The Quantitative Geomorphology of Upper Citarik Watershed and Its Implication to the Flash Flood Potential

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Abstract. The research area is the Upper Citarik Watershed, located in the eastern Bandung Basin, West Java, Indonesia. This research aims to identify the quantitative geomorphology, especially the morphometry of the Upper Citarik Watershed, and its implication for the potential of flash floods. This research was conducted through a studio analysis with the support of thematic maps such as geological and slope maps. The parameters used in this morphometry calculation consist of linear aspects (stream order, stream length, mean stream length, stream length ratio, bifurcation ratio, and mean bifurcation ratio); areal aspect (drainage density, drainage texture, form factor, ratio of circularity, ratio of elongation, and length of overland flow); and relief aspects (watershed relief and relief ratio). The research results show that the Upper Citarik Watershed consists of 17 sub-watersheds that share relatively similar characteristics, including elongated shape with high relief and rather steep - steep slopes. It is predominantly composed of volcanic rocks and slow rising of flash flood. It shows that from a quantitative geomorphology perspective, the research area has high resistance to flash floods. Land use changes need to be a concern to prevent a significant decrease in the ability of land to deal with the flash floods.

1 Introduction

Watershed is a certain area consisting of numerous rivers or streams, forming a stream network, and bounded by ridges or hills. It is also referred to as a natural hydrological entity originating from surface runoff to a river or a specific point [1]. Based on the coverage area, the watershed can be divided into several sub-watersheds. Both the watershed and sub-watersheds are naturally bounded by surrounding ridges or hills around. Research conducted through descriptive and quantitative approaches can be used to identify and analyze the characteristics of a watershed. One of the quantitative research that can be

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used to determine the characteristics of the watershed is morphometry. The results of this quantitative research can reveal various characteristics of the watershed [2–5]. Morphometric research can demonstrate the relationship between geomorphological and hydrological characteristics in a watershed, including those related to topography, slopes, and runoff [6].

The upper Citarik watershed is one of the upstream parts of the Citarum watershed in West Java, Indonesia. The existence of the Upper Citarik Watershed is very important for the entire Citarum Watershed and the surrounding area [3]. It presents interesting conditions to study from various aspects. This research aims to identify the morphometric characteristics of the Upper Citarik Watershed and their implications for flood potential.

2 Methodology

The research area is the Upper Citarik Watershed which is administratively included in the districts of Bandung, Sumedang, and Garut. It is precisely located at the coordinates 107°49'18.1" E - 107°57'27.4" E and 6°55' 15.7" S - 6°59'34.7" S (Fig. 1). This research activity was carried out through a studio analysis approach, focusing on the morphometric aspects of the watershed. The supporting data used includes thematic maps such as slope maps, geological maps, etc.

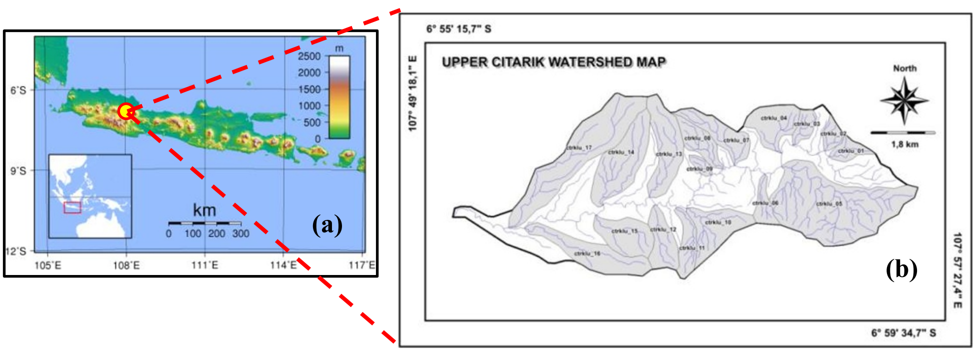

Fig. 1. (a) Java Island; (b) Research area in the Upper Citarik Watershed.

Several aspects of the watershed morphometry are used to determine the characteristics of the Upper Citarik Watershed. It consists of linear aspects (stream order, stream length of order "u", mean stream length, ratio of stream length, ratio of bifurcation, mean ratio of bifurcation); areal aspect (drainage density, drainage texture, form factor, ratio of circularity, ratio of elongation, and length of overland flow); and relief aspects (watershed relief and relief ratio) [7-10], as shown in Table 1.

