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Analysis of Bifurcation Ratio and Drainage Density in Ciemas, Cihaur, Girimukti and Sangrawayang Areas, Sukabumi District, West Java Province

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Abstract— *Quantitative geomorphological analysis is a way to interpret an area based on geomorphological data that can provide an overview of geological conditions and the processes that take place in it presented in a thematic map. The research area is located in Ciemas, Cihaur, Girimukti, and Sangrawayang areas, Sukabumi Regency, West Java Province. The study was conducted to determine the morphometric characteristics of the catchment area using ArcGIS software. The morphometry aspects to be studied consist of linear aspects (stream order (u), stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb), mean bifurcation ratio (Rbm). Areal aspects (drainage density (Dd), stream frequency (Fs), drainage texture (Rt), form factor (Rf), circularity ratio (Rc), elongation ratio (Re), length of overland flow (Lg). Based on the results of data processing, the study area was divided into 9 catchment areas with various morphometric characteristics. In general, the study area is not affected by strong structural control, the process of rapid lowering of the water level with a very rough density. Almost all catchment areas are dominated by an elongated shape and some rounded catchment areas. The length of the river surface flow each catchment area has a moderate flow with a rectangular drainage pattern type.*

Keywords— *Geomorphology, GIS, Morphometry, Sukabumi.*

I. INTRODUCTION

Quantitative geomorphological analysis is a way to interpret an area based on geomorphological data that can provide an overview of geological conditions and the processes that take place in it presented in a thematic map. A watershed is an area bordered by mountain ridges where rainwater falling in the area will be collected and flowed through small rivers to the main river. Watershed quantifiable analysis is required to determine the characteristics of watersheds in a region. Morphometric analysis is one of the quantitative analysis of morphology that can provide information regarding slope characteristics, topography, runoff water, surface water potential and so on that can be used in watershed planning. The study was conducted to determine the morphometric characteristics of the catchment area in relation to the conditions of the study area using ArcGIS software.

A. Regional Geology of the Research Area

The research area is in the Ciemas, Cihaur, Girimukti, and Sangrawayang areas, Sukabumi Regency, West Java which is included in the South Mountain Zone (Bemmelen, 1949). Based on the geological map of the Jampang and Balekambang Sheets (Sukamto, 1975) the research area is composed of rocks from Cikarang Members, the Jampang Formation of Lower Miocene age. There is a transverse fault oriented northeast – southwest with the southeastern part experiencing a fault plane.

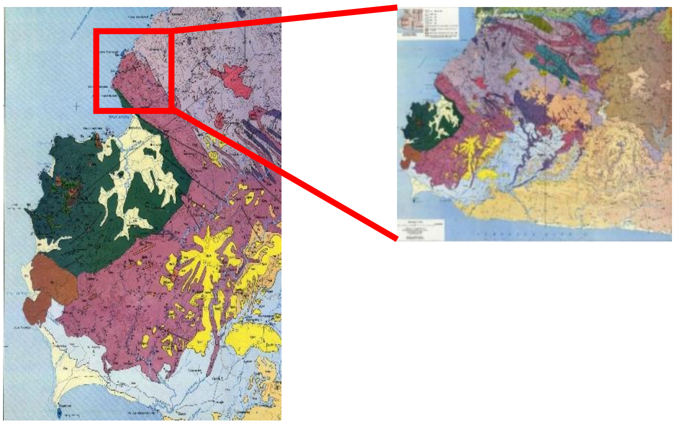

Fig. 1. Research area from the geological map of Jampang and Balekambang sheets (Sukamto, 1975)

B. Linear Aspects of Morphometry

- Stream order (u)

The order of the stream is a hierarchy of the branching position of the river flow in its order against the main river in a watershed. The greater the number of river orders, the longer the river flow and the wider the watershed. The determination of the river order can be done by many methods, such as the Strahler method, the Horton method, the Shreve method, the Scheidegger method and other methods that can determine the order of the river. However, the Strahler method is the most common and easy method to do. This method states that where a river that has no branches is called a 1st stream order, the confluence between two rivers of order 1 is called a stream order 2, and so on.

