IOP Conf. Series: Earth and Environmental Science **118** (2018) 012028 doi:10.1088/1755-1315/118/1/012028

Watershed-based Morphometric Analysis: A Review

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Abstract. Drainage basin/watershed analysis based on morphometric parameters is very important for watershed planning. Morphometric analysis of watershed is the best method to identify the relationship of various aspects in the area. Despite many technical papers were dealt with in this area of study, there is no particular standard classification and implication of each parameter. It is very confusing to evaluate a value of every morphometric parameter. This paper deals with the meaning of values of the various morphometric parameters, with adequate contextual information. A critical review is presented on each classification, the range of values, and their implications. Besides classification and its impact, the authors also concern about the quality of input data, either in data preparation or scale/the detail level of mapping. This review paper hopefully can give a comprehensive explanation to assist the upcoming research dealing with morphometric analysis.

1. Introduction

In geomorphology, morphometry is a quantification of morphology. Indices of watershed morphometry can interpret the shape and hydrological characteristics of a river basin [1]. Morphometric analysis of watershed is the best method to identify the relationship of various aspects in the area. It is a comparative evaluation of different watersheds in various geomorphological and topographical conditions [2]. Watershed is a natural hydrological entity from which surface runoff flows to a defined drain, channel, stream or river at a particular point [3].

Drainage basin/watershed analysis based on morphometric parameters is very important for watershed planning since it gives an idea about the basin characteristics regarding slope, topography, soil condition, runoff characteristics, surface water potential, etc. [2]. The morphometric analysis of watershed aids to know the aspects of linear, areal, and relief parameters [4].

Stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio, mean bifurcation ratio, drainage density, drainage texture, stream frequency, relief ratio, form factor, elongation ratio, circularity ratio, length of overland flow are the most common morphometric parameters [1–6]. The definition and formula for each parameter are the same as stated in many papers. Unfortunately, there is no complete classification for all parameters.

Some classifications are presented but not all. Several papers stated that a resulted value of a certain parameter belongs to high or low, and indicates a condition; but the range of value is not included. Even worse, in some papers, there is no statement of the implication of high or low value of a particular morphometric parameter. It is very confusing to evaluate a value of every morphometric parameter. This paper deals with the implication of values of the various morphometric parameters, with adequate contextual information. A critical review is presented on each classification, the range of values, and their implications. Besides classification and its impact, the authors also concern about the quality of input data, either in data preparation or in scale/the detail level of mapping. This review paper hopefully

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can give a comprehensive explanation to assist the incoming research dealing with morphometric analysis.

2. Morphometric Parameter

Ten morphometric parameters are discussed here, i.e., stream length ratio (Rl), bifurcation ratio (Rb), drainage density (Dd), drainage texture (Dt), stream frequency (Fs), elongation ratio (Re), circularity ratio (Rc), form factor (Rf), length of overland flow (Lg), and relief ratio (Rh).

2.1. Stream length ratio (Rl)

Stream length ratio (Rl) is the ratio of the total stream length of the one order to the next lower order of stream segment. An increasing trend in the stream length ratio from lower order to higher order indicates their mature geomorphic stage [6]. Therefore, there is no classification for Rl.

2.2. Bifurcation ratio (Rb)

Bifurcation ratio is the ratio of a number of the stream segments of specified order and a number of streams in the next higher order [1–6]. The Rb is dimensionless property [1]. Basically, there are two classes of Rb value; low and high. Low class means the drainage pattern is not affected by the geologic structures [1,3–6], whereas the high class means the drainage pattern is controlled by the geologic structures. The value range of the Rb classifications varies among the researchers, there is even no statement about it. Based on some papers, it can be concluded that less than five (5) may be classified into low, and more than five (5) into high [2,5,6].

