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Morphometric Analysis of Ghaghara River Basin, India, Using SRTM Data and GIS

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ABSTRACT

Morphometric analysis in the recent few years has derived attention in terms of its applicability in different aspects of geological and environmental perspectives. It provides an insight into the process driven changes such as drainage basin assessment, runoff, infiltration, basin evolution, natural and tectonic framework etc. The study of the Ghaghara River fluvial dynamics in a gentle sloping region and alluvial terrain has not been put forward in a broad perspective as compared to hilly or hard rock terrains and needs to be addressed effectively. In the present paper, the morphometric analysis of the Ghaghara River has been carried out to delineate various surface processes that carve the basin into fluvial terrain. The basin delineation has been done using Shuttle Radar Topographic Mission (SRTM) data using Arc GIS 10.3. The study shows stream varying from one to six (I-1844, II- 807, III-200, IV- 49, V-23 and VI-1) orders. The mean bifurcation ratio indicates that the basin is geologically and structurally controlled in flat regions. The low stream frequency value 0-5km^{-2}, explains that the basin under study is highly permeable. The length of overland flow (>0.7) is indicative of sheet erosion rather than channel erosion, while the drainage texture points towards the coarse texture. The morphometric analysis and observations from the measured parameters indicate an asymmetrical and elongated basin with neo-tectonic activities. Therefore, multi-fold interpretations are generated on the basis of the morphometric analysis of the Ghaghara river basin which may be useful in providing information relevant to societal interests.

INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of the earth surface, shape and dimensions of its landforms (Clarke, 1966). It defines linear, areal and relief aspects of the basin and slope contribution (Nag and Chakraborty, 2003). The drainage network of any region explains the existing three dimensional geometry of the region and also helps to narrate its evolutionary processes (Kale and Gupta, 2001; Della Seta et. al., 2014; Rai et. al., 2017). Morphometric analysis of the basin and sub-basin is a quantative approach for analyzing the distinct aspect and controls of drainage network viz. stream number and length of the streams, bifurcation ratio, drainage density, relief, aspect, slope and shape of the basin (Nautiyal, 1994; Srivastava et al., 1995; Srivastava, 1997; Nag, 1998; Agarwal 1998; Shreedevi et al., 2001, 2005, 2009; Vittala et al., 2004; Manjare et al., 2014). It helps in the identification of distinct geological processes, geomorphic development and drainage appraisals that are modified by natural phenomena. An attempt has been made to identify the drainage morphometric characteristics of the Ghaghara basin and its sub-basin (Horton, 1945; Strahler, 1964).

Further, the quantitative study of the drainage basin parameters plays a vital role in the hydrological investigations and assessment of groundwater potential, groundwater management, basin management, environment assessment and development of land suitability processes (Manjare et al., 2014; Kumar and Chaudhary, 2016).

Remote sensing (RS) is considered to be a very effective tool for interpretation of high resolution satellite data for understanding and managing the nature of a drainage basin. Presently, the geographical information system (GIS) is also a promising tool with remote sensing where different aspects of the morphometry (linear, aerial and relief aspects) can be calculated. Recently several researchers have used RS and GIS techniques for the evaluation of morphometric parameters and have advocated its strength for making inferences related to drainage basin analysis and societal relevances (Agarwal, 1998; Nag, 1998; Das and Mukherji, 2005; Pareta and Pareta, 2012). Thus GIS based evaluation using Shuttle Radar Topographic Mission (SRTM) data has given a precise, fast and inexpensive way for analysing hydrological systems (Smith and Sandwell, 2003; Grohmann, 2004).

In the present paper, an attempt has been made to delineate basin and sub-basin of Ghaghara river to infer the morphometric parameters for understanding the role of lithology and geologic structures in controlling the drainage pattern, density, infiltration, runoff, etc.

STUDY AREA

The present study area of Ghaghara river basin lies between 25° 45'00" N to 28°45'00" N latitude and 81°00'00" E to 84°45'00" E longitude with an area of about 57551 km^2. The Ghaghara river flows in NNW-SSE direction from Bahraich to Faizabad and then turns in NW-SE direction throughout the confluence to the Ganga river in Bihar. The tributaries of the Ghaghara river runs parallel to the Ghaghara river which gives rise to elongate shape of the basin. The catchment of the Ghaghara river covers 19% of the area of Nepal, 5% of Bihar and 76% of Uttar Pradesh in India (Fig.1).

The Ghaghara river is the second largest tributary of the Ganga river in length after Yamuna river. It rises from the Matstatung glacier in the Himalaya near Mansarowar lake in Tibet at an elevation of about 3,962m (Singh and Awasthi, 2011). The total length of the river is 1,080 km and traverses in NW-SE direction. It enters Uttar Pradesh through the Nepal border and confluences with the Ganga river in Bihar. It is a fact the Ghaghara river is the largest tributary of the Ganga river by volume and provides livelihood for many districts of Uttar Pradesh (Singh, 2018). The important tributaries of the Ghaghara river includes Sarda, Rapti, Little Gandak, Kuwana, Tirhi, Gauri, Sarju, Rohini, Mana and a few other small streams.