Fig. 2. Determination of the stream order using the Strahler method

- Stream Length (Lu) and Mean Stream Length (Lsm)

According to Vittala (2004) the first stream order of a watershed has the longest total length of the stream (Lu) and the higher the river order the shorter the total length of the stream. The average length of the stream can be calculated by the following formulation:

$$Lsm = \frac{Lu}{Nu}$$

(Lu) is the sum of the lengths of u-stream order and
(Nu) is the number of u- stream order segments.

- Stream Length Ratio (RL)

The stream length ratio is the ratio of the total length of a stream (Lu) in an order to the total length of a river in the lower order. The increase in the value of the river length ratio from the lower order to the higher order indicates the presence of advanced geomorphic levels in the watershed is influenced by the slope conditions of a watershed. Here is the formulation for calculating the stream length ratio:

$$R_L = \frac{L_u}{L_{u-1}}$$

(Lu) is the sum of the lengths of the stream of order u-1 and (Lu-1) is the sum of the lengths of stream of order u-1

- Bifurcation Ratio (Rb) and Mean Bifurcation Ratio (Rbm)

The bifurcation ratio from one order to another can differ due to the presence of lithological differences. The bifurcation ratio according to Strahler (1964) can be divided into 3 classes, including:

– Rb < 3, the flow of the river when experiencing a rise in water level will decrease slowly
– 3 > Rb < 5, river flow when experiencing a rise in water level will decrease not too slowly
– Rb > 5, the flow of the river when experiencing a rise in water level will decrease rapidly.

According to Chandrasekar, et al (2015) in Rendra (2021), rivers with a low grade bifurcation ratio (Rb < 5) are generally not affected by structural control, while rivers with a high class bifurcation ratio (Rb > 5) are generally affected by strong structural control. The greater the bifurcation ratio, the greater the likelihood of flash flooding. Here is the formulation for calculating the bifurcation ratio:

$$R_b = \frac{N_u}{N_{u+1}}$$

(Nu) is the number of segments of the stream order u+1 and (Nu+1) is the number of segments of the stream order u+1

C. Areal Aspects of Morphometry

- Drainage Density (Dd)

Drainage Density (Dd), is closely related to relief, valley density, rocks, soil, climate, and vegetation (Montgomery and Dietrich, 1989 in Rendra, 2021). There is a division of drainage density classes according to Smith (1950), including :

TABLE 1. Drainage density classification (Smith, 1950)

Dd	Class
< 2	Very Rough
2-4	Rough
4-6	Medium
6-8	Fine
>8	Very Fine

Watersheds that have a low (very rough) drainage density value are generally dominated by permeable, resistant rocks, have dense vegetation and have a low relief. Meanwhile, watersheds that have a high drainage density (very fine) are generally dominated by impermeable, non-resistant rocks, have sparse vegetation and have a high relief (Vittala, 2004). Here is the formulation for calculating drainage density :

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

(L) is the sum of the lengths of the entire river and
(A) is the area of the watershed under study.

- Stream Frequency (Fs)

Stream frequency is the total number of river segments in a watershed. Stream frequency is related to river density, lithology, and texture in a river network. Here is a formulation for calculating Stream frequency:

$$R_b = \frac{N_u}{A}$$

(Nu) is the number of u-order river segments and
(A) is the watershed area

- Drainage Texture (Rt)

Drainage texture is closely related to the value of drainage density (Dd). Rivers with a rough texture will show a low Dd value, while rivers with a smooth texture will show a high Dd value (Strahler, 1964 in Rendra, 2021). Here is the formulation for calculating the drainage texture:

$$R_t = \frac{N_u}{P}$$

(Nu) is the number of u-order river segments and
(A) is the circumference of the watershed

- Form Factor (Rf)

The form factor has a range of values from 0 to 1. Longitudinal watersheds generally have a low Rf value, while rounded (circular) watersheds generally have a high Rf value (Yangchan, et al, 2015 in Rendra, 2021). Here is the formulation for calculating the form factor in a watershed:

$$R_f = \frac{A}{{L_b}^2}$$

(A) is the watershed area and
(Lb) is the watershed length

- Circularity Ratio (Rc)

