Morphometric analysis based on GIS-approach for Major Sub-Watershed in upper Helmand River Basin, Afghanistan

Khan Mohammad Takal, Jyoti Sarup, Sushail Kumar Mittal

Abstract— the present study revealed the morphometric analysis for the Upper-Helmand river basin of Afghanistan. Basin- is further sub-divided into five sub-watersheds, namely SW - I, SW - II, SW - III, SW - IV and SW – V. ASTER DEM data has been used in Arc-GIS for carrying out morphometric analysis, stream order (U) and its correlation with other characteristics are obtained. Stream order for all the sub-watersheds is varying between 5 to 8 which shows drainage pattern as a dendritic to sub-dendritic pattern. The mean bifurcation ratio ranges 4.117 to 5.888 that shows sub-basins are under normal condition and high bifurcation ratio illustrate high control of drainage structure. The mean bifurcation ratio of the whole basin is 4.230, which depict that geological structures are not influenced the drainage pattern. Drainage density exhibits coarse drainage and texture exhibit fine drainage texture. Sub-watersheds elongation ratio is 0.44 to 0.496 that shows elongation pattern. The most suitable software in the present study for watershed delineation, using ASTER DEM data is Arc-GIS.

Key Words—Morphometric Analysis, Arc-GIS, Sub-watersheds, Upper Helmand, ASTER, DEM, SW.

1 Introduction

Mathematical analysis and measurement of the configuration of the earth's surface, shape and dimension of its landforms is called as morphometric analysis[1]. Watershed morphometric characteristics cover important information regarding its formation and development because all geomorphic and hydrologic processes occur within the watershed [21]. Quantitative description of the drainage system is provided by morphometric analysis of a watershed, which is a significant aspects of the watershed characterization [25]. Morphometric analysis of watershed can provide a quantitative information about the watershed rocks exposed of hydrological nature. The reliable index of permeability of rocks and their relationship between types of rock, hydrology status and their structure is provided by drainage map. Characterization of watershed and management, requires detail information of topography, drainage network, water divide, channel length, geomorphologic and geological setup measures [23]. To understand the hydrological system of the basin The ASTER data was utilized, that has given a reliable and suitable result [2] [12] [27]. Potent software which are used now a days for measuring different morphometric parameters is Arc-GIS. The object of the present study is to know the major sub-watersheds morphometric characteristics of Upper-Helmand river basin, in Afghanistan.

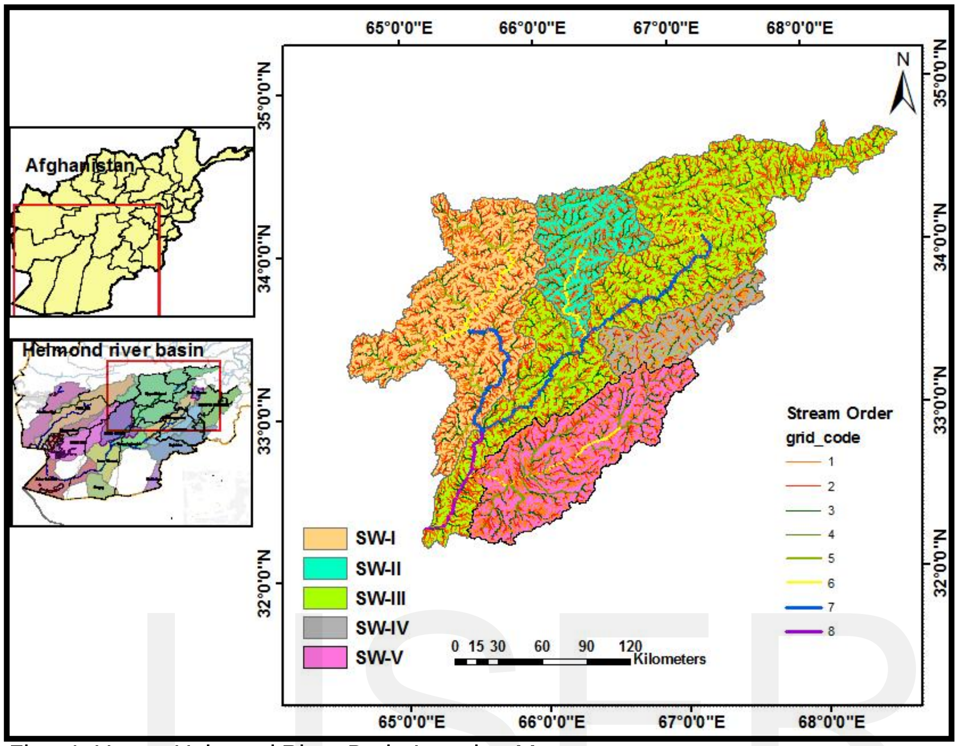
2 Study Area:

