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Effects of morphometric characteristics on flash flood response at arid area (case study of wadi deffa, el bayadh city, algeria)

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Abstract

In Algeria, flash floods are becoming one of the most damaging natural hazards. Therefore, the study of watershed morphometric parameters is very important since it is a significant element of the flow processes and flash flood generation. Especially in arid areas characterized by poor vegetation cover. This work deal with the analysis of the morphometric parameters upstream El Bayadh, 700 km south of the capital Algiers. The city has been hit by devastating flash floods in October 2011. The flooding impacted both population and property with 13 dead, tens of injured, hundreds of destroyed houses, 5 collapsed bridges, at an estimated cost of 6 billion dinars (600 million Euros). DEMs data has been used in the evaluation morphometric parameters including linear, areal and relief aspects using Geographic Information System (GIS) to assess flash flooding susceptibility and will be used for further investigation and diagnostic of the hydrologic behaviour in this studied arid watershed.

Key Words: Srtm Dem, Morphometric Analysis, GIS, Watershed, Flood, El Bayadh, Algeria.

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1. Introduction

Algerian arid and semi-arid region are commonly subjected to flash floods phenomenon due to sporadic rainstorm of short duration and high intensity. The magnitude of the material and human losses seems to be increased over the last two decades (Hafnaoui et al. 2009; Hachemi et Benkhaled 2016; Derdour et Bouanani 2017). El Bayadh city, 700km south of the capital Algiers, has been already suffers the problem of flash floods in October 2011. The flooding impacted both population and property with 13 dead, tens of injured, hundreds of destroyed houses, 5 collapsed bridges, at an estimated cost of 6 billion dinars (600 million Euros). This necessitate alternate endeavor to generate any information on watershed characteristics for planning and implementing suitable conservation measures. Morphometric analysis is one of the essential analyses required for development and management of watershed(Tamma Rao et al. 2012). Especially in arid and semi-arid areas characterized by poor vegetation cover. Prior to this time, the generation of morphometric parameters within watershed using traditional method, based on field observation and topographic maps, was a tedious activity. However, During the last two decades, the availability of digital elevation models data (DEM) has been continuously growing (Prasannakumar et al. 2011). Nowadays, DEM and geographical information systems (GIS) are increasingly being used for the computation of the morphometric parameters with reduced time and cost, and can be applied easily in both mountainous, highly dissected/rugged topography, and in accessible areas (Farhan et al. 2016). The application of morphometric analysis using remote sensing and GIS techniques for studying floods and flood hazard management have been reported by number of researchers(Ozdemir et Bird 2009; Subyani et al. 2010).

There are basically three important aspects used for doing morphometric analysis of a basin, namely linear, aerial and relief aspects. Linear aspects give the information about one dimensional parameters like: stream order, stream number and bifurcation ratio. Areal aspects deals with two dimensional parameters like: drainage density, stream length, stream length ratio, drainage texture, stream frequency, circularity ratio and form factor. Relief aspects deals with three dimensional parameters like: relief, relief ratio, slope and gradient ratio(Kumar et Chaudhary 2016).

The present study describes the results of morphometric analysis of Wadi Deffa wateshed, upstream El Bayadh city, using GIS technique with an aim to understand hydrologic characteristics of the watershed.

2. Study Area

The study area lies between latitude $33^0$38’00” to $33^0$46’00” N and longitude $00^0$59’45” to $01^0$09’50”E, with a drainage area about 145 km^2 And length about 5 Km. Wadi Deffa has its source in the mountains of Mekther and Zouireg Northern El Bayadh city and the Mountains Ksel and Eloustani eastern the city and flows over 5 km across El Bayadh city Sothern West of Algeria in North Africa (Figure 1). The region has a semi-arid climate. Strongly linked to the climate, the predominant land cover is that of the steppe.