The circularity ratio is closely related to geological structures, reliefs, and slopes. A watershed with a low Rc value generally has an elongated shape, is not controlled by the presence of geological structures and belongs to the young phase of the river network. Meanwhile, watersheds with high Rc values generally have a rounded shape, are controlled by geological structures, and belong to the old phase of the river network. (Wilson, et.al in Rendra, 2021). Here is the formulation for calculating the circularity ratio in a watershed:

$$R_c = \frac{4\pi a}{P^2}$$

(A) is the area of the watershed and
(P) is the circumference of the watershed

- Elongation Ratio (Re)

The elongation ratio can indicate the geological conditions of a watershed area. According to Strahler (1964), a river with a Re < value of 0.5 will have the shape of a watershed that is elongated, while a river with a value of Re 0.9 – 1.0 has a rounded shape. Generally, a rounded watershed shape will have a high maximum runoff and a higher risk of erosion compared to an elongated watershed. Here is the formulation for calculating the elongation ratio in a watershed:

$$R_e = \frac{\sqrt{(\frac{Au}{\pi})}}{Lb}$$

(A) is the area of the watershed and
(Lb) is the watershed length
Here is the range of values that Strahler (1964) used:

TABLE 2. Elongation ratio classification (Strahler, 1964)

Re	Keterangan
< 0.5	More Elongated
0.5 – 0.7	Elongated
0.7 – 0.8	Less Elongated
0.8 – 0.9	Oval
0.9 – 1.0	Circular

- Length of Overland Flow (Lg)

The length of overland flow is the distance between the water that passes on the ground surface measured from where it begins to flow until it enters the river. The length of overland flow can be controlled by the type of lithology, relief, permeability, slope of the slope, as well as the existing vegetation cover (Schumm, 1956). Watersheds with low Lg values are generally on short flow paths, water travel times are faster on steep slopes and prone to erosion. Meanwhile, watersheds with high Lg values are generally on long flow paths, long travel times on gentle slopes (Rekha, etc. 2011 in Rendra, 2021).

D. *Watershed Shape*

There are several forms of watersheds, Sosrodarsono and Takeda (1987) divide the shape of watersheds into 4 types, including:

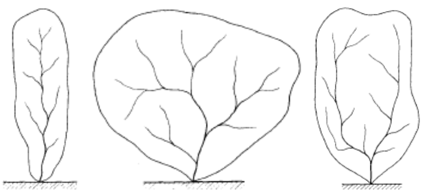

Fig. 3. Types of drainage shape; elongated shape (left), radial shape (center), and parallel shape (right)

- Elongated shape drainage area, where in the left and right areas the stream into the main river.
- Radial shape drainage area, where an existing tributary concentrates to a point in a circular (radial) manner
- Parallel shape drainage area, where there are two streams that are integrated downstream and tend to be parallel
- Complex shape drainage area, consisting of a wide variety of stream types. Only some streams have complex shapes

II. METHOD

The method carried out in this study is a quantitative analysis method to identify aspects of watershed morphometry using ArcGIS and Microsoft Excel software. The data used in this study includes river network data and topographic data. The morphometry aspects to be studied consist of linear aspects (stream order (u), stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb), mean bifurcation ratio (Rbm). Areal aspects (drainage density (Dd), stream frequency (Fs), drainage texture (Rt), form factor (Rf), circularity ratio (Rc), elongation ratio (Re), length of overland flow (Lg).

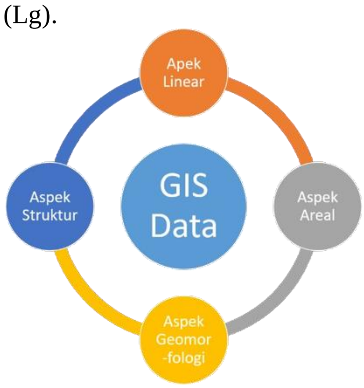

Fig. 4. Modeling diagram of research methods

III. RESULT AND DISCUSSION

A. *Linear Aspects of Morphometry*

- Stream Length (Lu) and Mean Stream Length (Lsm)

The value of the length of the river (Lu) in the study area ranged from 1.37 - 178.51 km (Table 3). Not all subwatersheds have ideal conditions where the higher the order of the river, the smaller the total length of the river. Some catchment areas such as DTA-5, DTA-6, and DTA-9 have total river lengths that do not always get smaller even though the river order is increasing. The mean value of river length (Lsm) ranges from 1.46 - 16.24 km (Table 3). Some catchment areas such as DTA-1, DTA-2, DTA-3, DTA-4 and DTA-7 have mean river length values that do not always increase even though the river order is increasing. This shows the influence of topographic, lithological, and slope conditions on the catchment area.