One-third of the Ghaghara river basin is covered by reserve forests and local hillocks. The basin falls in the fertile and low dipping Ganga plain with low to moderate relief and elongated in the NW-SE direction. The general topographic elevation in the NE, NW, SW and SE quadrant is 876m amsl, 691m amsl, 67m amsl, 112m amsl respectively. The Ghaghara river covers a denudational hill in the northern part of Ghaghara basin followed by piedmont zone having micro and mega alluvial fans (Singh, 1996) while the rest is covered by alluvial deposits indicating fluvial sediments and soils with weak,

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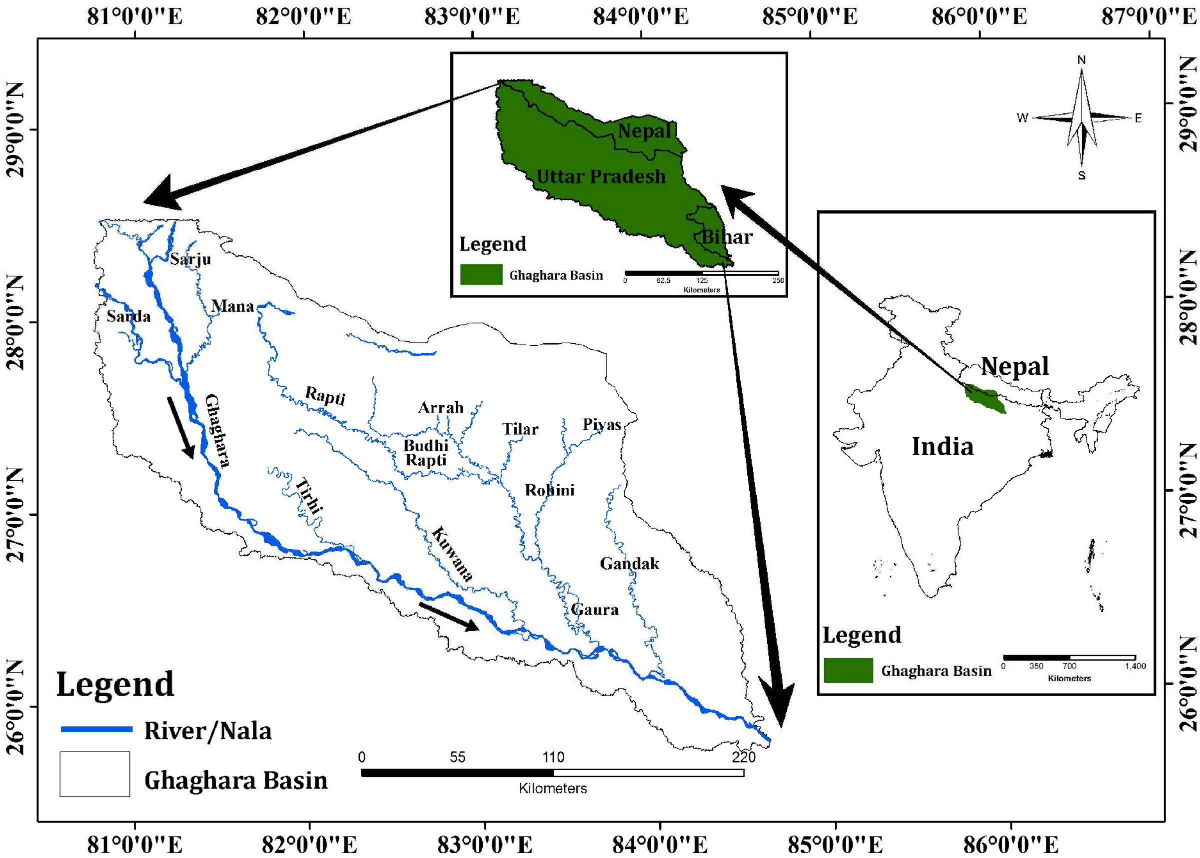

Fig.1. Location map of the Ghaghara basin.

moderate, and strong degree of development (Srivastava et. al., 2016). The Ghaghara river is the main channel in the study area which exhibits structural control and flows in NW-SE direction along with its tributaries.

The study area comprises parts of Nepal, Bihar and eastern Uttar Pradesh. Nepal area comprises the lesser Himalaya zone containing the midland metasedimentary group (Ishida and Ohta, 1973) followed by various major thrust zone including Main Frontal Thrust (MFT) and Main Boundary Thrust (MBT), trending in NW-SE and overlain with Quaternary alluvial deposits in Uttar Pradesh and Bihar.