Table 1. Morphometric parameters and formulas used in the research.

Morphometric parameters		Formula	Units
Linear Aspect	Stream length of order (L_u)	Lenght of the stream	km
	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$	km
	Ratio of stream length (R_L)	$R_L = L_u/L_{u-1}$	no unit (dimensionless)
	Ratio of bifurcation (R_b)	$R_b = N_u/N_{u+1}$	no unit (dimensionless)
	Mean ratio of bifurcation (R_{bm})	R_{bm} = mean ratio of all stream order	no unit (dimensionless)
Areal	Drainage density (D_d)	$D_d = L/A$	km^{-1}

Aspect	Drainage texture (D_t)	$D_t = N_u/P$	km^{-1}
	Form factor (R_f)	$R_f = A/(L_b)^2$	no unit (dimensionless)
	Ratio of circularity (R_c)	$R_c = (4\pi A)/P^2$	no unit (dimensionless)
	Ratio of elongation (R_e)	$R_e = 2 \sqrt{(A/\pi)}/ L_b$	no unit (dimensionless)
	Length of overland flow (L_g)	$L_g = 1/(2D_d)$	km
Relief Aspect	Watershed relief (R)	$R = H - h$	km
	Relief ratio (R_h)	$R_h = R/L_b$	no unit (dimensionless)

Notes:
L_u = total length of the stream of order "u" (km)
L_{u-1} = total length of the stream of next lower order (km)
N_u = number of stream segment of the order "u" (*no unit)*
N_{u+1} = number of segments in the next higher order (*no unit*)
L = total length of the stream (km)
A = watershed area (km^2)
L_b = length of the basin/watershed (km)
P = watershed perimeter (km)
D_d = drainage density (km^{-1})
H = highest point of watershed (km)
h = lowest point of watershed (km)
R = watershed relief (km)

2.1 Linear morphometry

The first stream order in a watershed has the highest total stream length (Lu). The higher the stream order, the smaller the total stream length [1]. This characteristic is commonly found in watersheds, but exceptions may exist where a watershed can have high relief with varying lithology or relatively steep slopes [1,11]. Meanwhile, a set of stream networks related to the mean stream length (Lsm) in a watershed can demonstrate its characteristics. Unlike the stream length (Lu), the mean value of stream length (Lsm) increases from the lower to higher orders. It is influenced by several factors in the watershed, such as watershed size, slope, topography, and lithology [2,12].

The ratio of stream length (RL) value has no units and does not have a specific classification [13]. An increase in the ratio of stream length (RL) value from lower to higher orders is related to slope or the topography and is influenced by geomorphic stages [1,11,12].

The ratio of bifurcation (Rb) has no unit, and its value can also differ from one order to another due to lithological variations [2]. The value of the ratio of bifurcation can be divided into low class (Rb<5) and high class (Rb>5) [6,12,14]. The high class indicates that the drainage pattern is influenced by strong structural control, while the low class is not influenced by structural control [1,2,7]. A large value also indicates a high potential for flash floods during heavy rains, according to [15].

2.2 Areal morphometry

The drainage density (Dd) value is related to relief, valley density, conditions of rocks and soil, as well as climate and vegetation [2]. The drainage density values can be divided into 5 classes according to [16], namely very coarse, coarse, moderate, fine, and very fine. According to [1,12], watersheds that have permeable and resistant subsurface conditions, low relief, and dense vegetation have low drainage density values (very coarse) while watersheds that have impermeable subsurface conditions, hilly high relief, and sparsely vegetated areas have high drainage density value (very fine). The distance between stream channels in a watershed is called drainage texture (Dt) [8]. It is related to lithology, slope relief, infiltration capacity [9], and is also related to climate, precipitation, relief, vegetation, also soil and rock characteristics [16]. The drainage texture (Dt) value is also related to the drainage density (Dd) value where the coarse drainage texture is indicated by a low Dd value while the fine drainage texture is indicated by a high Dd value, surface runoff, and high erosion potential [7,13].

Stream intensity in a watershed can be estimated through the form factor (Rf) [8]. The form factor (Rf) has a value range of 0-1. A large value indicates round (circular) watersheds, while small value indicates elongated (oval) watersheds [14]. Elongated watersheds show lower vulnerability to erosion, flooding, sediment transport, and vice versa [17]. The elongated watershed with a moderate drainage density (Dd) is estimated to have a low surface runoff discharge [7,10,11].