2.3. Drainage density (Dd)

Drainage density is the total length of streams of all orders (km) per drainage area (km^2) [1–6]. The value ranges of drainage density mostly are in km/km^2 [2–6], but a paper used another unit (m/km^2) [4]. There are five classes of drainage density with the following value ranges (km/km^2), i.e., very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (>8) [2,3]. However, based on some definitions about D classes, it can be highlighted that there are two main classes, low/coarse and high/fine class. Unfortunately, there are no value ranges for both two main classes of drainage density.

Low class of D shows a poorly drained basin with a slow hydrologic response. Surface runoff is not rapidly removed from the watershed making it highly susceptible to flooding, gully erosion, etc. [1,4]. Besides, low class of D has a permeable subsoil material, dense vegetation and low relief [1–6].

High class of D shows a quick hydrological response to rainfall events [1,4]. Besides, high class of D has an impermeable subsoil material, sparse vegetation and high/mountainous relief [1–6].

The flooding/high runoff and erosion are threatening the watershed with either low or high D value [1]. This is due to the watershed with high D value has sparse vegetation and mountainous relief [1–6]. The condition makes it susceptible to flood and erosion. No clear implication between the low and high drainage density concerning flood.

2.4. Drainage texture/ texture ratio (Dt)

Drainage texture is the total number of stream segments of all order in a river basin to the perimeter of the basin [1–6]. Unit of drainage texture is km^{-1}. The classification of drainage texture is the same with the classification of drainage density [3,5,6]. Classification of drainage texture mostly do not use a classification by applying certain values range for each class, but the classification tends to be more relative among studied watersheds by comparing one to another. A watershed which has very fine texture or the highest value of drainage texture (>8) implies that it has more risk of soil erosion.

2.5. Stream frequency (Fs)

Stream frequency (Fs) is the total number of channel segments of all stream orders per unit area ($km\text{-}^2$). A total number of channel segments are dimension-less. Commonly, there are the low and the high classes of stream frequency which are relative among the investigated watersheds in a research area.

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There is no mention about classifications and their value ranges. The relative value ranges of stream frequency sometimes make different implications of low and high class, for instance, the low class means low relief [1]; meanwhile, low class of stream frequency means high relief [2]. It was because of applying the relative value ranges. Relative value ranges can be applied if the interpreter has good knowledge about the morphology, otherwise the result will be not correct.

2.6. Elongation ratio (Re)

Elongation ratio is the ratio of the diameter of a circle of the same area as the basin to the maximum basin length [1–6]. Therefore, Re is a dimension-less property. Generally, elongation ratio value is classified into two classes, i.e., the low value which means elongated watershed, and high value which means circular watershed. There are many classifications used in some papers. Four classes of Re are elongated (<0.7), less elongated (0.7-0.8), oval (0.8-0.9), and circular (>0.9) [2]. Three classes of Re are less elongated (< 0.7), oval (0.8 – 0.9), and circular (>0.9) [3,5,6]. [3,5]. Last but not least, two classes of Re are the low class (<1) and high class (>1) [6].

The classification is not based on the strict value ranges, for instance, sub-basin I in Pavada, India which has 0.72 Re value is classified into high one [4]. There are four sub-basins in which their Re values ranging from 0.5 to 0.72; [4] classified 0.5 into low class and 0.72 into the high one. It means that the value ranges tend to be relative, not in absolute value. Basically, there are two classes based on the elongation ratio, i.e., the low value of Re (elongated watershed) has high relief and steep slope, and the high value of Re (circular watershed) has flat land with low relief and low slope. High relief watershed has a high susceptibility to erosion.

2.7. Circularity ratio (Rc)

Circularity ratio is the ratio between the areas of a watershed to the area of the circle having the same circumference as the perimeter of the watershed [1–6]. Rc is also a dimension-less property. There is a relationship between circularity ratio (Rc) value and the existence of structural disturbances [3,5,6]. It reminds us of the implication of bifurcation ratio (Rb) which stated that low value means no structural disturbances and a high value means the existence of strong structural control on the watershed. Similar to Rb, the low Rc means no structural disturbances and the high Rc means the existence of strong structural control on the watershed. It is proven by an analysis of Rb and Rc data in Pavada, India obtained from [3]. The nine sub-watersheds in their research study have the same class of Rb and Rc. Rb of those nine sub-watersheds varies from 3.2 to 4.7 and was classified into low Rb, and the Rc values which vary from 0.32 into 5.0 were classified into low Rc.

