International Journal of Academic Research and Development
ISSN: 2455-4197; Impact Factor: RJIF 5.22
Received: 20-10-2020; Accepted: 05-11-2020; Published: 22-11-2020
www.academicjournal.in
Volume 5; Issue 6; 2020; Page No. 62-66

Morphometric analysis of Harirod river basin, Afghanistan based on GIS

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Abstract
Harirod river basin is one of the fifth main river basin in Afghanistan that is located in western part of the country and covering around 35,695 sq. km area. This river has 2,405 km perimeter and originate from Baba mountains, flow in west direct through Daykundi and Herat province about 612 km to pass the Iran border. Morphometric analysis is carried out for the basin using ASTER DEM data and by means of geo-processing tools in GIS. Twenty-three different morphometric parameters of the river basin are analyzed in the study. Bifurcation ratio for the Harirod river basin is around 4.42 which illustrate strong structure disturbance by the drainage. The Rho value for Harirod River basin is 0.54 that indicate higher hydrologic storage during the floods and reduction of effects of erosion during higher discharges. The value of stream frequency is 0.11, while the value of drainage density is around 0.51, both of these parameter has low values and indicate that the Harirod River basin has permeable sub surface material, dense vegetative cover and low relief. While infiltration number for this river basin is 0.11, illustrates that, the study area has permeable surface as displayed by stream density and stream frequency.

Keywords: Harirod, province, morphometric, frequency

1. Introduction
Afghanistan is a landlocked country and has a very important economic position among the Asian countries, nearly four decades of war have hampered the country's development. Despite working in a variety of sectors in Afghanistan over the past 20 years, the country is still lagging behind neighbors in terms of access to public services such as; access to education, quality health care, reliable security, investor safety, unemployment and so on are significantly lower. The country, which covers an area of about 650,000 sq. km, has sufficient resources of surface water. Agriculture and livestock are an important part of the country's economy. There are five major river basins: Helmand, Amu Darya, Kabul, North and Harirod. Much of the water still flows from these rivers to the Congolese countries each year, but unfortunately the country still does not have the capacity to fully manage and utilize water. This study coverers Harirod river basin, one of the fifth most important basin in Afghanistan, and analyze important morphometric parameters that play an important role in the management of a river basin.

Study Area
Harirod River is one of the most important river basin in Afghanistan selected for the study. This river originates from the Baba mountains in Bamyan and flow to the west direction through Daykundi and Herat provinces around 612 km and cross the border in Kohestan district to Iran. This river basin located between latitudes of 34°55'24.186 and 33°40'20.465"N and longitudes of 66°45'39.929 to 61°2'19.832"E. generally the river rain/snow feed, but rain is the main source of water at low altitude of the catchment, moreover, this river basin that cover the area about 35,695 sq. km and has 2405 km perimeter as shown in figure 1. Recently a dam by name Salmah has been constructed on this river which has the capacity to store around 640 Mm^3 of water, and 42 Mw electricity production. Moreover, an irrigation system is designed on the river to provide water for about 75,000-hectares agriculture land in Herat province.

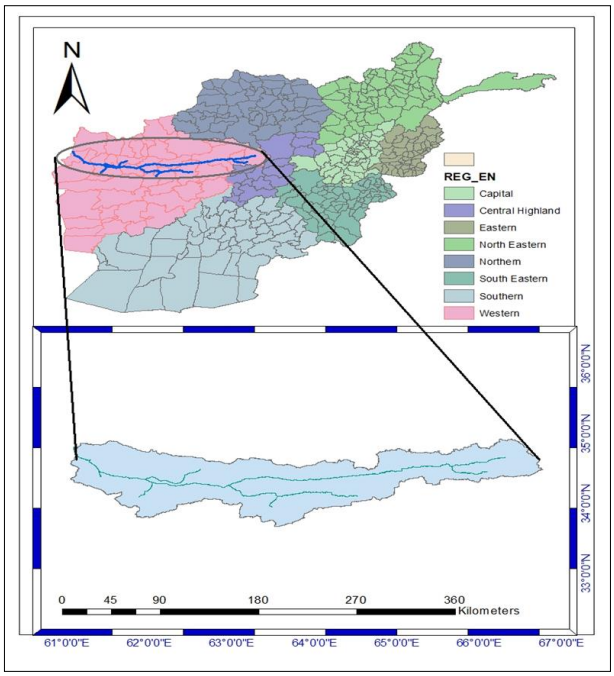

Fig 1: Study area watershed

Materials and Methods
Advanced space born Thermal Emission and Reflection Radiometer (ASTER) (DEM) of 30-meter resolution images are used for the morphometric analysis of this river basin. DEM is a generic term for the digital cartographic representation of the elevation of the land at regularly spaced intervals in x, y and z direction. Arc-GIS 10.2 has been used for the various morphometric quantity of the Harirod river which is located in the western part of Afghanistan. For the entire watershed about 16 DEM