3. Data and methods

Morphometric analysis of the Wadi Deffa watershed has been essentially carried out using SRTM (Shuttle Radar Topographic Mission) DEM data with 30-m resolution downloaded from USGS website. Automated extractions of Basic morphometric parameters such as: area (A), basin length (Lb), perimeter (P), stream order (u), stream number (Nu) and stream length (Lu), have been achieved in GIS environment using ArcGIS. Other morphometric parameters have been calculated using the basic morphometric information automatically extracted. The calculated parameters of Wadi Deffa watershed are given in three major heads, such as linear, aerial, and relief aspects. The linear aspects were studied using the methods of Horton (1945), Strahler (1964),Schumm (1956), the areal aspects using those of Schumm (1956), Miller (1953), and Horton (1932), and the relief aspects employing the techniques of Melton (1957) and Schumm (1956).

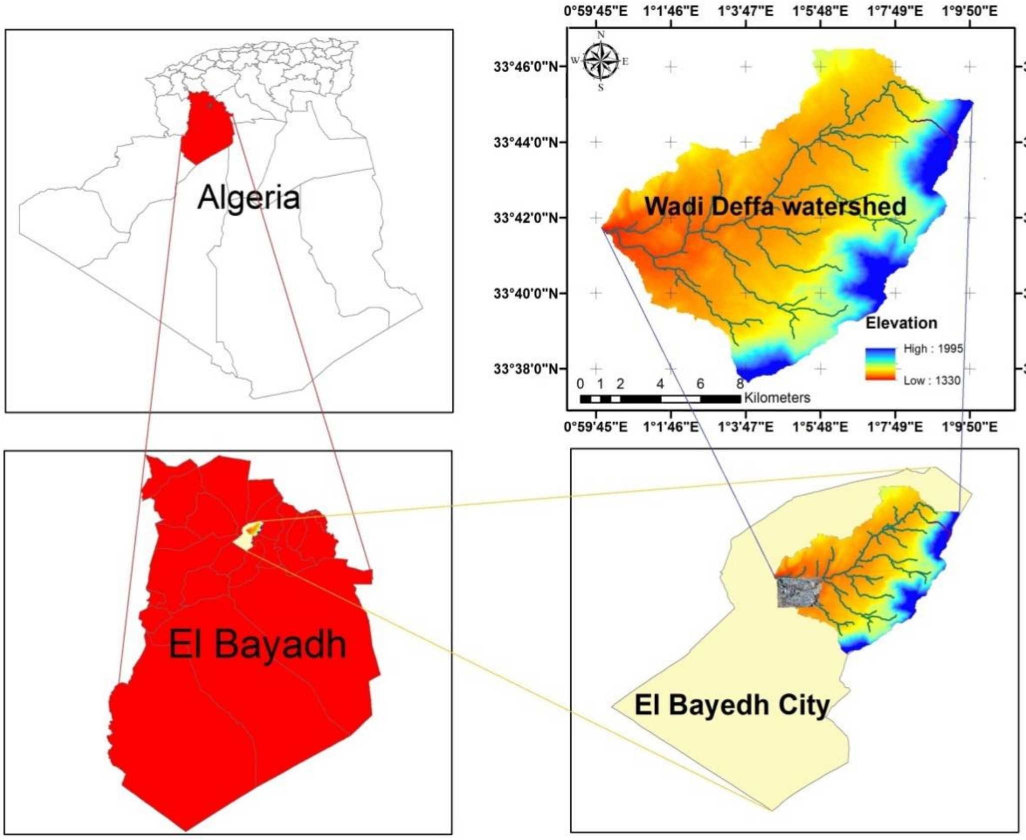

Figure 1: Location map of Wadi Deffa Watershed.

4. Results and Discussions

The morphometric parameters analysis of wadi Deffa watershed achieved through measurement of the linear, aerial and the relief aspects are highlighted in below.