The ratio of elongation (Re) has no units and can be classified into very elongated, elongated, less elongated, oval, circular [7]. Circular watersheds are characterized by higher surface runoff conditions, maximum flood rates, and more intensive erosion risks than elongated or oval watersheds [7,11,17]. The ratio of elongation indicates geological condition of a particular area [2].

The ratio of circularity (Rc) has no units and is related to geological structure, climate, relief, slope, and land cover. A low ratio of circularity is related to the young stage of the stream network and an elongated watershed, while a high ratio of circularity is related to the old stage of the stream network and circular watershed [6]. A value of $Rc<0.5$ indicates an elongated watershed, while a value of $Rc>0.5$ indicates a circular watershed [1,2,12]. A low Rc value indicates the undeveloped geological structure, while a high Rc value indicates the influence of geological structure [13].

Several factors such as the lithology, relief, permeability, climate, and vegetation, influence the length of overland flow (Lg) value [9]. A low length of overland flow (Lg) value indicates a shorter waterway, faster water travel time on relatively steep slopes, and proneness to erosion and flooding [2], and vice versa.

2.3 Relief morphometry

Relief morphometry consists of watershed relief and slope ratio. The difference in height between the highest point and the lowest point in the watershed is referred to as the watershed relief (R), while the comparison between the difference in the maximum height of the watershed relief and the length of the watershed is referred to as the relief ratio (Rh) [9]. Some researchers do not provide a special classification for the relief ratio. According to [1,2,13], a large relief ratio (Rh) value indicates low relief and gentle slopes, while a small relief ratio (Rh) value indicates high relief and steep slopes.

3 Result and discussion

3.1 Linear morphometry

Stream length (Lu) in the 17 Upper Citarik Sub-watersheds ranged from 0.17 - 17.09 km (Table 2). Most of the sub-watersheds show ideal conditions, where the higher the stream order, the smaller the total length of the stream. However, in some parts of the Ctrklu_05, Ctrklu_06, and Ctrklu_10 sub-watersheds, some of the stream length values have increased. This shows the influence of slope, relief, and variations in lithology that control the value of the the stream length (Lu). On the other hand, mean stream length (Lsm) in the 17 Upper Citarik Sub-watersheds ranged from 0.15 - 2.24 km (Table 2). Under ideal conditions in a watershed, the higher the stream order, the larger mean stream length (Lsm). However, in some parts of the sub-watershed, such as Ctrklu_05, Ctrklu_09, and Ctrklu_10, the mean stream length (Lsm) is not actually large. This indicates the influence of the size, slope, topography, and lithology of the sub-watershed.

The ratio of stream length (RL) in the Upper Citarik watershed ranges from 0.12 - 1.30 (Table 3). Most of the identified stream length ratio (RL) values are only RL2_1 values, which means that only a few sub-watersheds can be analyzed. For instance, the Ctrklu_05 and Ctrklu_17 sub-watersheds show a trend of decreasing values, indicating that they are at a young geomorphic stage.

Table 2. Stream length (L_u) and mean stream length (L_{sm}) of Upper Citarik Watershed.

No	Sub Watershed	Stream length (L_u) (km)				Mean stream length (L_{sm}) (km)			
		order_1	order_2	order_3	order_4	L_{sm1}	L_{sm2}	L_{sm3}	L_{sm4}
1	Ctrklu_01	1.68	0.57	-	-	0.56	0.29	-	-
2	Ctrklu_02	1.49	0.52	0.17	-	0.37	0.26	0.17	-
3	Ctrklu_03	1.77	0.70	-	-	0.44	0.23	-	-
4	Ctrklu_04	2.23	0.95	-	-	0.56	0.32	-	-
5	Ctrklu_05	17.09	6.15	1.77	2.31	0.52	0.31	0.44	0.46
6	Ctrklu_06	1.15	1.23	-	-	0.38	0.62	-	-
7	Ctrklu_07	3.18	1.82	-	-	0.64	0.45	-	-
8	Ctrklu_08	3.22	1.25	-	-	0.64	0.31	-	-
9	Ctrklu_09	1.18	0.26	-	-	0.59	0.26	-	-
10	Ctrklu_10	4.80	0.59	0.63	-	0.80	0.15	0.63	-
11	Ctrklu_11	2.13	1.62	-	-	0.53	0.54	-	-
12	Ctrklu_12	2.34	1.29	-	-	0.78	0.64	-	-
13	Ctrklu_13	3.95	2.19	-	-	0.99	0.73	-	-
14	Ctrklu_14	6.97	1.30	-	-	1.16	0.26	-	-
15	Ctrklu_15	2.21	1.55	-	-	0.74	0.78	-	-
16	Ctrklu_16	2.61	2.24	-	-	1.30	2.24	-	-
17	Ctrklu_17	5.30	4.06	1.37	-	1.06	1.35	1.37	-