Geomorphologically, the Ghaghara basin is divided into two litho-units namely older Alluvium (Varanasi older alluvium and T_2 terrace surface) and newer alluvium (Bangar and Khadar). The older alluvium forms the higher interfluves area, while the newer alluvium forms the low interfluve area (Uniyal et. al., 2018). The older alluvium is the oldest geomorphic unit and formed by the extensive deposition of unconsolidated sediment comprising Indo-Gangetic alluvium characterized by various fluvial landforms and different lithologies *viz.* kankar, gravel, sand, silt clay etc. The low land broad river valley having old flood plain (OFP) also referred to T_1 terrace surface is juxtaposing the active flood plain (T_0); although the former surface is at 1 to 2 meters higher elevation. Further, the OFP is bounded by older alluvial plain (OAP) on the either side and is incised within the latter surface, characterized by the presence of fluvial terraces and active flood plain (T_0 terrace surface) with the latter surface occupying lower elevation and juxtaposing the present day river channel. Active flood plain (AFP) is nearly flat, low-lying, poorly drained, having surface with little or no relief and is formed by the lateral and vertical accretion of river deposits made up of unconsolidated material comprising sand, silt, clay etc (Singh 1996). It appears as the narrow strip of land running parallel and sub-parallel to the Ghaghara river and its tributaries, is 1 to 3 meters lower in elevation than the OFP.

Climatically, the entire basin is subtropical. It experiences above average rainfall due to the Indian Summer Monsoon (ISM) which is a great concern for agriculture and in the utilization of natural resources (Singh and Sontakke, 2002).

METHODOLOGY

The data preparation for the drainage basin analysis of the Ghaghara river was done using SRTM data with 90m resolution downloaded from https://earthexplorer.usgs.gov/ because of the high precision of SRTM-DEM data and low algorithmic errors and data gaps (Reuter et al., 2007, Rawat et al., 2014). The stream network is generated by hydrological and spatial analyst (SA) tools in Arc-GIS 10.3 (as Fill DEM, calculation of flow direction, flow-accumulation, condition and generate raster as stream order then converting into vector data) (Fig.2 & Fig.3). The threshold in the present study has been set at 2km² for the SRTM 90m resolution (Liya Chen et. al., 2018). The numerical analysis of drainage has been carried out using various formulas given in Table 1. The basin and sub-basin has been generated using SRTM through basin tool and pour point tool in spatial analyst (Rai et. al., 2017).

The study area has been subdivided into 27 sub-basins, based on the stream arrangement. Minimum 3^{rd} order sub-basins were considered for quantitative morphometric analysis. The morphometric calculations have been shown in Tables 2 to 6. It easily interprets the relationship between the various aspects of drainage patterns, geological, climatic regimes and various parameters in numerical terms.

The Shuttle Radar Topographic Mission (SRTM) data has been used for extracting drainages and delineating the basin and sub-basins (Fig.4). Geographic Information System (GIS) was used for topology construction of the drainage layer and calculation of various drainage characteristics such as drainage density, bifurcation ratio, circulatory

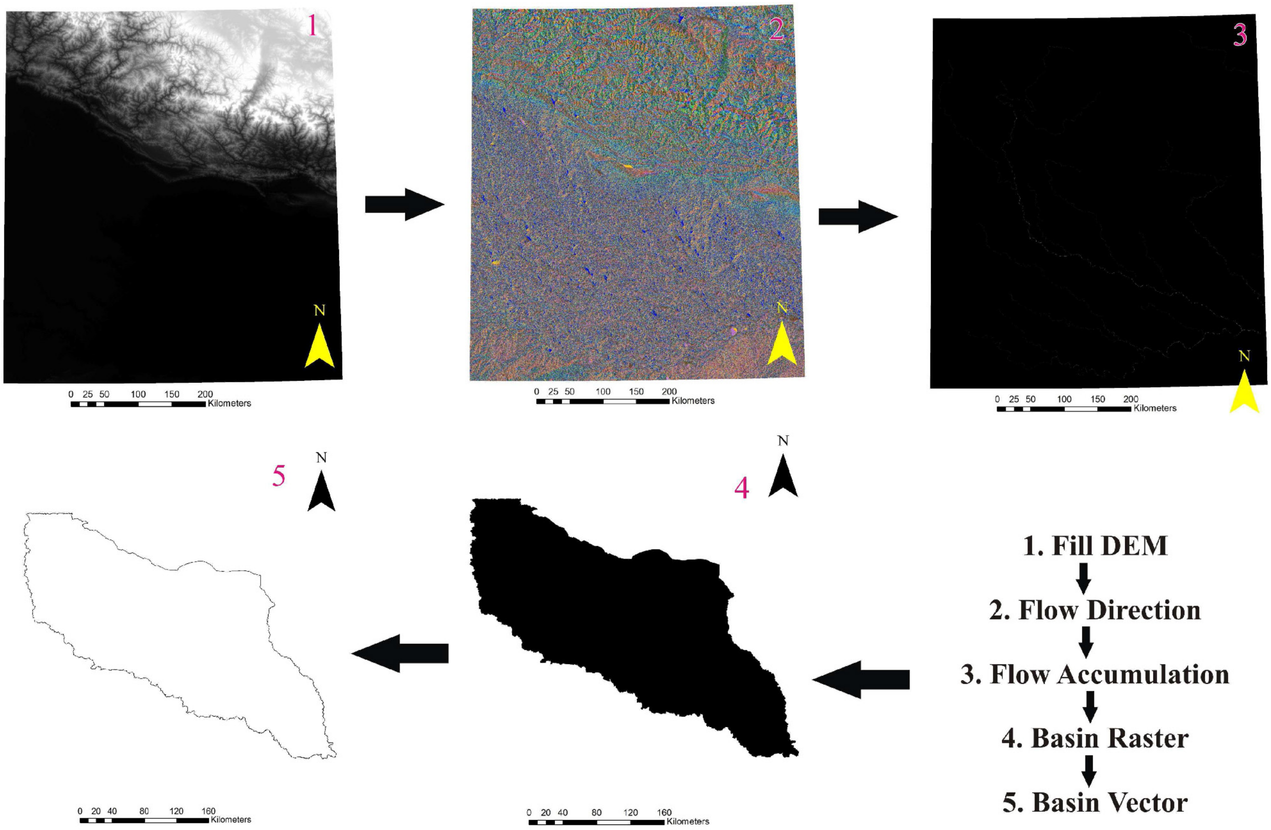

Fig.2. Delineation of the Ghaghara river basin boundary through SRTM data.