images are mosaicked and spatial analysis tool is used to evaluate morphometric parameters of the basin. Filling of the DEM images, flow direction and flow accumulation are the first process that needed to done in order to extract the drainage network of the study area. Moreover, 2,500 thresholds were applied for extraction of stream network while, for classification of stream order Strahler's method has been used in this research. All the parameters and their mathematical expressions are shown in the Table 1 used in the study.

Table 1: Morphometic parameters, Mathematic relationship and references

SN	Morphometric Parameters	Mathematical Relationship	References
1	Stream number(Nu)	$Nu = N1 + N2 + \cdots Nu$	Horton* (1945)
2	Stream length (Lu)	Lu= L1+L2+….+Ln	Horton* (1945)
3	Mean stream length (Lsm)	$Lsm = Lu/Nu$	Strahler* (1964)
4	Drainage density (Dd)	$Dd = Lu/A$	Horton*(1945)
5	Stream length ratio (RL)	$RL = Lu/Lu - 1$	Horton*(1945)
6	Bifurcation ration (Rb)	$Rb = Nu/Nu + 1$	Schumm* (1956)
7	Stream density(Fs)	$Fs = \sum Nu/A$	Horton*(1945)
8	Total basin Relief (R), m	$R = H - h$	Strahler*(1952)
9	Form factor (Ff)	$Ff = A/L^2$	Horton* (1945)
10	Circularity ratio (Rc)	$Rc = 4\pi A/P^2$	Strahler* (1964)
11	Elongation ratio (Re)	$Re = D/L$	Schumm*(1956)
12	Rho coefficient (ρ)	$\rho = Lur/Rb$	Horton*(1945)
13	Lemniscate (K)	$K = L\hat{}2/(4 * A)$	Chorley* (1957)
14	Fitness ratio(Rf)	$Rf = CI/P$	Melton* (1957)
15	Drainage texture(Dt)	$Dt = Nu/P$	Horton* (1945)
16	Infiltration number(If)	$If = Fs * Dd$	Faniran* (1968)
17	Mean basin width(Wb)	$Wb = A/L$	Horton* (1945)

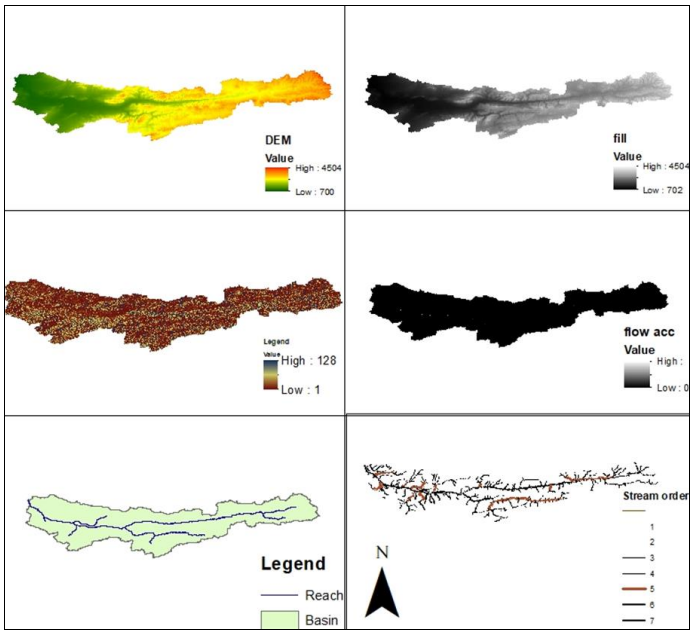

Fig 2: Stream order and Watershad dilieation process in GIS

Liner Aspects of Drainage Basin

Liner aspect for the study area consists of stream order, stream number, stream length, mean stream length, mean stream length ratio and bifurcation ratio.