The upper-Helmand River basin is located between latitudes 32.254 to 34.653 N and longtitude 65.092 to 68.687 E, from 968 m to 5036 m high from mean sea level, correspondingly with area of 46,793 Km2 (Figure 1). The Upper-Helmand river basin area is embodied by large hills, burried pediments, valleis and alluvial plains. The soil textures is silty clay, sandy, loamy and alluvium. The upper-Helmand river basin originate in a westerly extension of the Hindu Kush mountain range near Paghman about 40 kilometers west of Kabul and runs southwesterly for about 590 kilometers to the reservoir of Kajaki dam. The river water comes mostly from rainfall at the average elevations of the basin in winter and spring season and from melting snows in the high altitude of mountains which escalate to elevations of 5036 meters. Range of Annual precipitations varies between 100mm to 670mm and precipitate mostly at higher altitudes during winter and spring [4]. The mountains cause many local variations, though the upper-Helmand river basin is categorized by a dry continental climate. The temperatures of this rigions is varing from minus (-) 10 °C in winter to plus (+) 34 °C in summer. The fluctuations in temperature are not uniform in character over the whole basin.

The catchment is very important in the context of serving intersectorial demands including drinking, irrigation and hydropower generation. There is one major reservoir exist in the drainage basin with storage capacity of 1,844 Mm3 at the current spillway elevation [14].

3 Methodology, delineation of drainage maps and Database Preparation:

The study area drainage map (Fiure-1) is extracted from ASTER DEM data. The data with 30m resolution available on (http://earthexplorer.usgs.gov/), this data has been analyzed in Arc-GIS 10.3 for preparing, slope map, Aspect map, drainage network and the delineation of watershed boundary from main river joining. For best management, the study area is further sub-divided into five watersheds, namely SW-I, SW-II, SW-III, SW-IV, and SW-V. Strahler's method was used to classify all the sub-watersheds perimeters and the drainage order. Morphometric parameters and formulae used for are tabulated in Table 1 to study the drainage characteristics different morphometric parameters were used.



Figur1. Upper-Helmand River Basin Location Map

Table.1 Morphometric parameters

SN	Parameters	Formula	References
1	Stream order (U)	Hierarchical rank	[25]
2	Stream Number (Nu)	Number of streams	[25]
3	Stream length(Lu)	Length of stream	[7]
4	Mean stream length (Lsm)	Lsm = Lu / Nu	[25]
5	Stream length ratio (RL)	RL = Lu / Lu – 1	[7]
6	Bifurcation ratio (Rb)	Rb = Nu / Nu + 1	[19]
7	Mean bifurcation ratio (Rbm)	Rbm=average of bifurcation ratios of all order	[26]
8	Drainage density (Dd)	Dd=Lu / A	[7]
9	Drainage texture (T)	T=Dd x Fs	[22]
10	Stream frequency (Fs)	Fs=Nu / A	[7]
11	Elongation ratio (Re)	Re=D / L	[19]
12	Circularity ratio (Rc)	Rc = 4ΠA / P2	[25]
13	Form factor (Ff)	Ff =A / L2	[7]
14	Relief (R)	R=H / h	[6]