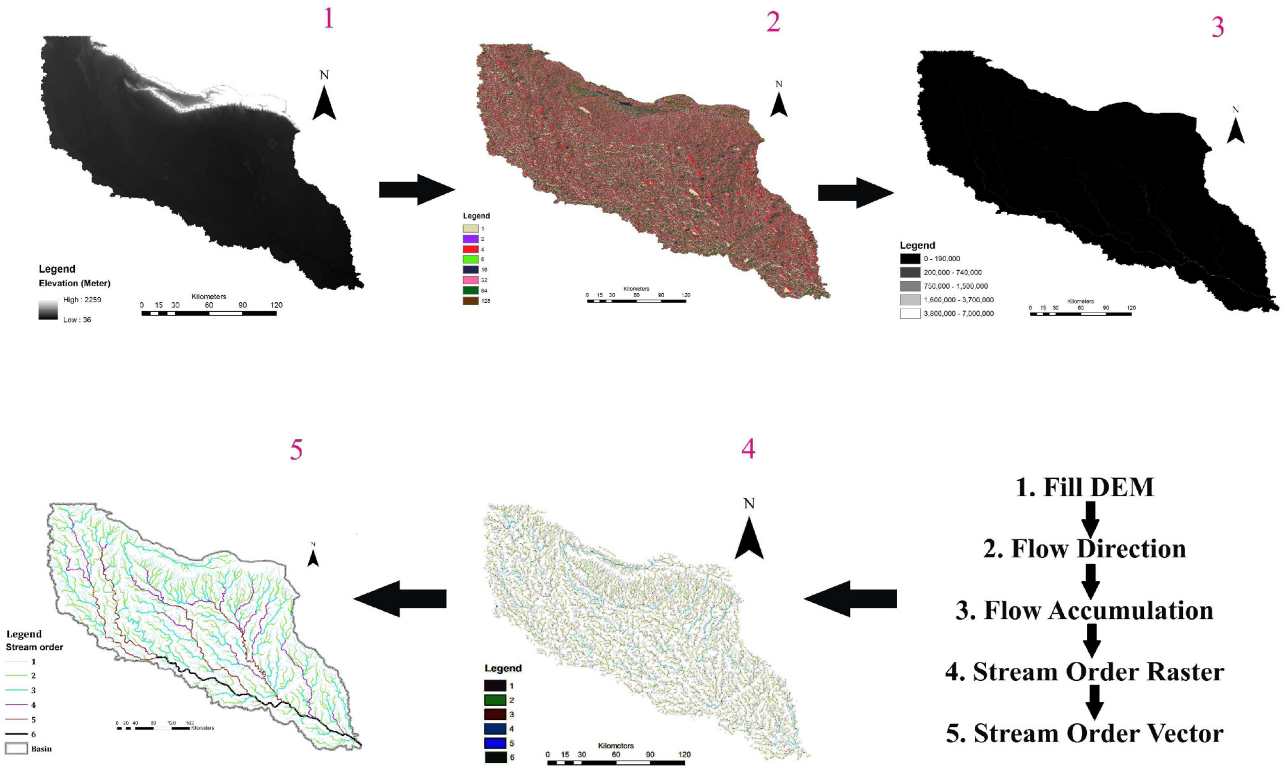

Fig.3. Extraction of drainage networks from DEM.