Stream order

Based on hierarchic ranking of stream order proposed by Strahler (1964) [8] it is the first step of drainage basin analysis. The smallest stream that doesn't have any branch is generally called first stream order. The second order has at least two first order tributary, while it is needed to join two second order streams to form a third order and so on. For Harirod river basin the stream order ranges from 1 to 7. Generally, the first order segments are too high and slightly decrease as order increase and finally the highest order is only one segment. Different orders of streams in different sub-watersheds of Harirod river basin have been presented in Table 2.

Stream number

The number of stream segment in each order known as stream number. The stream numbers of Harirod river basin given in Table 2. It can be seen that the number of streams decreases with increase in the order of the stream. First order has around 4,045 stream while seventh order has only one stream.

Stream length

It is the total length of streams in a particular order. The numbers of streams of various orders of the watershed were

estimated and their value is given in Table 2. This parameter gives the figures of drainage texture and slope of the basin. As it seems that by increasing the stream order the length of stream decreasing.

Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of the stream segments of given order 'Nu' to the number of streams in the next higher order (Nu+1), Table 1. It is a dimensionless property range from 3 to 5 and shows the degree of integration prevailing between streams of various orders in a drainage basin. Strahler (1957) demonstrated that bifurcation shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. Less structure disturbance and strong drainage pattern has the area which having small value of Rb (Strahler 1964). [8] Present study, indicates that the Harirod river basin has higher values of Rb that illustrate comparatively strong structural disturbance.

Table 2: Linear parameter of the Harirod river basin

SN	Harirod river basin							
1	Stream Order	1	2	3	4	5	6	7
2	Stream Number	5,045	1,128	241	52	14	2.00	1.00
3	Stream Length	11,160	5,649	2,357	957	514	338.00	251.00
4	Mean Stream Length Km	2.21	5.01	9.78	18.40	36.71	169.00	251.00
5	Stream Length Ratio		2.26	1.95	1.88	1.99	4.60	1.50
6	Bifurcation Ratio		4.47	4.68	4.63	3.71	7.00	2.00

Areal Aspects of Drainage Basin

Basin Area and perimeter

Both of this important parameter are calculated by Arc-SWAT based on these two, some other features of the basin such as elongation ratio, form factor, circularity ratio etc. are evaluated. Area and perimeter of the Harirod basin are 35,695 km2 and 2,408 km respectively.

Basin Length

The basin length of the Harirod River is around 612 km, it is the length stream from the outlet of the basin to the remotest point of the basin where first order is just started.

Basin Width

The width of the Harirod river basin is about 58.33, is the ratio of the basin area to the length of basin, W= A/Lb.

Lemniscate

The Lemniscate value (K) (Charley, 1957) is used to determine the slope of basin. $K=Lb^2/4*A$. The K value for the Harirod river watershed is 2.62 Table 3.

Form Factor

Form factor proposed by Horton (1945) to predict the flow intensity of a basin of a defined area and is defined as the ratio of basin area to the square of the basin length. Generally, Form Factor (Ff) has the value range from 0.1 to 0.8, smaller value of this parameter indicates more elongated shape of the basin while higher value indicates its tendency to be a circular (Aher *et al*., 2014). Form factor for the study area is about 0.10, indicates the watershed is relatively elongated and will have flatter peak flow over lengthy time.

Compactness Coefficient

It is ratio between the perimeter of the watershed and the perimeter of the circle that has the same area as watershed. Generally, compactness coefficient is used to remark the relationship of a hydrological basin with that of a circular basin having the same area as the hydrological basin (Javed *et al*., 2009).[3] So higher value of Cc indicates the long watersheds with smaller floods, while low value illustrates high peak flood with short duration. The value of Cc for the study area is 3.59 and show long basin and smaller flood.

Circularity Ratio

The 'Rc' is influenced more by the lithological characteristics of the basin rather than anything else. (Miller 1953) stated that circularity ratio is the ratio of the area of the basin to the area of circle whose circumference is equal to that of perimeter of the basin. The circularity ratio (Rc) for Harirod basin is 0.08 and shown less circular shape moreover, it is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin (Vittala *et al*., 2004).

Elongation Ratio

Elongation ratio (Re) is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length (Schumm 1956). It is used evaluate the shape of the river basin, climatic and geologic types are the factors that has influence on the value. Generally, the values of elongation ratio are varying from 0.6 to 1.0 for most of the basins, and can be grouped into three categories circular (>0.9), less elongated (0.9–0.8) and elongated (<0.7) (Javed *et al*., 2009). [3] Elongation ratios for Harirod river entire watershed is 0.35 which indicate that the watershed is elongated Table 3.

