (Rc) value. A youth stage of drainage basin is reflected by low ratio of circularity (Rc) value while a mature stage of drainage basin reflected by high ratio of circularity (Rc) value [18]. Ratio of circularity (Rc) value can be calculated using Eq. (5) [10].

$$R_c = \frac{4\pi A}{P^2} \tag{5}$$

Where A is the area of drainage basin (km^2) and P is the perimeter of drainage basin (km).

3.3 Rainfall

One of the main factors of flooding is the high intensity of rainfall. During the rainy season, the intensity of rainfall is high. Flooding can occur due to high rainfall around 3000 mm/year [19]. High rainfall intensity causes water to infiltrate into the ground and flow on the surface. Water that flows on the surface is known as surface runoff.

Indonesia is a tropical country which has 2 seasons, the dry and rainy season. The rainy season is related to the tropical climate in Indonesia. However, global warming conditions have resulted in climate change and erratic seasonal periods [5]. Hence, the data on mean annual rainfall from 1961 to 1990 is needed to determine long-term rainfall conditions in the research area.

4. RESULTS AND DISCUSSIONS

4.1 Morphology and Drainage Pattern of The Research Area

The research area has several landforms, namely hills in the south and west to north; elongated hills in the north; volcanic cone of Mount Kaledong and Mount Malang in the southwest and central of the research area; and plains in the central of the research area. It can be seen in Fig.3 that the research area has plains to very steep slope area.

Based on the Slope Map of the Cipancar watershed (Fig.3), most of the research areas did not show a high risk of flooding. However, it should be noted that there are plain areas too in the central of the research area. Hence, it is necessary to calculate morphometric parameters.

The research area has three drainage patterns, namely radial, subdendritic, and subparallel (Fig.4). Radial pattern indicate that the research area has volcanic cones which indicate steep slopes and tend to have low flood potential. Subdendritic pattern indicate that the research area is influenced by structure but does not show the potential for flooding. Subparallel pattern indicate that the research area has elongated intermediate-steep slopes.

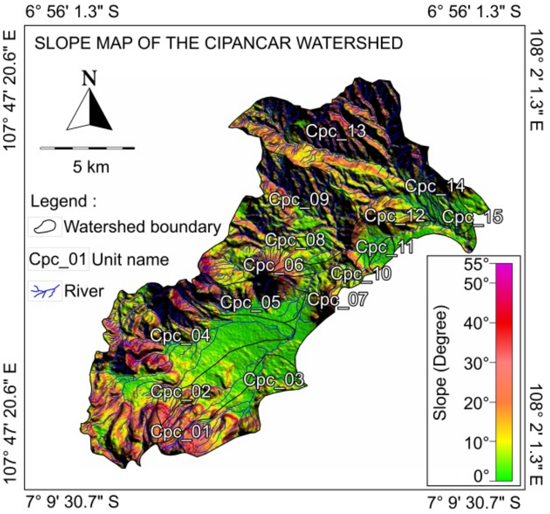

Fig. 3 Slope Map of the Cipancar watershed

4.2 Geology of The Research Area

The research area consists of the dominance of volcanic rocks, namely breccias, tuffs, lava, etc. In general, these rocks are young quaternary volcanic products. These volcanic products come from volcanic activities around them such as Mount Guntur, Pangkalan, Kendang, Mandalawangi, and Mandalagiri. In addition, based on regional geology characteristics it is known that the research area does not show a dominant geological structure. However, there are indications of estimated fault structures in the southwest of the research area. It can be indicated by the subdendritic drainage pattern previously discussed.

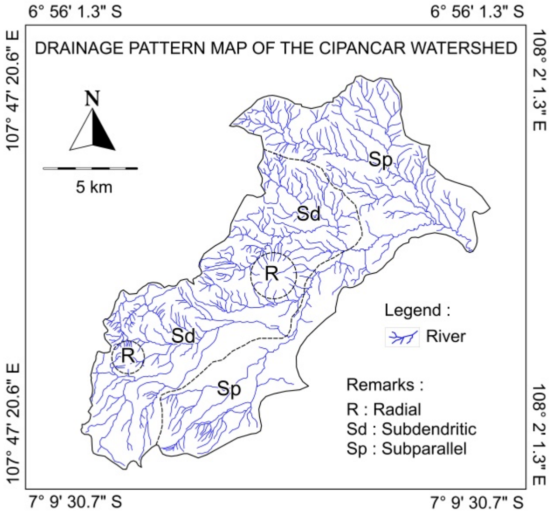

Fig. 4 Drainage Pattern of the Cipancar watershed

Based on regional geology map, it is known that the research area is composed of young volcanic rocks (Fig.5). Young volcanic rocks tend not to be well consolidated. Unconsolidated rock has a faster infiltration capacity than consolidated rock. Therefore, most of the research area has a greater water infiltration capacity and cause relatively small surface runoff to occur. However, it needs to be examined from the aspect of watershed morphometry.