Table 3. Stream length (L_u) and mean stream length (L_{sm}) of Upper Citarik Watershed.

No	Sub Watershed	R_L		
		R_{L2_1}	R_{L3_2}	R_{L4_3}
1	Ctrklu_01	0.34	-	-
2	Ctrklu_02	0.35	0.33	-
3	Ctrklu_03	0.40	-	-
4	Ctrklu_04	0.43	-	-
5	Ctrklu_05	0.36	0.29	1.30
6	Ctrklu_06	1.07	-	-
7	Ctrklu_07	0.57	-	-
8	Ctrklu_08	0.39	-	-
9	Ctrklu_09	0.22	-	-
10	Ctrklu_10	0.12	1.07	-

11	Ctrklu_11	0.76	-	-
12	Ctrklu_12	0.55	-	-
13	Ctrklu_13	0.55	-	-
14	Ctrklu_14	0.19	-	-
15	Ctrklu_15	0.70	-	-
16	Ctrklu_16	0.86	-	-
17	Ctrklu_17	0.77	0.34	-

The ratio of bifurcation (Rb) in the 17 Upper Citarik Sub-watersheds ranges from 0.80 to 5.00 and the mean ratio of bifurcation (Rbm) falls between 1.20 - 2.75 (Table 4). It shows a slow rise in the water level, indicating a relatively low potential for flash floods. Moreover, it indicates the absence of significant structural control and the low potential for flash floods.

Table 4. Ratio of bifurcation (R_b) and mean ratio of bifurcation (R_{bm}) of Upper Citarik Watershed.

No	Sub Watershed	R_b			R_{bm}
		R_{b1_2}	R_{b2_3}	R_{b3_4}	
1	Ctrklu_01	1.50	-	-	1.50
2	Ctrklu_02	2.00	2.00	-	2.00
3	Ctrklu_03	1.33	-	-	1.33
4	Ctrklu_04	1.33	-	-	1.33
5	Ctrklu_05	1.65	5.00	0.80	2.48
6	Ctrklu_06	1.50	-	-	1.50
7	Ctrklu_07	1.25	-	-	1.25
8	Ctrklu_08	1.25	-	-	1.25
9	Ctrklu_09	2.00	-	-	2.00
10	Ctrklu_10	1.50	4.00	-	2.75
11	Ctrklu_11	1.33	-	-	1.33
12	Ctrklu_12	1.50	-	-	1.50
13	Ctrklu_13	1.33	-	-	1.33
14	Ctrklu_14	1.20	-	-	1.20
15	Ctrklu_15	1.50	-	-	1.50
16	Ctrklu_16	2.00	-	-	2.00
17	Ctrklu_17	1.67	3.00	-	2.33

3.2 Areal morphometry

Based on the calculation results, 17 Upper Citarik Sub-watersheds have drainage density (Dd) values ranging between 2.35 and 6.20 (Table 5). It indicates the Upper Citarik Sub-watershed has a coarse to fine drainage density. Most of the upstream sub-watersheds have higher drainage density (Dd) values than downstream Sub-watersheds, indicating that the upstream areas are hilly areas with high relief, and dense vegetation. On the other hand, the drainage texture (Dt) value ranges from 0.36 to 5.55 (Table 5). It indicates the Upper Citarik Sub-watershed has very coarse to moderate drainage texture.