- Stream Length Ratio (RL)

The value of the stream length ratio (RL) in the study area ranged from 0.08 – 1.79 (Table 3). In general, the study area has a catchment area with a tendency to increase the value of the stream length ratio (RL) from the lower order to the higher order. This suggests some of the catchment areas in the study area have advanced geomorphic stages. However, in some catchment areas such as DTA-2, DTA-4, DTA-7 has a tendency for the stream length ratio (RL) value to decrease. This suggests some of those catchments have young geomorphic stages.

Dadan Wildan, Aliyuddin Jamil, Sri Wahyuni, Murni Sulastri, Nana Sulaksana and Pradnya Paramarta Raditya Rendra, "Analysis of Bifurcation Ratio and Drainage Density in Ciemas, Cihaur, Girimukti and Sangrawayang Areas, Sukabumi District, West Java Province," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 5, Issue 9, pp. 65-70, 2023.

- Bifurcation Ratio (Rb) and Mean Bifurcation Ratio (Rbm)

The value of the stream bifurcation ratio (Rb) in the study area ranged from 2.00 – 8.00 and the mean stream bifurcation ratio (Rbm) between 38.83 – 23.44 (Table 3). In general, the study area has a river channel with a relatively not very fast rise in floodwater levels. However, there is a DTA-2 with a stream bifurcation ratio (Rb) of 8.00 this high value can occur due to differences in lithological types.

B. *Areal Aspects of Morphometry*

- Drainage Density (Dd)

The drainage density value (Dd) in the study area ranged from 0.00357 – 0.01644 (Table 4). In general, the range of such values indicates that the catchment has a very rough drainage density. The range of Dd values indicates that the study area has the characteristics of relatively permeable subsurface conditions, fairly dense vegetation, and low-high relief variations.

- Stream Frequency (Fs)

The stream frequency values (Fs) in the study area ranged from 0.00002 - 0.00145 (Table 4). Some examples of high-value catchment areas such as DTA-1, DTA-2, DTA-3, DTA-4, DTA-6 and DTA-9. Examples of catchment areas with low values such as DTA-5, DTA-7, and DTA-8.

- Drainage Texture (Rt)

The drainage texture value (Rt) in the study area ranged from 0.00893 – 0.31696 (Table 4). The range of such values indicates that the catchment has a very rough drainage texture. The range of values indicates that the study area has characteristics of surface runoff conditions and relatively low erosion potential.

- Form Factor (Rf)

Form factor (Rf) values in the study area ranged from 0.31 – 10.58 (Table 4). The range of such values indicates that the catchment area has an elongated to rounded watershed shape. A low form factor value indicates an elongated catchment shape with a low susceptibility to flooding, but otherwise some examples of high form factor (Rf) values indicate a relatively rounded catchment shape. However, the characteristics of the catchment area need to be supported by other aspects such as slope conditions and stream density to identify potential flooding and erosion in some of these catchment areas.

- Circularity Ratio (Rc)

The value of the circularity ratio (Rc) in the study area ranged from 40.58 – 70.48 (Table 4). Based on the calculation results, all catchment areas have a value of Rc > 0.5 which is the shape of a round catchment area.

- Elongation Ratio (Re)

The value of the elongation ratio (Re) in the study area ranged from 0.63 - 3.67 (Table 4). In general, a considerable Rc value of > 0.75 on the catchment area indicates a weak or inactive tectonic influence.

- Length of Overland Flow (Lg)

The value of the length of overland flow (Lg) in the study area ranges from 0.00179 -0.00822 (Table 4). The range of such values indicates that the catchment area has varied surface flow characteristics.

Based on the results of the calculation of several watershed morphometric parameters, the general results of the study showed that 9 catchment areas had various morphometric characteristics. The rivers in the study area are included in the rectangular drainage pattern, where in some places of river defection there is generally a change in lithological variations of soft rocks and can eventually deflect because there are hard rocks. All of these weak areas are certainly corroborated by regionally identifiable patterns of straightness. After ovelay data on the regional geological map of The Jampang and Balekambang Sheets (Sukamto, 1975) there was an anomaly that rivers were found in the ocean area. This needs to be the material for the author's evaluation in the future whether there are errors in digitizing the map or other errors that can be corrected in the future.