RHO coefficient

Horton 1945 defined this parameter as the ratio between the stream length ratio and bifurcation and stated that by calculating this value one could estimate how much water will be lost as runoff during flood period and also determine the amount of water which could be stored in a basin showing the drainage capacity of a basin. The Rho value for Harirod river entire watershed is 0.54 Table 3. These indicate higher hydrologic storage during the floods and reduction of effects of erosion during higher discharges.

Stream frequency

According to Horton (1945), stream frequency (Fs) is defined as the ratio of the total number of stream of all the orders in the basin to the total area of the basin.

Stream frequency that having low values represents low relief and permeable sub surface material while, watersheds with higher values of stream frequency indicate resistant/low conducting subsurface material, sparse vegetation and high relief (Javed *et al.*, 2009).[3] For Harirod river basin stream density is 0.18 Table3.

Drainage Density

Strahler 1964[8] define the drainage density as the total length of the stream in a basin to the total area of the basin, is one of the important indicators of the landform element and provides a numerical measurement of landscape dissection and runoff potential (Chorley 1969).[2] It used to indicate the climate and geologic types of the area. Generally low drainage density occurs in the area that having resistant and high permeable subsoil material dense vegetative cover and low relief. While high drainage density is the resultant of weak or impermeable subsurface material, thin vegetation and mountainous relief (Grohmann *et al.*, 2004). Drainage density for Harirod river basin is 0.59 which indicate this basin has vegetative cover and permeable subsoil material Table 3.

Drainage Texture

Drainage texture is an important geomorphic concept which defines the relative capacity of drainage line, the ratio of stream number of all order of basin to the perimeter of that basin Horton (1945). According to (Smith 1950) many parameters like soil type, infiltration capacity has a bearing on drainage texture. He has classified drainage texture in to five different textures such as, very coarse less than 2, coarse from 2 to 4, moderate from 4 to 6, fine from 6 to 8, and very fine >8. For Harirod river entire watershed the drainage texture is about 2.7 this indicates that, the Harirod river basin has generally coarse drainage texture Table 3.

Infiltration Number

Infiltration number is an important parameter that give idea about the infiltration capacity of a surface high value of infiltration number indicates lower infiltration capacity and higher runoff while, low value of the infiltration indicates high infiltration capacity and low runoff (Pareta *et al.*, 2011). The infiltration number is the multiplication of drainage density and stream frequency If = Dd*Sf. The infiltration number for Harirod basin is around 0.11 that illustrate low runoff and high infiltration capacity Table 3.

Relief

Basin relief is the difference between maximum and minimum point of the entire basin, and it has the effect on the channel slope which controls the flood pattern and the amount of sediments which get transported. Relief for the Harirod river basin is about 3,804m (Table 3).

Slope Aspect of Drainage Basin

Slope

The slope of a terrain refers to the amount of inclination of physical feature, topographic landform to the horizontal surface. It is one of the most important and specific feature of the earth's surface form moreover, the amount of sediment that are transport from a basin is depend on the slope of the that basin. Soil erosion and flow line of surface water are influenced by slope of that area.