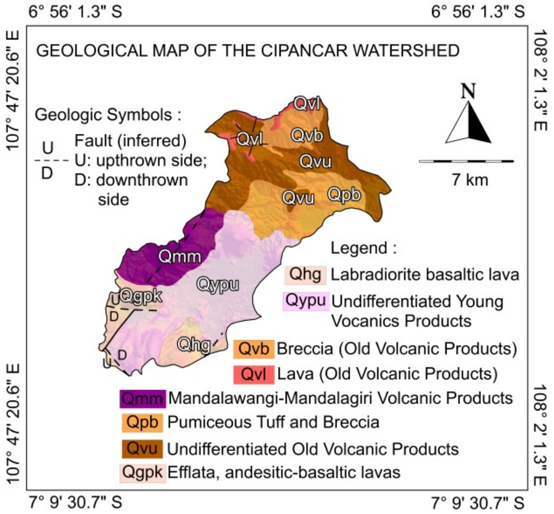

Fig. 5 Geological Map of the Cipancar watershed (modified from [20]–[22])

4.3 Drainage Density and Drainage Texture

Based on the morphometric calculations, the research area has drainage density (Dd) value ranging from 1.74-3.10 (Table 4). Those values indicate that most of the Cipancar watershed has very coarse to coarse drainage density. This also proves that the research area has relatively homogenous characteristics and is not too much different from one sub-watershed to another. Moreover, it also reflects that the research area is composed of relatively permeable rocks, fairly dense vegetation, and low-high relief.

There was no significant difference between the drainage density (Dd) and drainage texture (Dt) parameters. Based on the morphometric calculations, the sub-wateshеds in the research area have drainage texture (Dt) values ranging from 0.41-4.38 (Table 4). Those values indicate that the sub-wateshеds in the research area have coarse to intermediate drainage density. It also proves that the drainage texture (Dt) parameter shows the same characteristics as the drainage density (Dd) parameter. It indicates that most of the research area has a moderate potential for surface runoff and erosion.

4.4 Form Factor, Ratio of Elongation, and Ratio of Circularity

Based on the morphometric calculations, the research area has Form factor (Rf) value ranging from 0.13-0.68 (Table 4). In general, the Form factor (Rf) values reflect the elongated to circular shape of subwatersheds in the research area. The circular basin shapes are indicated in the Cpc_09 and Cpc_10 subwatershed while elongated shapes are indicated in other subwatersheds.

The ratio of elongation (Re) values of the 15 subwatersheds in the research arae ranged from 0.41-0.93 (Table 4). These values indicate that the 15 subwatersheds have elongated to circular basin shape. The oval-circular basin shapes are shown in the Cpc_09 and Cpc_10 subwatershed while very elongated to elongated shapes are identified in other subwatersheds.

The ratio of circularity (Rc) values of the 15 subwatersheds in the research area ranged from 0.35-0.72 (Table 4). These values also indicates that the subwatersheds have elongated to circular basin shape. The circular basin shapes are shown in the Cpc_09 and Cpc_10 subwatershed while elongated shapes are indicated in other subwatersheds.

Based on the calculations of these three parameters (Rf, Re, and Rc), it can be seen that the research area is dominated by very elongated to elongated subwatersheds. No significant difference was found between the three parameters (Rf, Re, and Rc). The oval-circular subwatersheds indicate that the denudation process works intensively, the infiltration capacity is large, and the surface runoff is low such as Cpc_09 and Cpc_10 subwatershed while the other very elongated-elongated 13 subwatersheds indicate high susceptibility to erosion and sediment load.

4.5 Rainfall

Rainfall conditions in the research area are related to the amount of water received by an area whether it will be absorbed into the ground as groundwater or will flow over the surface as runoff. Based on the map (Fig.6), the research area has rainfall ranging from 2000-2500 mm/year. It shows that the entire research area has a rainfall that is not too high. It also shows that the Cipancar watershed, which consists of Cicalengka, Selaawi, South Sumedang, Balubur Limbangan, Cibiuk, Kadungora, Cikandung, Leuwigoong, and Leles subdistricts, does not have a large flood potential.

Based on the results, the 15 subwatersheds in the Cipancar watershed have very low, low, and moderate flood risk (Table 4). The very low and low flood risk have been identified in almost all subwatersheds with very steep to slightly steep slopes, subparallel and radial drainage patterns, and has very elongated to elongated watershed shape. These areas are located on the south and west of the research area, especially in the upstream of the Cipancar watershed such as Leles, Cikandung, Leuwigoong, Cicalengka, and South Sumedang districts; and some areas of Kadungora, Cibiuk, Balubur Limbangan, and Selaawi districts. On the other hand, the moderate flood risk have been identified in a small part of the subwatersheds with slightly steep to gentle slopes, subparallel and subdendritic drainage patterns, and has oval to circular watershed shape. These areas are located in the middle and the eastern edge of the research area, especially in the middle to downstream of the Cipancar watershed such as some areas of Kadungora, Cibiuk, Balubur Limbangan, and Selaawi districts.