3.1 The basin watershed automatic extraction by the required systematic process: figure. 2.

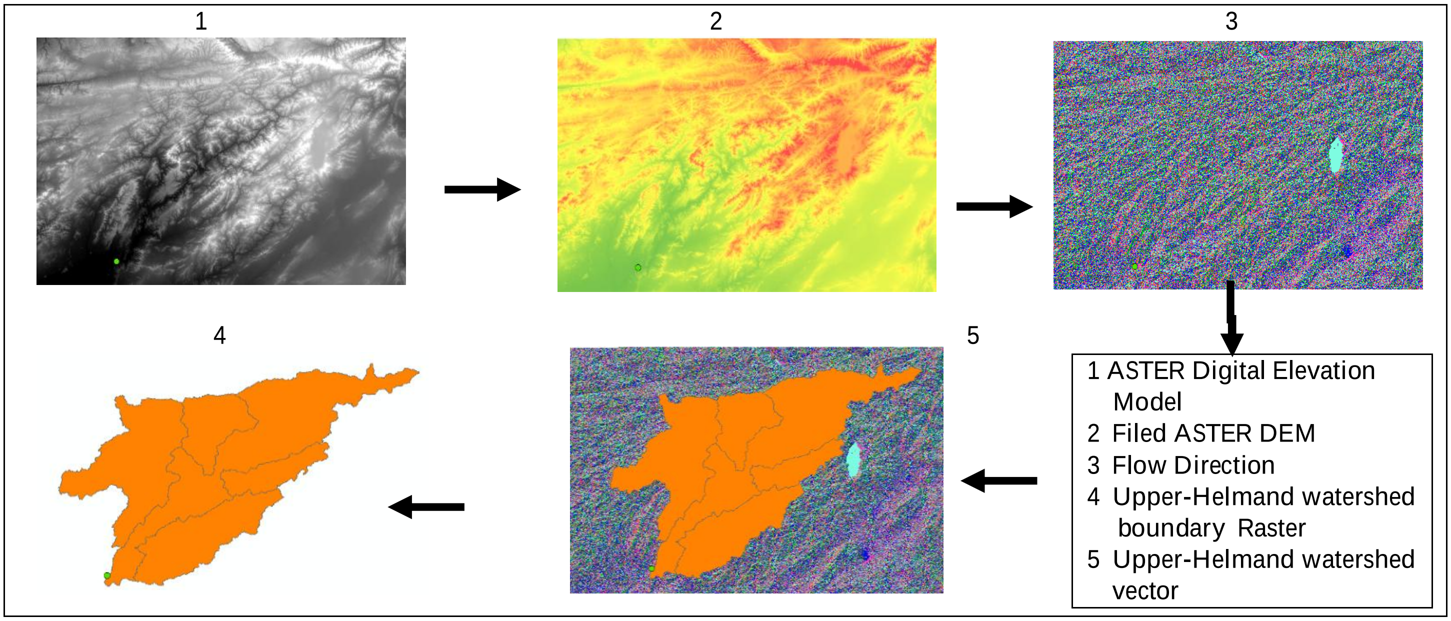


Figure. 2

3.2 Automatic Extraction of drainage network:

Upper-Helmand river basin drainage network is extracted from geo-processing tools in ARC GIS. Creating stream order based on Strahler AN, 1964 method, this method output is basis for making a stream / drainage network grid. Stream order with no tributaries is called as a first-order stream. Link of two first-order stream segments form a second-order stream segment and so on. Upper-Helmand river basin highest stream order is carried out as eight. Two technique are required for input model parameters: Minimum upstream area in hectares and a Digital Elevation Model, which is the minimum drainage area required to create a stream segment [10]. Smooth line tool in ArcGIS-10.3 is used for the output of the drainage network (Figure. 3). Morphometric evaluation of the drainage basin, such as stream order, stream number,stream length, bifurcation ratio, stream length ratio, basin length, basin area, elongation ratio, relief ratio, stream frequency, drainage density, circulatory ratio, form factor and etc., have been evaluated, in Table.1 all mathematical standard formulae are listed. Also, the slope and aspect map of the study area are extracted from the ASTER DEM by ArcGIS-10.3 spatial analyst module (Figure. 4).

4 RESULT AND DISCUSSION:

The drainage area of all five sub-watershed totally cover an area Of 46,793 km2, which the drainage pattern looks like dendritic to to Subdendritic. While, geology, general topography and rainfall Characteristics of the area are influenced by the drainage pattern. Aspect, slope and contour map are prepared by Arc-GIS 10.3 utilizing ASTER DEM data. Various morphometric parameters of the Upper-Helmand river basin are calculated and shown in Table. 2.

4.1 Slope and Aspect:

Aspect denotes the direction of mountain slope face side. Output raster data values are set signify the compass direction of the aspect (Figure.4). Slope and aspect maps are very important for climate and temperature of the area. The study area vegetation can be influenced by aspect [12]. Slope is a significant parameter for geomorphic studies of a basin. slope distribution map helps in planning for deferent aspects such as, agriculture, settlement, planning of engineering structures.