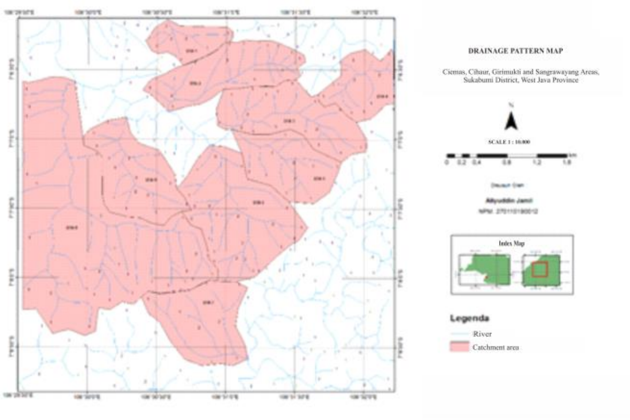

Fig. 5. Map of drainage patterns of order 3 catchment areas

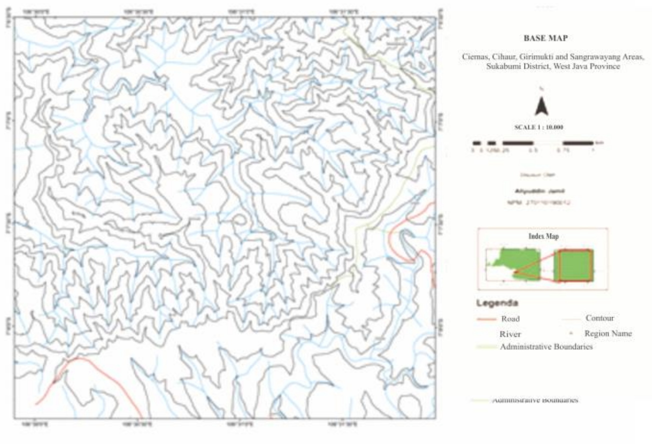

Fig. 6. Base map at the research area

IV. Conclusion

Based on the results of data processing, the study area was divided into 9 catchment areas with various morphometric characteristics. In general, that the study area is not affected by strong structural control, the process of rapid lowering of the water level with a very rough density. Almost all catchments are dominated by an elongated shape and some rounded catchment areas. The length of the river surface flow of each catchment area is included in a moderate flow, some of which are short and long with a rectangular type of drainage

Dadan Wildan, Aliyuddin Jamil, Sri Wahyuni, Murni Sulastri, Nana Sulaksana and Pradnya Paramarta Raditya Rendra, "Analysis of Bifurcation Ratio and Drainage Density in Ciemas, Cihaur, Girimukti and Sangrawayang Areas, Sukabumi District, West Java Province," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 5, Issue 9, pp. 65-70, 2023.

pattern, where in some river defections there is generally a change in lithological variations between soft rocks and hard bricks so that river defections occur.

Linear Aspects

TABLE 3. Results of linear aspect data calculation

DTA	Streams Length (km)				Streams Segments				Lsm			RL		Rb		Rbm	
	Orde 1	Orde 2	Orde 3	Total	Orde 1	Orde 2	Orde 3	Total	1	2	3	2-1	3-2	1-2	2-3	1-2	2-3
DTA-1	14.48	3,99	1,37	19,84	5	2	1	8	2,90	2,00	1,37	0,28	0,34	2,50	2.00		
DTA-2	44.98	17,69	2,03	64,7	16	2	1	19	2,81	8,85	2,03	0,39	0,11	8,00	2.00		
DTA-3	178.51	13,7	2,03	194,24	14	2	1	17	12,75	6,85	2,03	0,08	0,15	7,00	2.00		
DTA-4	19,99	8	2,85	30,84	9	2	1	12	2,22	4,00	2,85	0,40	0,36	4,50	2.00		
DTA-5	28,87	4,94	8,82	42,63	9	2	1	12	3,21	2,47	8,82	0,17	1,79	4,50	2.00	3 8.83	2 3.44
DTA-6	58,06	15,62	16,24	89,92	18	6	1	25	3,23	2,60	16,24	0,27	1,04	3,00	6.00		
DTA-7	19,76	21,09	3,74	44,59	6	3	1	10	3,29	7,03	3,74	1,07	0,18	2,00	3.00		
DTA-8	114,47	33,95	16,24	164,66	28	4	1	33	4,09	8,49	16,24	0,30	0,48	7,00	4.00		
DTA-9	30,6	5,83	9,88	46,31	12	4	1	17	2,55	1,46	9,88	0,19	1,69	3,00	4.00		