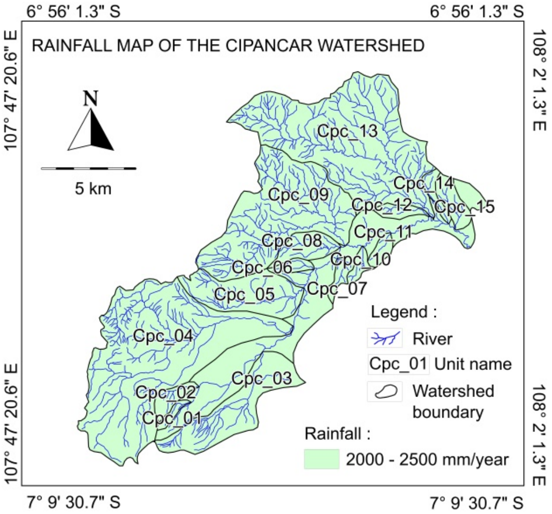

Fig. 6 Rainfall map of the Cipancar watershed

Table 4 Morphology and Morphometric Aspects of the Cipancar watershed

Sub watershed	Drainage Pattern	Slope	Dd	Dt	Basin Texture	Rf	Re	Rc	Basin Shape	Flood Risk
Cpc_01	Subparallel	Very steep	3.00	0.57	Coarse	0.14	0.42	0.39	Very Elongated	Very low
Cpc_02	Subparallel	Very steep-gentle	2.41	1.13	Coarse	0.26	0.57	0.53	Elongated	Very low
Cpc_03	Subparallel	Very steep-gentle	2.31	1.38	Coarse	0.19	0.50	0.37	Elongated	Low
Cpc_04	Subdendritic and radial	Very steep-gentle	2.38	3.49	Coarse	0.34	0.66	0.44	Elongated	Low
Cpc_05	Subdendritic	Very steep-gentle	2.53	1.73	Coarse	0.28	0.60	0.52	Elongated	Low
Cpc_06	Subdendritic	Very steep-gentle	2.81	0.53	Coarse	0.18	0.48	0.49	Very elongated	Very low
Cpc_07	Subparallel	Very steep-slightly steep	2.80	0.89	Coarse	0.22	0.54	0.43	Elongated	Very low
Cpc_08	Subdendritic	Very steep-slightly steep	2.53	0.83	Coarse	0.22	0.53	0.55	Elongated	Very low
Cpc_09	Subdendritic	Very steep-slightly steep	3.10	4.20	Coarse - Intermediate	0.68	0.93	0.52	Circular	Low-moderate
Cpc_10	Subparallel	Slightly steep-gentle	2.67	1.23	Coarse	0.58	0.86	0.49	Oval - Circular	Low-moderate
Cpc_11	Subparallel	Slightly steep-gentle	1.74	0.60	Very coarse - Coarse	0.31	0.63	0.72	Elongated	Low
Cpc_12	Subparallel	Slightly steep-gentle	2.79	0.76	Coarse	0.17	0.46	0.46	Very elongated	Very low
Cpc_13	Subparallel	Very steep-gentle	2.92	4.38	Coarse - Intermediate	0.29	0.61	0.46	Elongated	Very low
Cpc_14	Subparallel	Slightly steep-gentle	2.90	0.41	Coarse	0.13	0.41	0.35	Very elongated	Very low
Cpc_15	Subparallel	Slightly steep-gentle	1.93	0.76	Very coarse - Coarse	0.25	0.57	0.61	Elongated	Very low

The three flood risks are also influenced by rainfall in the research area. As previously stated, the research area had rainfall that was not too high, namely 2000-2500 mm/year. This resulted in the volume of water received by the watershed is not too high either. Local communities and local government need to maintain good watershed conservation through integration of watershed management, land use conservation, and environmental damage prevention.

5. CONCLUSION

Based on morphometric calculations, the research area has drainage density (Dd) value ranging from 1.74-3.10 and drainage texture (Dt) value ranging from 0.41-4.38. It indicates that most of the research area is composed of relatively permeable rocks, fairly dense vegetation, and low-high relief. It has a moderate potential for surface runoff and erosion. Form factor (Rf) values of subwatersheds are 0.13-0.68. Ratio of elongation (Re) ranged from 0.41-0.93. Ratio of circularity (Rc) ranged from 0.35-0.72. Form factor (Rf), ratio of elongation (Re), and ratio of circularity (Rc) value indicate that research area is dominated by very elongated to elongated subwatersheds and can be classified into very low to moderate flood risk. The very low-low flood risk have been identified in almost all subwatersheds, especially in the upstream of the Cipancar watershed such as Leles, Cikandung, Leuwigoong, Cicalengka, and South Sumedang districts; and some areas of Kadungora, Cibiuk, Balubur Limbangan, and Selaawi districts. The low-moderate flood risk have been identified in a small part of the subwatersheds, especially in the middle to downstream of the Cipancar watershed such as some areas of Kadungora, Cibiuk, Balubur Limbangan, and Selaawi districts. Rainfall conditions do not have a significant effect on the potential for flooding. This results show that the quantitative geomorphology can be used to determine the flood risk in a particular area. Local communities and government need to maintain good watershed conservation through integration of watershed management, land use conservation, and environmental damage prevention.

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