4.2 Linear Aspect of the Drainage Basin:

4.2.1 Stream order (U):

For watershed delineation stream order is the first measureable analysis. Streams order ranking of the present study has been carried out based on the method suggested by Miller 1953[10]. The Upper-Helmand basin stream orders are classified into eight orders. Details of linear, aerial and relief parameters of upper-Helmand sub-watersheds are stated in Table 2-a. Upper-Helmand river basin could be labeled as an eight-order stream (Figure.3). First stream order is observed as a maximum stream order and then for second order. Therefore, it has be noticed that there is an increases in stream order as the stream frequency decreases and vice versa.

4.2.2 Stream Number (Nu):

Stream number is the total count of streams segment of perspective stream order. The numbers of stream segments of each order makes an inverse geometric series with order number [10], Table 2-a.

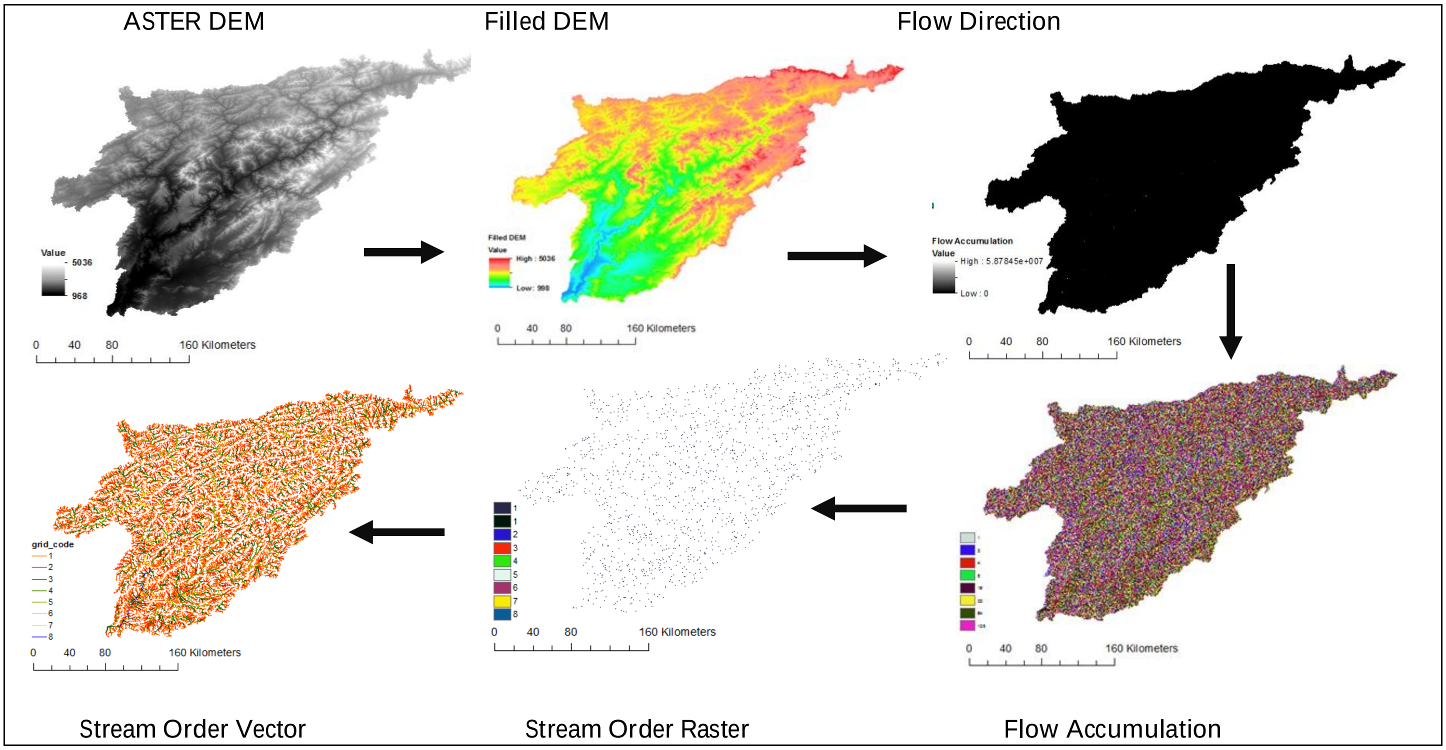


Figure. 3

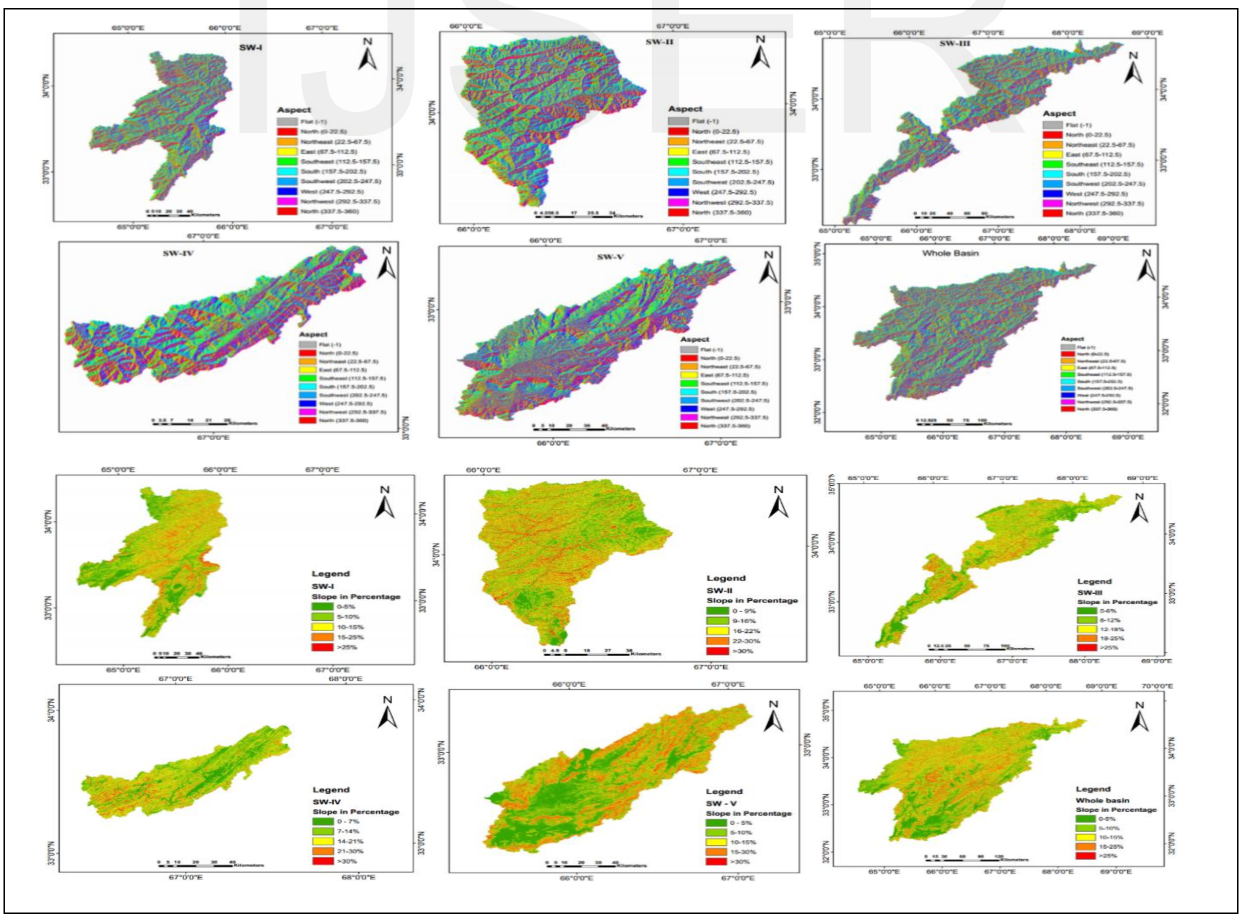


Figure.4

4.2.3 Stream length (Lu):

Each of the successive order streams length delineate the total length of stream segment of in a basin tend to speculate a direct geometric sequences in which the average length of the first term is of the stream of the first order [7]. Measure of the stream length is hydrological characteristics of the bedrock and the drainage extent. Anyway, the bedrock and formation is permeable, when only a small number of relatively longer streams are formed in a well-drained watershed, a large number of streams of smaller length are developed where the bedrocks and formations are less permeable [29]. All order stream length in upper-Helmand river basin is presented in Table. 2-a. It is obviously notified that the stream order is decreasing the cumulative stream length is increasing so first order is higher. Various order stream length under sub-watersheds of upper-Helmand river basin is shown in Table. 2-a.

4.2.4 Mean Stream Length (Lsm):

The characteristic size of components of a drainage network and its contributing surfaces are revealed by mean stream length (Lu) [29]. It is the ratio of the total stream length of order 'U' to the number of stream segments in the order Table 2-a.