4.1. Linear aspects

The basin area, basin perimeter, and basin length of the wadi Deffa watershed were found to be about 135 km2, 58.35 km, and 16.65 km respectively. The determination of stream order (U) and the fluvial hierarchy is the first and most important step in the morphometric characterization of basin (Kanth et Hassan 2012). Stream ordering of the watershed was computed using ArcGIS software by applying the methods proposed by Strahler (1964). The stream order of the watershed varies from first orders to forth order. The total number of 131streams were identified, 66 first order streams, 34 second order streams, 25 third order streams and 6 fourth order streams respectively. The total length of streams in the micro-watershed is about 124.52 km and the main channel is 23.13 km. The total length of stream segment is highest in first order streams and decreases as the stream order increases. The stream mean length defined as the ratios of total length of a particular ordered stream to total number of streams of same order are also calculated and presented. The Bifurcation ratio (Rb) is used to express the ratio of the number of streams of any select order and next higher order (Schumn, 1956). The bifurcation ratio of this research ranges between 1.36 and 4.16 and the mean bifurcation ration is 2.49 (table 1).

Table 1: Linear Aspect of the Drainage Network of the wadi Deffa Basin

	U-Stream order	Nu-Stream Number	Lu-Stream length (km)	Lu_m-Stream mean length (km)	Lm-Main Channel Length (km)	Rb-Bifurcation Ratio	
Results	1	66	68.121	1.032	23.13	Nu_1/ Nu_2	1.94
	2	34	33.073	0.923		Nu_2/ Nu_3	1.36
	3	25	17.544	0.702		Nu_3/ Nu_4	4.16
	4	6	5.778	0.963		Mean	2.49
Total	-	131	124.516	0.950		-	-
References	Strahler (1964)	Horton (1945)	Strahler (1964)	Strahler (1964)	Horton (1945)	Schumm (1956)	

4.2. Areal aspects

The areal aspects are two dimensional properties of a basin. The aerial aspects of the drainage basin such as Coefficient of compactness (Kc), drainage density (Dd), stream frequency (Fs), elongation ratio (Re), circularity ratio (Rc) and form factor ratio (Rf) were calculated and presented at table 2. The results indicated that the drainage density of the study area is 0.92. A high value of the drainage density indicates a relatively high density of streams inducing a rapid storm response giving rise to a higher runoff yield. Using the ArcGIS kernel density function the drainage density map of the watershed is prepared and illustrated at the figure 2-D. The drainage density varied from value of 0.476 $km·km^{-2}$ to a maximum value of 4.51 $km·km^{-2}$ observed in the north-west of the study area. The stream frequency of the watershed is 0.97. This value indicates a positive correlation with the drainage density value. The calculated texture ratio of the watershed is 1.13. According to Smith (1958) the texture ration of the basin belong to the coarse classes ($<6.4\ km^{-1}$). The elongation ratio values are close to 1 typically very low relief and values in 0.6–0.8 are associated with high relief and moderate to steep ground slop. These values can be grouped into three categories: 1) circular (>0.9); 2) oval (0.9 to 0.8); 3) elongated (<0.7) (Strahler 1964). For the study areathe elongation ratio is 0.79, which suggests that the basin belongs to the less elongated shape basin and moderate relief. The circularity ratio of 0.5 indicates that the basin is less elongated in shape. This measure confirms that of the elongation ration. The Form factor is commonly used to identify different basin shapes (Horton, 1932). The value of form factor would always be less than 0.7854 (for a perfect circular watershed). The high form factor experiences larger peak flows of shorter duration, and low form factor experiences lower peak flows of longer duration (Waikar et Nilawar 2014). The form factor of the study area is 0.45.