2.8. Form factor (Rf)

Form factor is a ratio of watershed area to the square of the length of the watershed. Flood hydrograph always affects the basin form [4]. There are some different value ranges of form factor. The range values for form factor are <0.78 (elongated) and >0.78 (circular) [1,6]. There are also other range values for Rf classification, i.e., elongated (0 or low value) and circular (1) [4]. An elongated watershed means it has low peak flows for longer duration while a circular watershed means it has high peak flows for a shorter duration.

2.9. The length of overland flow (Lg or AOLF)

Length of overland flow is a length of water over the ground before it gets concentrated into certain stream channels. Lg = 1/(Dd X 2), where Dd (drainage density) is in km/km^2. Length of overland flow is mentioned with other term, i.e., average over land flow (AOLF) [4]. Dd as an input in calculating Lg must be in km/km^2. There are three classes of Lg i.e., low value (< 0.2), moderate value (0.2 – 0.3), and high value (>0.3) [2]. Low value of Lg indicates high relief [6], short flow paths, more runoff, and less infiltration [2] which leads to more vulnerable to the flash flooding [1]. Meanwhile, a high value of Lg means gentle slopes and long flow paths [1], more infiltration, and reduced runoff [2].

2.10. Relief ratio (Rh)

Relief Ratio (Rh) is the difference in the elevation of the highest and lowest points in a watershed. No one mentioned about the value range of relief ratio [1–6]. To classify it, researchers did it based on the values of relief ratio in their study area relatively. Generally, the low value of relief ratio means low relief and the high value means steep slope and high relief.

Generally, there is a correlation between drainage density (Dd), drainage texture (Dt), and stream frequency (Fs). It is about the ratio between the stream and the size of watershed although there is a difference. Related to stream, it can be a total length or the number of streams. Meanwhile related to the size of watershed, it can be an area or perimeter. Based on those three parameter values of 9 sub-watersheds in Pavada, India [3], it can be identified what kind of correlation they have among them (Figure 1).

Elongation ratio (Re), circularity ratio (Rc), and form factor (Rf) have the same goal to identify the form of watershed either elongated, circular, or oval. It needs confirmation by an analysis on a number of Re, Rc, and Rf values in a study area [3] presented in Figure 2.

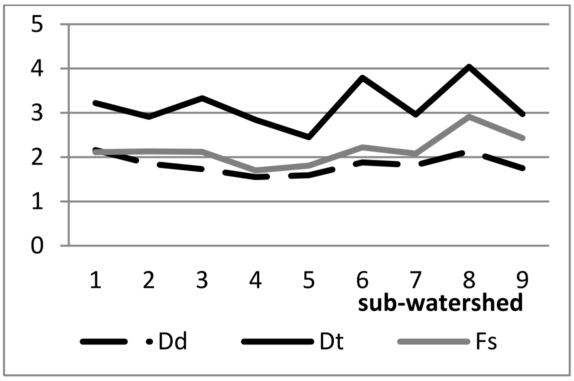

Figure 1. Graph of Dd, Dt, and Fs values in 9 sub-watersheds in Pavada, India.

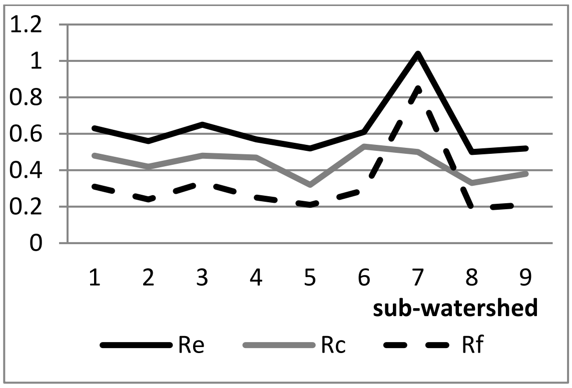

Figure 2. Graph of Re, Rc, and Rf values in 9 sub-watersheds in Pavada, India.