4.2.5 Stream Length Ratio (RL):

The length ratio is obtained by the ratio order streams segments length to next lower order streams length [7]. As per Horton 1945 suggest of stream lengths that the stream lengths of stream segments of each of the sequential orders of a watershed partiality to speculate a direct geometric sequence in which the first term stream length is the average length of segments of the first order Table 2-a. Their late youth stage of geomorphic change specified by changes of stream length ratio from one order to another order [24].

4.2.6 Bifurcation Ratio (Rb)

The ratio of the number of streams of any given order to the number of streams in next higher order is expressed by Bifurcation ratio [19]. Its ratios typically range 3.0 to 5.0, for those basins in which drainage pattern are not distorted by the geologic structure [24]. Bifurcation ratio state that a small range of changes for different regions [25]. Upper-Helmand basin mean bifurcation ratio value is 4.230 for (Table 2-a). That shows the geological structures are moderate disturbing the drainage pattern.

4.3 Areal Aspect of the Drainage Basin:

The significant parameters in quantitative morphology are area of a basin (A) and perimeter (P). All the order of basins are cumulated upon horizontal plan of the area. Length of the basin boundary which can be draw from topography map is called perimeter. Hydrological-lay most important perimeter is basin area because storm hydrograph, magnitudes of peak and mean runoff are effected directly from it. Drainage basin aerial aspect like drainage density, stream frequency, elongation ratio, circularity ratio, form factor ratio are estimated and the results are shown in Table 2-b.

4.3.1 Drainage Density (Dd):

Total length of stream channels per unit area in the watershed is denoted by drainage density [7]. Lithology beneath the basin area organize and control the drainage density. Basin topography fineness is computed by drainage density. Drainage density is one of the essential parameter in quantitative geomorphology. Drainage density is function of other parameters include, aspect, slope, relief, nature of drainage, and shape of the basin. High drainage density is function of higher relief and steep slope. Hence, generally, mountainous regions will have a high drainage density values. High precipitation and runoff volume are create high drainage density values [26]. Thus, the area with high drainage density value is more incidental for flooding. In permeable basins with high infiltration rates drainage is nearly zero. The drainage density low value shows relatively long flow of surface water. Generally drainage density can be classify as a poor, medium and excellent Table. 4. The result show that the Upper-Helmand basin is having a moderate drainage density and soil erosion chance is in the basin area. It is computing by the formula $\sum L\mu / A\mu$ and the values are given in Table. 2-b.

Table 4. Deju's Drainage Density Classification

Density	Range in km
Poor	0.5
Medium	0.5-1.5
Excellent	1.5

4.3.2 Stream Frequency (Fs)

The ratio between total number of stream segments of all orders and unit area is denoted by stream frequency [25]. It is calculated by the formula of $F = N\mu / A\mu$= Number of streams / Area of the Basin. Stream frequency result value of the study area is varying from 0.327 to 0.382. Table.2-b

4.3.3 Elongation Ratio (Re)

Elongation ratio states the shape of any basin. It is the ratio between of diameter of a circle having same perimeter to the maximum length of the basin [19]. Elongation ratio control the dis charge characteristics of any watershed. The study area elongation ratio resulted values are varying between 0.44-0.496 Table 2-b.

4.3.2 Circulatory ratio (Rc):

Circulatory is the ratio between basin area and the area of the circle which having the same perimeter as that of the basin area [10]. Watershed discharge is controlled by circulatory ratio. Upper-Helmand basin sub-watershed circulatory ratio range 0.100 to 0.381 Table.2-b.

4.3.3 Form Factor (Ff)

It is a dimensionless ratio of basin area to the square length of basin (Area of the basin /Square length of the basin) [7]. If the value of form factor is larger, basin shape will be a circular form. If the form factor is smaller than the basin will have an elongated form. Form factor of the upper- Helmand basin range from 0.170 to 0.193. Hence, all sub basins have the elongated form Table. 2-b.