4.2. Relief aspects

The relief aspects of the drainage basin analysis have relationship with the study of three-dimensional features involving area, volume, and altitude of vertical dimension of landforms to analyse different geo-hydrological characteristics (Hajam et al.2013). The table 3 presents the considered relief aspects in this study. The basin relief value of the watershed, obtained from the highest point on the watershed perimeter to the mouth of the stream, is 662.3 m. To show spatial variation of relative relief from one place to another the value of relative relief is calculated from the DEM using range analysis in ArcGIS software. Figure 2B illustrate the relative relief map where the maximum value is 236.7 m observed in the eastern parts of the watershed. Using the basin relief (662.3 m), a relief ratio was computed as suggested by Schumm (1956), which is 0.040. Ruggedness index is the product of the basin relief and the drainage density. Wadi Deffa watershed has a ruggedness index of 0.61. For better understanding of morphometry as well as physiographic attribute, dissection index analysis is performed (Schumm, 1956). Relative relief and maximum altitude are used to compute the dissection index. Higher the value of dissection index, larger is the undulation and instability of the terrain. Maximum dissection index is 0.132 observed in the eastern part of the watershed (Figure 2C), while the dissection index of whole watershed is 0.34. Using slope tool in ArcGIS the maximum rate of change between each cell and its neighbours was calculated (figure 2F). The watershed region possesses a maximum slope of 64.58 % in the eastern part. The aspect of the basin provides the direction of the slopes. It is a very important parameter for understanding the impact of sun on the area's local climate. The result indicates that Wadi Deffa watershed shows a high percentage north and south facing slopes (Figure 2G).

Table 2: Aerial Aspect of the watershed of the wadi Deffa Basin

	Aerial aspect		
	Formula	Reference	Result
A-Drainage area (km^2)	-	Schumm (1956)	135.22
P-Perimeter (km)	-	Schumm (1956)	58.35
L-Basin length (km)	-	Schumm (1956)	16.65
Kc-Coefficient of compactness	$Kc = 0.28 \frac{P}{\sqrt{A}}$	Horton (1945)	1.405
F-Basin form	$F = \frac{A}{L^2}$	Horton (1945)	0.49
Dd-Drainage density ($km \cdot km^{-2}$)	$Dd = \frac{Lu}{A}$	Horton (1945)	0.92
Fs-Stream frequency	$Fs = \frac{\sum Nu}{A}$	Horton (1945)	0.97
Rt-Texture ratio	$Rt = \frac{\sum N1}{P}$	Schumm (1956)	1.13
Re-Elongation ratio	$Re = 1.128 \frac{\sqrt{A}}{L}$	Schumm (1956)	0.79
Rc-Circulatory ratio	$Rc = 4\pi \frac{A}{P^2}$	Miller (1953)	0.5
R_f-Form factor ratio	$R_f = \frac{A}{L^2}$	Horton (1945)	0.49

5. Conclusion

Morphometric analysis of drainage system is essential to any watershed related study. The interferometric SRTM DEM data were successfully used for the study of wadi Deffa watershed morphometry. The results of analysis of the watershed attributes show that the watershed has a moderate relief and less elongated shape. From the analysis of morphometric variables, we conclude that the watershed has low susceptibility to be flash flooded. The observed events at the region can be due to specific climate condition, land use and land cover of the watershed and/or urban flood vulnerability of the city. Deep analysis of those last is required for better understanding flood phenomenon in this arid area.