Table 1. Formulae Adopted for Calculation of Morphometric Parameters

Sr. No.	Morphometric parameters	Formula	Reference
1	Stream Order	Hierarchical rank	Strahler (1964)
2	Stream Length (Lu)	Length of the Stream	Horton (1945)
3	Mean Stream Length (Lsm)	Lsm= Lu/Nu Where, Lsm = Mean Stream Length; Lu=Total Stream Length of order 'u'; Nu= Total no. of stream segments of order 'u'	Schumn (1956)
4	Stream Length ratio (RL)	RL=Lu/Lu-1 Where, RL= Stream Length ratio; Lu=Total stream length of the order 'u'; Lu-1=The total stream length of its next order	Horton (1945)
5	Bifurcation ratio (Rb)	Rb=Nu/Nu+1, Where, Rb= Bifurcation ratio Nu=Total no. of stream segments of order 'u' Nu+1=Number of segments of the next, higher order	Schumn (1956)
6	Mean Bifurcation ratio	Rbm =Average of Bifurcation ratios of all orders	Strahler (1957)
7	Relief ratio (Rf)	Rh = H/Lb Where, Rh = Relief ratio, H= Total Relief (Relative Relief) of the basin (km), Lb=Basic length	Schumn (1956)
8	Drainage Density (D)	D = Lu/A,Where, D= Drainage Density, Lu=Total stream length of all orders, A= Area of the basin (km^2)	Horton (1945)
9	Stream Frequency (Fs)	Fs= Nu/A Where, Fs= Stream Frequency, Nu=Total no. of streams of all orders, A= Area of the basin(km^2)	Horton (1932)
10	Drainage Texture (Rt)	Rt=Nu/P Where, Rt = Drainage Texture, Nu = Total no. of streams of all orders, P = Perimeter (km)	Horton (1945)
11	Form Factor (Rf)	Rf= A/Lb^2 Where, Rf=Form Factor, A=Area of the basin(km^2), Lb^2= Square of Basin length	Horton (1932)
12	Circulatory Ratio (Rc)	$Rc=4*Pi*A/P^2$ Where, Rc=Circulatory ratio, Pi=Pi value i.e., 3.14 A= Area of the basin(km^2), P^2=Square of the perimeter.	Miller (1953)
13	Elongation ratio (Re)	$Re = 2\sqrt{(A/\pi)}/Lb$ Where. Re=Elongation ratio, A=Area of the basin(km^2), Pi='Pi' value i.e., 3.14 Lb= Basin length	Schumn (1956)
14	Length of overland flow (Lg)	Lg = 1/D*2, where, Lg=Length of overland flow, D= Drainage Density	Horton (1945)
15	Ruggedness number (Rn)	Rn = D*H/5280 Where, D= Drainage density H = Total Relief	Singh (1971)
16	Sinuosity index (Si)	Si = (X/Y) Where, X = Average Drainage length, Y= Basin length	Leopold (1964)
17	Constant of Stream maintenance (C)	C = 1/D Where, D = Drainage density	Schumn (1956)
18	Rho coefficient (ρ)	(ρ) = Lu/Rb Where, Lu= stream length ratio Rb= bifurcation ratio.	Horton (1945)

ratio, stream frequency and elongation ratios for basin evolution studies and understanding the drainage evolution and symmetry. The morphometric parameters are computed using ArcGIS 10.3 software.

A morphometric evaluation includes stream order (Nu), Bifurcation ratio (Rb), stream length (Lu), stream frequency, elongation ratio (Re), form factor (Rf), circulatory ratio (Rc), drainage density (D) and ruggedness number, calculated by the various formulae as given in Table 1.

The discharge capacity of Ghaghara basin is moderate because the relief ratio is moderate and the groundwater potential is meagre. These studies are extremely useful for planning rainwater harvesting and watershed management.

RESULTS

The drainage basin in the present study was divided into 27 sub-basins to get broader aspect inferences of smaller channel developments and their variations in the basin morphology. Based on lithology, geomorphology, geology and elevation, the drainage is delineated into six order stream with dendritic to sub-dendritic patterns at the higher elevation, pinnate herringbone and parallel to sub-parallel in lower elevation. The analysis has been done based on the following sub heads-

Area, Perimeter and Basin Length of the Ghaghara Basin

The Ghaghara river basin covers an area (A) of 57551 km^2, covering 72% area of left bank and 28% area of the right bank of the Ghaghara River. The total perimeter (P) of the Ghaghara river basin is 13007.43 km and the total basin lengths of all Ghaghara basin is 3987.82 km.

LINEAR ASPECT

Stream Order

Ghaghara basin is divided into six order stream and ranked based on Strahler (1964), and according to this techniques two I^{st} order stream join to produce one II^{nd} order stream and similarly II^{nd} order stream joint together to form III^{rd} order stream followed by IV^{th} , V^{th} and VI^{th} order. There are III, IV^{th} and V^{th} stream order basin present in the whole basin among these 27 sub-basin and the stream order ranges from III^{rd} to VI^{th} order streams. The III^{rd} order sub-basin is 3, 7 and 25, IV^{th} order sub-basin is 1, 2, 6,8, 9, 12, 14, 15, 18, 23, 24, and 27, V^{th} order sub-basin is 4, 5, 10, 11, 13, 16, 17, 19, 20, 21, 22, 26 (Table 2).

Stream Number (Nu)

Stream Number is computed by the total number of streams present in the basin. The total numbers of stream order are: I^{st} = 1840, II^{nd} = 806, III^{rd} = 197, IV^{th} = 41, V^{th} = 11, VI^{th} = 1.

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

Stream length is defined by the total length of individual stream segments of each order of that order. It will increase when stream order increase. The total length of the streams is 16813.3km in entire basin. The total length of first order streams is 8295.4km, second order streams are 4066.52km, third order streams are 2294.38km, fourth order streams are 983.06km, fifth order streams are 847.52km and sixth order streams are 326.59km.

The Lsm is the ratio of the total length of streams to the total number of streams and the particular ordered stream given in Table.3. The mean length of segments of a given order must be higher than the length of the next lower order but less than the length of next higher order, if the length of higher order is less than the next high order. It shows a sudden change in gradient or topography (Agarwal et al. 2018). In the present study the Lsm is increasing in 1^{st} to 5^{th} order while decreases in 6th order indicating some topographic influences in the Ghaghara basin.