The form factor (Rf) value of the 17 Upper Citarik Sub-watersheds ranged from 0.13-0.73 (Table 5), indicating a elongated to circular watershed in the research area. Ctrklu_01, Ctrklu_02, and Cpl_10 have form factor (Rf) value of 0.52, 0.52, and 0.73, respectively, indicating a relatively circular shape of the watershed. In contrast, Ctrklu_11, Ctrklu_16, and Cpl_17 have form factor (Rf) value of 0.16, 0.13, and 0.13 respectively, showings a relatively elongated watershed. The ratio of elongation (Re) values ranged from 0.41 to 0.96 (Table 5). It indicates that the 17 Upper Citarik Sub-watersheds have a very elongated to circular watershed. In general, all of the sub-watersheds are dominated by elongated to very elongated shapes. Only the Ctrklu_10 sub-watershed shows a circular shape. This can be observed from the map showing the relatively wide upstream part of the Ctrklu_10 Sub-watershed. The predominance of elongated to very circular shapes indicates a lower maximum flood rate and less intensive erosion risk. The ratio of circularity (Rc) values ranged from 0.35 to 0.74 (Table 5). It indicates a similarity with the ratio of elongation value that show a predominance of elongated watershed. In addition, the elongated watershed also indicates the young phase of the stream network.

The length of overland flow (Lg) value of the 17 Upper Citarik Sub-watersheds ranged from 0.08-0.21 (Table 5). It indicates that in general the 17 Upper Citarik Sub-watersheds share relatively same characteristics. The low value indicates that the stream is short, and the water travel time is fast.

Table 5. Drainage density (D_d), drainage texture (D_t), form factor (R_f), ratio of elongation (R_e), ratio of circularity (R_c), and length of overland flow (L_g).

No	Sub Watershed	D_d (km^{-1})	D_t (km^{-1})	R_f	R_e	R_c	L_g (km)
1	Ctrklu_01	4.58	1.42	0.52	0.81	0.50	0.11
2	Ctrklu_02	5.61	2.62	0.52	0.81	0.68	0.09
3	Ctrklu_03	5.47	2.40	0.36	0.68	0.67	0.09
4	Ctrklu_04	2.35	1.36	0.57	0.85	0.64	0.21
5	Ctrklu_05	4.51	5.55	0.32	0.64	0.61	0.11
6	Ctrklu_06	4.44	1.29	0.24	0.56	0.45	0.11
7	Ctrklu_07	4.07	1.46	0.16	0.45	0.40	0.12
8	Ctrklu_08	4.93	1.83	0.18	0.48	0.47	0.10
9	Ctrklu_09	6.20	1.49	0.30	0.62	0.72	0.08
10	Ctrklu_10	3.73	1.72	0.73	0.96	0.50	0.13
11	Ctrklu_11	4.60	1.45	0.16	0.45	0.44	0.11
12	Ctrklu_12	3.29	1.03	0.32	0.64	0.58	0.15
13	Ctrklu_13	3.20	0.98	0.18	0.48	0.48	0.16
14	Ctrklu_14	3.54	1.52	0.22	0.53	0.56	0.14
15	Ctrklu_15	2.52	1.00	0.34	0.66	0.74	0.20
16	Ctrklu_16	2.42	0.36	0.13	0.41	0.35	0.21
17	Ctrklu_17	2.61	0.75	0.13	0.41	0.36	0.19

3.3 Relief morphometry

The watershed relief (R) values ranged from 0.13 - 1.35 while the relief ratio (Rh) values ranged from 0.12 - 0.91 (Table 6). The 17 Upper Citarik Sub-watersheds have relatively the same slope characteristics. In general, the research area is located in an area with high relief and steep slopes.

Table 6. Watershed relief (R) and relief ratio (R_h).

No	Sub Watershed	R	R_h
1	Ctrklu_01	0.25	0.26
2	Ctrklu_02	0.25	0.29
3	Ctrklu_03	0.20	0.18
4	Ctrklu_04	0.23	0.15
5	Ctrklu_05	0.50	0.12
6	Ctrklu_06	0.28	0.18
7	Ctrklu_07	0.39	0.14
8	Ctrklu_08	0.40	0.18
9	Ctrklu_09	0.13	0.14
10	Ctrklu_10	1.35	0.91
11	Ctrklu_11	0.33	0.15
12	Ctrklu_12	0.40	0.22
13	Ctrklu_13	0.74	0.23
14	Ctrklu_14	0.84	0.26
15	Ctrklu_15	0.51	0.24
16	Ctrklu_16	0.68	0.17
17	Ctrklu_17	0.98	0.18

3.4 Morphometric characteristics and potential for flash floods

The research area has 17 sub-watersheds and show relatively uniform characteristics. It can be seen that almost all sub-watersheds are elongated or oval. It shows that the research area is located in relatively high topography and steep slopes. This observations aligns with the Slope Map of the Research Area (Fig. 2), which shows the relatively steep slope of the research area.