Areal Aspects

TABLE 4. Results of Areal aspect data calculation

DTA	Streams Length (km)				Area DTA (km2)	Circumference DTA (km)	Dd	Fs			Rt			Rf	Rc	Re	Lg
	Orde 1	Orde 2	Orde 3	Total				1	2	3	1	2	3				
DTA-1	14,48	3,99	1,37	19,84	4166,12	35,91	0,00476	0,00120	0,00048	0,00024	0,13924	0,05569	0,02785	10,58	40,58	3,67	0,00238
DTA-2	44,98	17,69	2,03	64,7	10997,46	57,26	0,00588	0,00145	0,00018	0,00009	0,27943	0,03493	0,01746	2,63	42,13	1,83	0,00294
DTA-3	178,51	13,7	2,03	194,24	11813,51	52,62	0,01644	0,00119	0,00017	0,00008	0,26606	0,03801	0,01900	0,31	53,59	0,63	0,00822
DTA-4	19,99	8	2,85	30,84	6445,40	39,65	0,00478	0,00140	0,00031	0,00016	0,22699	0,05044	0,02522	6,78	51,49	2,94	0,00239
DTA-5	28,87	4,94	8,82	42,63	9054,43	40,17	0,00471	0,00099	0,00022	0,00011	0,22405	0,04979	0,02489	4,98	70,48	2,52	0,00235
DTA-6	58,06	15,62	16,24	89,92	18049,57	56,79	0,00498	0,00100	0,00033	0,00006	0,31696	0,10565	0,01761	2,23	70,29	1,69	0,00249
DTA-7	19,76	21,09	3,74	44,59	10940,03	44,43	0,00408	0,00055	0,00027	0,00009	0,13504	0,06752	0,02251	5,50	69,61	2,65	0,00204
DTA-8	114,47	33,95	16,24	164,66	46119,30	111,97	0,00357	0,00061	0,00009	0,00002	0,25007	0,03572	0,00893	1,70	46,20	1,47	0,00179
DTA-9	30,6	5,83	9,88	46,31	11252,96	46,28	0,00412	0,00107	0,00036	0,00009	0,25929	0,08643	0,02161	5,25	65,99	2,59	0,00206

TABLE 5. Interpretation results of data processing

DTA		Structure Control (Chandrasekar, dkk. 2015)	Flood Rise (Strahler, 2017)	Drainage Density (Smith, 1950)	Geomorphic Stages (Singh, 1997)	Watershed Shape	Length of Overland Flow
DTA-1	**1-2**	Weak	Slowly	Very Rough	Advanced geomorphic stages	Circular	Short
	2-3	Weak	Slowly				
DTA-2	**1-2**	Strong	Rapidly	Very Rough	-	Elongated	Moderate
	2-3	Weak	Slowly				
DTA-3	**1-2**	Strong	Slowly	Very Rough	Advanced geomorphic stages	Elongated	Moderate
	2-3	Weak	Rapidly				
DTA-4	**1-2**	Weak	Moderately	Very Rough	-	Circular	Short
	2-3	Weak	Rapidly				
DTA-5	**1-2**	Weak	Moderately	Very Rough	Advanced geomorphic stages	Elongated	Moderate
	2-3	Weak	Rapidly				
DTA-6	**1-2**	Weak	Rapidly	Very Rough	Advanced geomorphic stages	Elongated	Moderate
	2-3	Strong	Rapidly				
DTA-7	**1-2**	Weak	Rapidly	Very Rough	-	Circular	Moderate
	2-3	Weak	Rapidly				
DTA-8	**1-2**	Strong	Slowly	Very Rough	Advanced geomorphic stages	Elongated	Length
	2-3	Weak	Moderately				
DTA-9	**1-2**	Weak	Rapidly	Very Rough	Advanced geomorphic stages	Elongated	Moderate
	2-3	Weak	Moderately				

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