Bifurcation Ratio (Rb)

It is the ratio of the number of streams of a particular order (Nu) to

Table 2. Basin Area, Stream Numbers and Stream length of the Study area Sub basins

Sub-basin name	Stream order	Basin area (Km^2)	Stream no. (Nu)						Stream Length in Km (Lu)					
			I	II	III	IV	V	VI	I	II	III	IV	V	VI
1	IV	2892.16	100	38	13	1	-	-	450.78	189.75	147.51	71.37	-	-
2	IV	1534.19	52	29	3	2	-	-	305.25	160.39	19.47	62.27	-	-
3	III	1456.10	47	25	8	-	-	-	258.04	123.4	85.22	-	-	-
4	V	5063.29	173	76	16	8	1	-	738.93	334.97	179.1	166.91	169.86	-
5	V	3374.93	104	53	11	5	1	-	611.67	334.98	170.58	51.94	20.11	-
6	IV	1565.91	37	15	7	2	-	-	228.8	72.85	65.3	45.38	-	-
7	III	1177.18	27	16	4	-	-	-	128.67	111.67	33.97	-	-	-
8	IV	333.05	13	7	1	-	1	-	45.81	31.07	19.52	-	169.86	-
9	IV	1445.02	51	15	6	2	-	-	223.8	50.42	67.75	60.47	-	-
10	V	618.12	18	4	1	2	1	-	89.7	10.76	16.33	108.17	78.46	-
11	V	1082.20	37	15	4	1	2	-	143.31	87.91	44.2	38.42	64.85	-
12	IV	2911.93	69	37	9	4	-	-	451.06	250.26	65.42	92.39	-	-
13	V	6039.60	189	87	21	3	2	-	864.96	536.67	232.02	32.83	225.75	-
14	IV	1526.56	49	10	3	-	1	-	184.09	40.62	31.85	-	169.86	-
15	IV	3060.77	102	43	15	4	-	-	406.16	203.01	145.39	94.16	-	-
16	V	1691.97	49	19	6	2	3	-	215.05	69.27	80.79	57.79	112.75	-
17	V	330.34	11	6	2	1	2	-	48.71	13.61	7.46	7.96	113.09	-
18	IV	2456.10	92	35	9	2	-	-	366.98	143.18	129.99	77.83	-	-
19	V	2611.88	88	28	6	1	2	-	375.67	100.16	118.53	49.09	218.75	-
20	V	3435.93	112	45	10	-	3	1	418.33	213.9	132.9	-	500.45	148.32
21	V	2491.61	94	43	10	1	2	-	323.47	183.17	163.42	37.82	100.3	-
22	V	1043.71	30	14	1	-	1	2	116.48	61.37	24.09	-	140.29	203.83
23	IV	1386.58	44	24	3	-	1	2	140.36	114.96	23.68	-	52.35	178.27
24	IV	3830.07	126	62	15	5	-	-	629.84	316.82	114.65	147.23	-	-
25	III	1251.13	39	16	6	-	-	-	206.25	63.82	89	-	-	
26	V	1965.76	63	28	6	3	-	1	261.62	160.73	99.16	65.69	-	122.76
27	IV	975.20	28	17	4	-	-	1	118.74	87.63	66.75	-	-	122.76

Table 3. Mean Stream Length and Stream Length ratio of the Study area Sub basins

Sub-basin name	Mean Stream Length in Km (LSM = Lu/Nu)						Stream Length Ratio (RL)(Lu/Lu-1)					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
1	4.50	4.99	11.34	71.37	-	-	0.42	0.78	0.48	-	-	-
2	5.87	5.53	6.49	31.13	-	-	0.53	0.12	3.20	-	-	-
3	5.49	4.94	10.65	-	-	-	0.48	0.69		-	-	-
4	4.27	4.40	11.19	20.86	169.86	-	0.45	0.53	0.93	1.02		
5	5.88	6.32	15.50	10.38	20.11	-	0.55	0.51	0.30	0.39		
6	6.18	4.85	9.32	22.69	-	-	0.32	0.90	0.69			
7	4.76	6.97	8.49	-	-	-	0.87	0.30				
8	3.52	4.43	19.52	-	169.86	-	0.68	0.63				
9	4.38	3.36	11.29	30.24	-	-	0.23	1.34	0.89			
10	4.98	2.69	16.33	54.08	78.46	-	0.12	1.52	6.62	0.73		
11	3.87	5.86	11.05	38.42	32.43	-	0.61	0.50	0.87	1.69		
12	6.53	6.76	7.26	23.09	-	-	0.55	0.26	1.41			
13	4.57	6.16	11.04	10.94	112.87	-	0.62	0.43	0.14	6.88		
14	3.75	4.06	10.61	-	169.86	-	0.22	0.78				
15	3.98	4.72	9.69	23.54	-	-	0.50	0.72	0.65			
16	4.38	3.64	13.46	28.90	37.58	-	0.32	1.17	0.72	1.95		
17	4.40	2.26	3.73	7.96	56.55	-	0.28	0.55	1.07	14.21		
18	3.98	4.09	14.44	38.92	-	-	0.39	0.91	0.60			
19	4.26	3.57	19.76	49.09	109.38	-	0.27	1.18	0.41	4.46		
20	3.73	4.75	13.29	-	166.82	148.32	0.51	0.62				
21	3.44	4.25	16.34	37.82	50.15	-	0.57	0.89	0.23	2.65		
22	3.88	4.38	24.09	-	140.29	101.92	0.53	0.39				
23	3.19	4.79	7.89	-	52.35	89.14	0.82	0.21				
24	4.99	5.11	7.64	29.45	-	-	0.50	0.36	1.28			
25	5.28	3.98	14.83	-	-	-	0.31	1.39				
26	4.14	5.74	16.52	21.89	-	122.76	0.61	0.62	0.66			
27	4.24	5.15	16.68	-	-	122.76	0.74	0.76				