Based on the geological map of the research area (Fig. 3), it can be seen that the research area is composed of predominantly volcanic rock. Most of the Upper Citarik Sub-watersheds are dominated by elongated shapes, lithology of volcanic rock composition, and the slow rise in flood level indicates that the research area has relatively high resistance to potential flooding. This is also suported by various calculation parameters that have been presented previously, such as (R_b) value (0.80 to 5.00) and the mean ratio of bifurcation (R_{bm}) value (1.20 - 2.75), indicating a relatively low potential for flash floods, form factor (R_f) value (0.13-0.73), ratio of elongation (R_e) value (0.41 to 0.96) and ratio of circularity (R_c) value (0.35 to 0.74), indicating predominantly elongated watershed and low potential for flash floods.

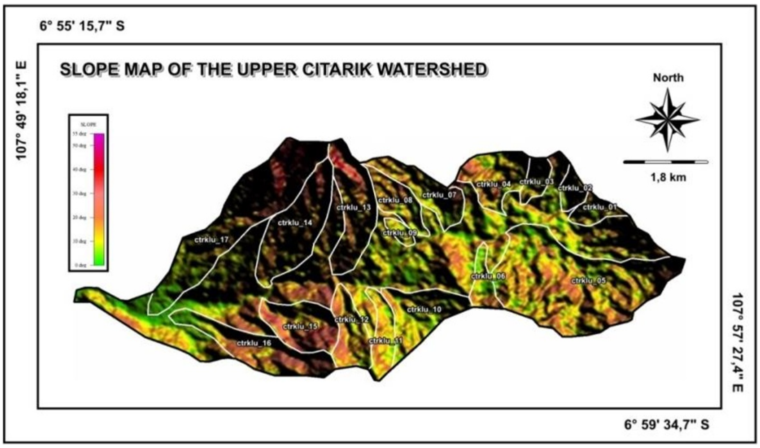

Fig. 2. Slope map of the research area.

As one of the catchment areas of the Upper Citarum watershed, it is important to maintain the condition of the Upper Citarik Watershed to avoid various natural damages such as floods, landslides, etc. It is undeniable that disasters that occur can also be accelerated by human intervention. Therefore, sustainable conservation in the Upper Citarik watershed need to be carried out.

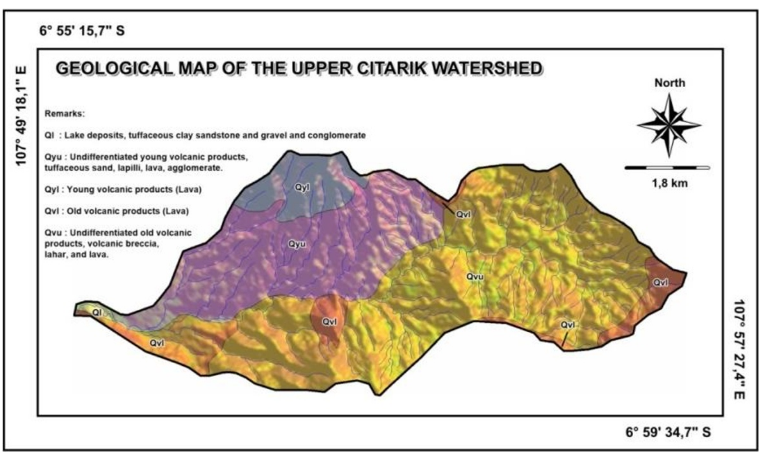

Fig. 3. Geological map of the research area (modified from [18]).

4 Conclusion

The existence of the Upper Citarik Watershed is very important for the entire Citarum Watershed and the surrounding area. It consists of 17 sub-watersheds that are dominated by elongated shapes on high relief and relatively steep slopes, composed of volcanic rocks, and have a slow increase in flooding. It indicates that the research area has a relatively high resistance to flooding. In addition, its position in the upstream area means that the Upper Citarik Watershed needs to be maintained carefully. Therefore, the Upper Citarik Watershed requires sustainable conservation so that environmental damage does not occur which results in various disasters such as floods, landslides, and others.

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