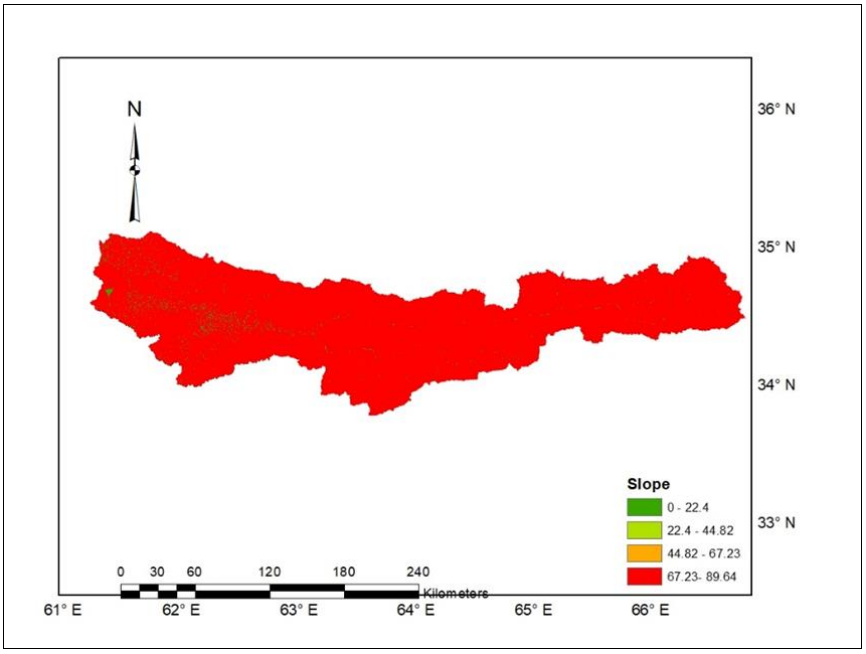

Fig 1: Slope map of the study area

Aspect

The aspect of a terrain is the direction to which it faces. Aspect of the basin is very important parameter as it has influences on local climate condition, vegetation type, precipitation patterns, snow melt and wind exposure.

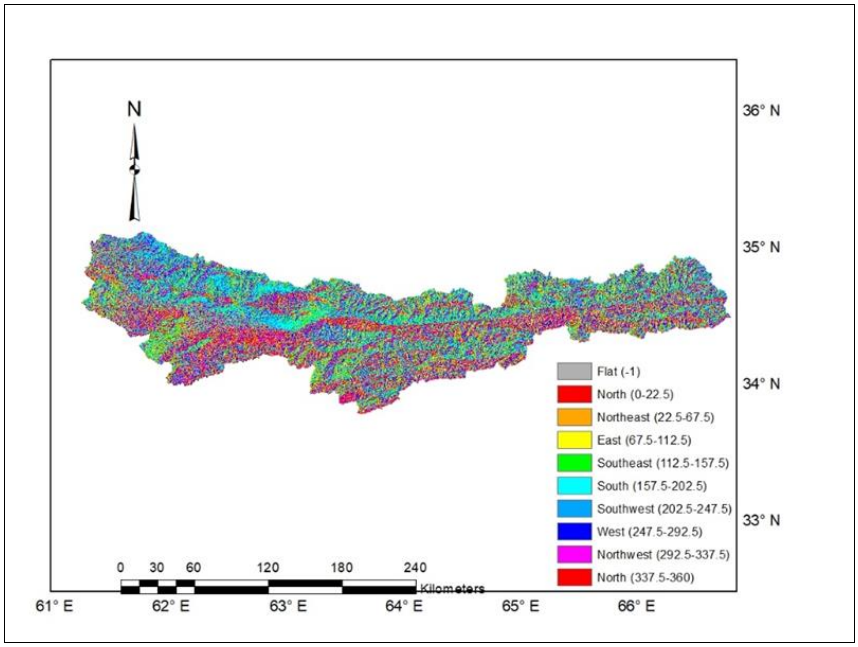

Fig 4: Aspect map of the study area

Table 1: Areal parameters of the Harirod river basin

Harirod watershed		
No	**Parameters**	**For the entire basin**
1	Area A Sq. km	35695
2	Perimeter P km	2405
3	Basin Length L km	612
4	F factor	0.10
5	Shape factor	10.49
6	Compactness R	3.59
7	Circulatory R	0.08
8	Elongation R	0.35
9	Stream density	0.18
10	Drainage density	0.59
11	RHO coefficient	0.54
12	Lemniscate K	2.62
13	Fitness Ratio	0.25
14	Drainage Texture	2.70
15	Infiltration number	0.11
16	Basin width	58.33
17	Relief	3804

Conclusion

Generally, configuration and physical characteristics of the basin is established by morphometric analysis, in this study around 23 different morphometric parameters of the Harirod river basin has analysis by GIS. Bifurcation ratio for the Harirod river basin is around 4.42 which illustrate strong structure disturbance by the drainage. It has evaluated that the average Rho coefficient for this river basin is about 0.54 is an important parameter of a basin which facilitate evaluation of storage capacity of drainage network. The Rho value for Harirod river basin is 0.54 as shown in, Table 3, indicates higher hydrologic storage during the floods and reduction of effects of erosion during higher discharges. The value of stream frequency is 0.11, while the value of drainage density is around 0.51, both of the parameters has low values and indicate that the Harirod river basin has permeable sub surface material, dense vegetative cover and low relief. Infiltration number gives an idea about the infiltration characteristics of the basin. Low infiltration number indication high infiltration capacity and low runoff, Infiltration number for the Harirod river basin is 0.11. It illustrates that the study area has permeable surface as displayed by stream density and stream frequency.

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