Drainage density has a positive correlation with the stream frequency [1,3]; yet Figure 1 shows that drainage density and stream frequency have a little bit different trends. Drainage texture has no positive correlation with drainage density and frequency either.

The values of Re and Rf form the same trend (Figure 2), the greater value of Re, the greater value of Rf. It means Re and Rf have a positive correlation. The value trend of Rc is different compared to Re and Rf. To identify the form of a watershed, those three parameters (Re, Rc and Rf) should be considered. Based on those three parameters, the form of a watershed may be determined.

3. The Quality of Input Data

Every parameter has a certain formula to obtain a value for each. Input is an essential role in producing the result. Based on the reference papers, there is no discussion either in data preparation or map scale which much influences the result of the analysis.

The main input data for morphometric processing are three layers of map, i.e., watershed area map, drainage map, and elevation map. Drainage map and elevation map can be derived from topography map. Drainage map can be given or generated from topographic map. Recently some researchers used DEM (Digital Elevation Model) data to extract both drainage map, watershed area map, and elevation map. Drainage map is extracted automatically by GIS (Geographic Information System) from DEM which is an essential input in defining the morphometric parameter values. DEM must be edited before generating elevation and stream map [4] but no one mention about the editing of the derived stream map. Sometimes the resulted stream map contains errors which must be edited. Therefore, the stream map derived from DEM data should be checked.

Those map layers should have a scale that corresponds to each other. Watershed, as an area unit in a morphometric analysis which is compared to each other, may vary in size. It can be fully watershed, sub-watershed, micro-watershed, etc. The mean area of a watershed is less than 500 km^2. Watershed is further classified into sub-watershed (±30-50 km2), mini-watershed (±10-30 km2) and micro-watershed (±5-10 km^2) [3]. It represents that the scale of mapping in a morphometric analysis is also vary. It can be in a small scale, a medium scale, and a big scale. The spatial resolution of DEM data used as input data in a morphometric analysis should be considered, for instance, SRTM and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM with 30 m spatial resolution can be used in medium scale mapping and TerraSAR-X with 9 m spatial resolution can be used in bigger scale mapping.

4. Conclusions

So many parameters with their interrelated implications make it confusing to characterize each watershed compared to the others in a research area. It has been observed that not every parameter has strict value ranges to classify their parameter values. This paper explains a critical review of some morphometric parameters with their difference in the value range, implication, and overlapping as well as the quality of input data. The morphometric analysis should notice the raw data, scale, and processing to produce the accurate result.

Basically, the watershed is classified according to its shape, i.e., elongated and circular. The elongated watershed has high relief and young geomorphic stage. Due to its high relief, it leads to more vulnerable to erosion. Circular watershed has low relief and mature geomorphic stage. Because of its low relief, it leads to more vulnerable to flooding. The mature geomorphic stage is also defined by an increasing trend in the stream length ratio (Rl) from lower order to higher order.

The elongated watershed is identified by a high value of drainage density (Dd), texture ratio (Dt), stream frequency (Fs), relief ratio (Rh), and low value of elongation ratio (Re), circularity ratio (Rc), form factor (Rf), length of overland flow (Lg), and bifurcation ratio (Rb). The opposite of those elongated parameter values are the characteristics of a circular watershed. Concerning the structural control, it is a different thing with topography. Either the elongated or circular watershed can be affected by the geologic control. The relation among the values of morphometric parameters can assist in a watershed analysis even though it is not supported by a good understanding of morphology in a study area.

Acknowledgments

The authors thank the head of Research Center for Geotechnology for the opportunity given to the authors. We thank Dr. Adrin Tohari who was willing to guide the authors in completing their writing. We acknowledge the reviewer and editor of GCGE2017.

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