Table.2-a Linear Parameters

No	Parameter	SW-I						
1	Stream order (U)	I	II	III	IV	V	VI	VII
2	Stream Number (Nu)	3699	415	107	24	7	2	1
	Stream length(Lu) in Km	3573	1686	838	298	223	161	143
4	Mean stream length (Lsm) in Km	0.97	4.06	7.83	12.4	31.8	80.6	143
5	Stream length ratio (RL)	0.47	0.5	0.36	0.75	0.72	0.89	
6	Bifurcation ratio (Rb)		8.91	3.88	4.46	3.43	3.5	2

No	Parameter	SW-II					
1	Stream order (U)	I	II	III	IV	V	VI
2	Stream Number (Nu)	1,334	178	35	5.00	2.00	1.00
	Stream length(Lu) in Km	1438.8	640.4	379.2	107.1	58.30	107.10
4	Mean stream length (Lsm) in Km	1.079	3.598	10.83	21.41	29.17	107.11
5	Stream length ratio (RL)	0.45	0.59	0.28	0.46	1.84	
6	Bifurcation ratio (Rb)		7.494	5.09	7.00	2.50	2.00

No	Parameter	SW-III							
1	Stream order (U)	I	II	III	IV	V	VI	VII	VIII
2	Stream Number (Nu)	6193	769	184	37	9	2	1	1
3	Stream length(Lu) in Km	5883	2639	1422	525	251	95	283	100
4	Mean stream length (Lsm) in Km	0.95	3.43	7.73	14.18	27.86	47.43	283.11	100
5	Stream length ratio (RL)	0.45	0.54	0.37	0.48	0.38	2.99	0.35	
6	Bifurcation ratio (Rb)		8.05	4.18	4.97	4.11	4.50	2.00	1

No	Parameter	SW-IV				
1	Stream order (U)	I	II	III	IV	V
2	Stream Number (Nu)	1004	142	30	8	1
3	Stream length(Lu) in Km	1041.65	463.15	244.21	82.61	139.11
4	Mean stream length (Lsm) in Km	1.034	3.26	8.140	10.33	139.11
5	Stream length ratio (RL)	0.45	0.53	0.34	1.68	
6	Bifurcation ratio (Rb)		7.07	4.73	3.75	8.00

No	Parameter	Whole Basin							
1	Stream order (U)	I	II	III	IV	V	VI	VII	VIII
2	Stream Number (Nu)	14719	1926	432	94	24	6	2	1
3	Stream length(Lu) in Km	14826	6793	3558	1376	784	506	427	100
4	Mean stream length (Lsm) in Km	1.01	3.53	8.24	14.64	32.65	84.40	213.44	100
5	Stream length ratio (RL)	0.458	0.52	0.39	0.570	0.65	0.84	0.234	
6	Bifurcation ratio (Rb)		7.64	4.46	4.60	3.92	4.00	3.00	2.00

No	Parameter	SW-V					
1	Stream order (U)	I	II	III	IV	V	VI
2	Stream Number (Nu)	2489	422	76	20	5	1
3	Stream length(Lu) in Km	2890	1365	675	363	113	143
4	Mean stream length (Lsm) in Km	1.161	3.24	8.88	18.15	22.50	143.18
5	Stream length ratio (RL)	0.47	0.49	0.538	0.31	1.27	
6	Bifurcation ratio (Rb)		5.90	5.55	3.80	4.00	5.00

Table. 2-b Areal and Relief Parameters

SN	Parameter	SW-I	SW-II	SW-III	SW-IV	SW-V	Whole Basin
1	Mean bifurcation ratio (Rbm)	4.36	4.82	4.12	5.89	4.85	4.23
2	Perimeter (P) in Km	892.23	395.59	1558.42	420.6	627.44	1762
3	Basin area in Km2	11,676.84	4748.27	18851.96	3266.87	8248.73	46793
4	Basin Length in Km(Schumm 1956)	268.02	160.77	351.83	130	220.01	589.65
5	Drainage density (Dd)	0.59	0.58	0.59	0.60	0.67	0.61
6	Stream frequency (Fs)	0.364	0.327	0.382	0.363	0.365	0.37
7	Elongation ratio (Re)	0.455	0.48	0.44	0.496	0.466	0.41
8	Circularity ratio (Rc)	0.18	0.38	0.10	0.23	0.26	0.19
9	Form factor (Ff)	0.16	0.18	0.15	0.19	0.17	0.14
10	Relief (R)	2883	2761	4068	3424	3053	4068