the number of streams of the higher orders (Nu+1) (Strahler, 1964). Rb value is less than 3 for those basins where the terrain is almost flat and doesn't have any structural influence. When Rb value ranges between 3 to 5, it indicates that even though the basin has geological structures it has less influence on the drainage pattern**.** Mean bifurcation ratio of Ghaghara river basin is 3.58. The sub-basins (3, 6, 7, 9, 10, 11, 12, 16, 17, 27) show that the basin lies in flat region, the sub-basins (2, 4, 5, 8, 13, 14, 15, 18, 19, 20, 21, 23, 24, 26) are structurally controlled but does not distort the drainage pattern and sub-basins (1,22,25) are lithologically and structurally controlled basins (Table 4).

AREAL ASPECTS

Drainage Density (D)

Drainage density is defined as the closeness in spacing of channels. Low drainage density and high drainage density refers to coarse and fine drainage texture respectively (Strahler, 1964). The amount and

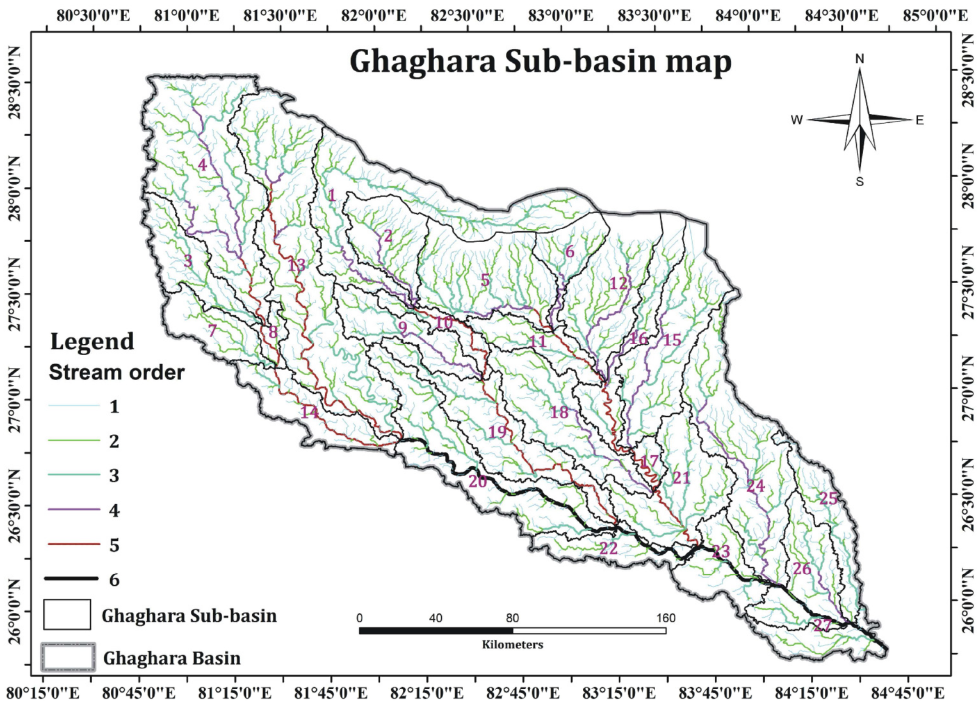

Fig.4. Stream order and sub-basins of Ghaghara basin

type of precipitation influence directly the quantity and character of surface runoff (Bali et al, 2011).

The drainage density of the study area ranges from 0.23 km^{-1} to 0.80km^{-1} (Table 6). The low drainage density indicating that the Ghaghara basin has coarse drainage texture. Thus, the basin shows less runoff and high percolation in this regime.

Drainage Texture (T)

Drainage texture is the total number of stream segments of all order in a basin per perimeter of the basin. It deals with the study of the relative spacing of drainage lines.

The drainage texture of the sub-basin ranges from 0.11 to 0.39 (Table.6), showing that the texture is very coarse. Drainage texture relies upon the relief, water capacity and essential lithology of the terrain and is not affected by natural phenomena such as relief, vegetation, rock type and soil type, climate, rainfall, and stage of development. Drainage texture is classified into 5 different classes i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8) (Smith, 1950).