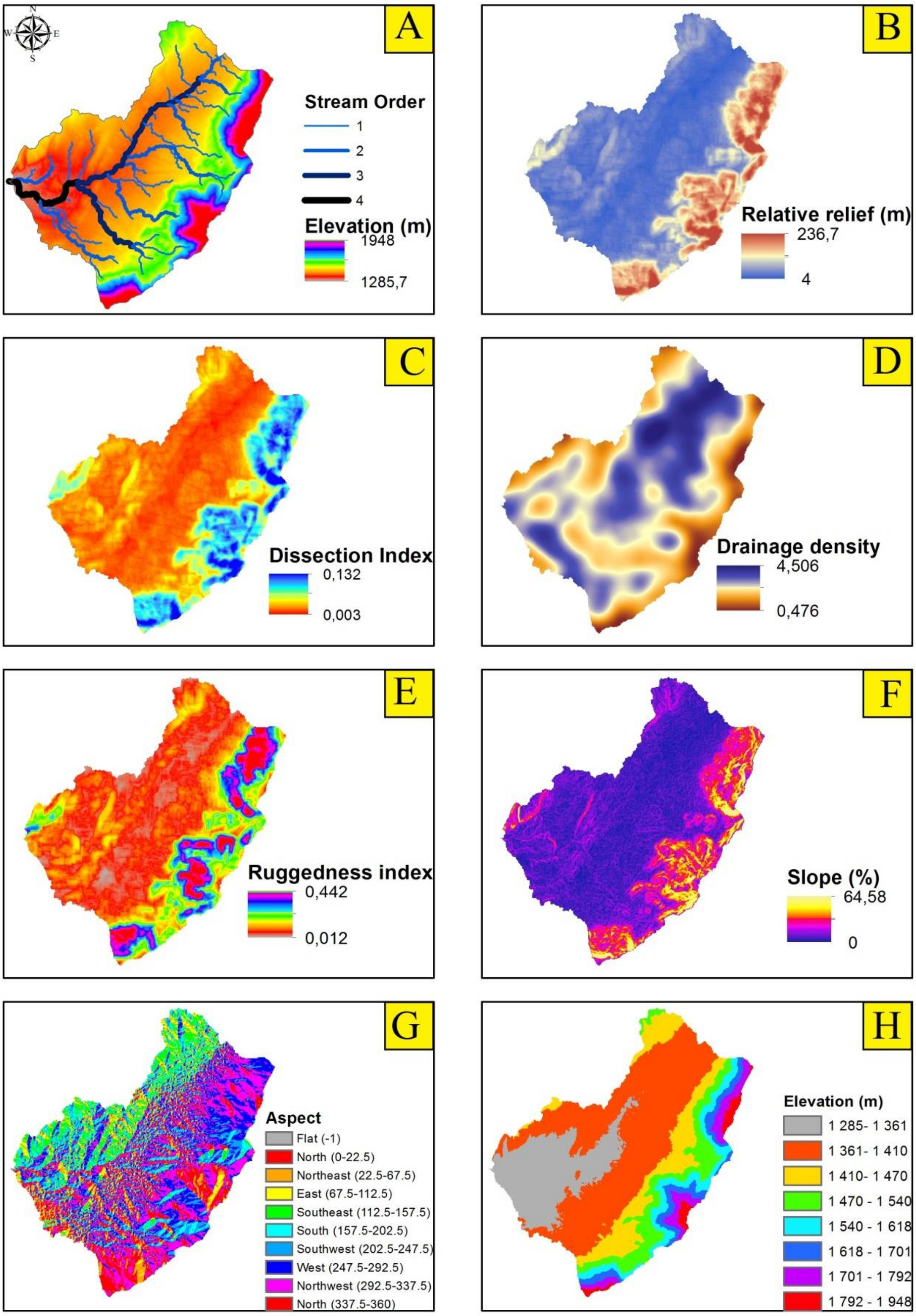

Figure 2: Stream order (2A), relative relief (2B), dissection index (2C), drainage density (2D), Ruggedness index (2E), slope map (2F), aspect map (2G) and elevation map generated from SRTM DEM.

Table 3: morphometric parameters of wadi Deffa watershed

	Relief aspect		
	Formula	Reference	Result
Bh-Bassin relief	$Bh = h_{max} - h_{min}$	Schumm (1956)	662.3
Rr-Relief Ratio	$Rr = Bh / L$	Schumm (1956)	0.040
Ri-Ruggedness index	$Ri = Bh \times Dd$	Melton (1958)	0.61
Di-Dissection index	$Di = Bh / h_{max}$	Schumm (1956)	0.34
Slope map	-	ArcGIS	Figure 2
Aspect map	-	ArcGIS	Figure 2

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