Table.3 Stream order relationship with other characteristics

SW	No	Characteristic	Developed Equation	R^2
SW-I	1	Stream Numbers	$Nu = -10.608x^5 + 244.13x^4 - 2173.5x^3 + 9343.6x^2 - 19415x + 15708$	0.9994
	2	Stream length	$Lu=4.0556x^4-100.71x^3+949.47x^2 4047.5x+6759.9$	0.9991
	3	Mean stream length in Km	$Lsm= 1.1732x^3 - 7.4714x^2 + 16.873x - 9.2436$	0.9979
	4	Bifurcation Ratio	$Rb=14.973x^{-0.941}$	0.8163
SW-II	1	Stream Numbers	$Nu = -6.275x^5 + 128.04x^4 - 1022.5x^3 + 4005.5x^2 - 7740.7x + 5970$	1
	2	Stream length	$Lu= -13.843x3 + 236.16x2 - 1322.4x + 2519.3$	0.9918
	3	Mean stream length in Km	$Lsm=0.5944e^{0.8557x}$	0.9722
	4	Bifurcation Ratio	$Rb=19.357x^{-1.158}$	0.695
SW-III	1	Stream Numbers	$Nu = 2.6306x^6 - 80.382x^5 + 992.88x^4 - 6336.9x^3 + 22042x^2 - 39751x + 29322$	0.9999
	2	Stream length	$Lu = 5.9872x^4 - 154.71x^3 + 1501.1x^2 -6532.1x+11014$	0.9965
	3	Mean stream length in Km	$Lsm=0.7108e^{0.7235x}$	0.9226
	4	Bifurcation Ratio	$Rb=14.096e^{-0.28x}$	0.7767
SW-IV	1	Stream Numbers	$Nu = 24.375x^4 - 353.75x^3 + 1888.1x^2 - 4415.8x+3861$	1
	2	Stream length	$Lu = -11.79x^3 + 200.92x^2 - 1065.7x + 1911.6$	0.995
	3	Mean stream length in Km	$Lsm= 5.6098x^4 - 56.989x^3 + 203.02x^2 -292.05x+141.45$	1
	4	Bifurcation Ratio	$Rb= y = 0.6466x^3 - 5.1425x^2 + 11.09x + 0.2876$	1
SW-V	1	Stream Numbers	$Nu = -8.025x^5 + 169.62x^4 - 1413.1x^3 + 5820.9x^2 - 11933x + 9853$	1
	2	Stream length	$Lu = -34.441x^3 + 531.94x^2 - 2792.6x + 5162.5$	1
	3	Mean stream length in Km	$Lsm= 1.1533x^5 - 17.658x^4 + 101.63x^3 - 270.32x^2 + 330.77x - 144.41$	0.997
	4	Bifurcation Ratio	$Rb= -0.188x^4 + 3.1922x^3 - 19.093x2 + 46.686x - 33.634$	1
Whole Basin	1	Stream Numbers	$Nu = y = -21.496x^5 + 557.25x^4 - 5565.1x^3 + 26684x^2 - 61371x+54401$	0.9984
	2	Stream length	$Lu = y = 16.913x^4 - 425.93x^3 + 4006.9x^2 - 16950x + 28101$	0.9985
	3	Mean stream length in Km	$Lsm= -0.2685x^6 + 6.4255x^5 - 59.966x^4 + 278.24x^3 - 668.77x^2+779.3x-334.07$	0.9988
	4	Bifurcation Ratio	$Rb=12.541x^{-0.764}$	0.84

4.3.4 Relief (R)

Difference in elevation between lowest and the highest point of a basin is defined as a relief [8]. Relief has an important use of effect on basin land-forms development, drainage characteristics, subsurface and surface water flow, erosional properties of the terrain and permeability. The total relief of SW-I, SW-II, SW-III, SW-IV and SW-V are 2883, 2761, 4068, 3424 and 3053 respectively. High gravity of water flow, low permeable and high runoff conditions are specified by the high relief value Table. 2-b.

5 CONCLUSION

For geo-morphometric analysis and arrangement of the sub-watersheds of upper-Helmand basin, use of Arc- GIS is an effective tool. The morphometric analysis of the upper-Helmand sub-watersheds and subsequent corroboration represent that, drainage patterns are dendritic to sub-dendritic with a moderate texture. All sub-watershed are in normal category because of a good stream bifurcation and stream length ratio. Moderate drainage density denote that the basin area is large and of low permeable sub-soil and moderate drainage texture. Stream frequency value result that, sub-basins are increasing stream population. All sub-watershed and as a whole watershed, the values of circulatory ratio and form factor represent as elongated basins. For water potentiality zone and erosion susceptibility of watershed study are analyzed by on mapping of hydromorphic units and their spatial distribution. The morphometric analysis result also represent that the all sub-basins have varying degrees of erosion intensity. So, for future erosion activities a proper soil erosion control measures are required for these sub-watersheds to prevent any further erosion activity

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