Stream Frequency (Fs)

Stream frequency refers directly to the lithological characteristics

Table 4. Bifurcation ratio and Mean bifurcation ratio of the study area sub-basins

Sub-basin name	Bifurcation Ratio (Rb) Rb= Nu/Nu+1						Mean Bifurcation Ratio (Rbm)
	I	II	III	IV	V	VI	
1	2.63	2.92	13				6.18
2	1.79	9.67	1.5				4.32
3	3	1.88	3.13				2.51
4	2.28	4.75	2	8			4.26
5	1.96	4.82	2.2	5			3.50
6	2.47	2.14	3.5				2.70
7	1.69	4					2.85
8	1.86	7					4.43
9	3.4	2.5	3				2.97
10	4.5	4	0.5	2			2.75
11	2.47	3.75	4	0.5			2.68
12	1.86	4.11	2.25				2.74
13	2.17	4.14	7	1.5			3.70
14	4.9	3.33					4.12
15	2.37	2.87	3.75				3.00
16	2.58	3.17	3	0.67			2.36
17	1.83	3	2	0.5			1.83
18	2.63	3.89	4.5				3.67
19	3.14	4.67	6	0.5			3.58
20	2.49	4.5			3		3.33
21	2.19	4.3	10	0.5			4.25
22	2.14	14			0.5		5.55
23	1.83	8			0.5		3.44
24	2.03	4.13	3				3.05
25	2.63	2.92	13				6.18
26	1.79	9.67	1.5				4.32
27	1.88	3.13					2.51

Table 5. Perimeter, Basin length, Total relief, Relief ratio, Elongation ratio, Length of overland flow and Constant of stream maintenance of the study area sub-basins

Sub-basin name	Peri-meter	Basin Length	Total Relief	Relief Ratio	Elongation Ratio	Length of Overland flow	Constant of stream maintenance
1	671.84	244.81	166	0.76	0.25	0.67	4.35
2	310.65	97.48	157	1.58	0.45	5.61	3.85
3	421.72	120.97	57	1.07	0.36	6.24	4.29
4	720.19	189.23	158	0.72	0.42	6.37	3.57
5	449.53	146.54	173	1.06	0.45	5.68	3.57
6	322.47	99.87	176	2	0.45	7.6	3.45
7	314.83	108.86	53	1.14	0.36	8.58	3.58
8	177.96	45.23	36	2.47	0.46	2.5	3.45
9	428.62	121.23	48	0.88	0.35	7.18	3.33
10	332.28	112.15	49	0.91	0.25	4.07	3.33
11	368.09	110.18	41	0.82	0.34	5.72	3.23
12	430.08	142.37	188	1.05	0.43	6.78	3.23
13	935.77	325.18	169	0.4	0.27	6.38	3.13
14	443.17	123.78	60	0.87	0.36	7.16	3.12
15	541.69	169.2	186	0.69	0.37	7.21	3.13
16	607.31	199.07	188	0.63	0.23	6.32	3.13
17	150.15	55.62	43	1.44	0.37	3.47	3.03
18	558.05	158.24	48	0.54	0.35	6.84	2.86
19	749.64	219.01	54	0.41	0.26	6.06	2.86
20	785.45	215.48	67	0.43	0.31	4.86	2.78
21	524.6	108.35	41	0.73	0.52	6.17	2.7
22	420.99	121.47	40	0.65	0.3	3.82	2.46
23	363.73	82.44	50	0.85	0.51	5.44	2.44
24	709.47	234.64	205	0.35	0.3	6.34	2.04
25	473.16	169.57	40	0.42	0.24	6.97	1.72
26	424.08	98.13	50	0.67	0.51	8.72	1.25
27	371.91	108.73	50	0.56	0.32	4.93	1.91

Table 6. Drainage density, Stream frequency, Form factor, Circulatory ratio, Drainage texture, Ruggedness number and Sinuosity index of the study area sub-basins

Sub-basin name	Drainage density	Stream Freq-uency	Form Factor	Circu-latory Ratio	Drainage texture	Rugged-ness number	Sinu-osity index
1	0.3	0.62	0.05	0.08	0.23	0.009	0.02
2	0.36	0.88	0.16	0.2	0.28	0.011	0.07
3	0.32	0.66	0.1	0.1	0.19	0.003	0.05
4	0.31	1.45	0.14	0.12	0.38	0.009	0.03
5	0.35	1.19	0.16	0.21	0.39	0.012	0.05
6	0.26	0.61	0.16	0.19	0.19	0.009	0.07
7	0.23	0.43	0.1	0.15	0.15	0.002	0.05
8	0.8	0.49	0.16	0.13	0.12	0.005	0.27
9	0.28	0.61	0.1	0.1	0.17	0.003	0.04
10	0.49	0.23	0.05	0.07	0.08	0.005	0.1
11	0.35	0.54	0.09	0.1	0.16	0.003	0.06
12	0.3	0.84	0.14	0.2	0.28	0.011	0.05
13	0.31	0.93	0.06	0.09	0.32	0.01	0.02
14	0.28	0.51	0.1	0.1	0.14	0.003	0.05
15	0.28	0.97	0.11	0.13	0.3	0.01	0.03
16	0.32	0.4	0.04	0.06	0.13	0.011	0.03
17	0.58	0.38	0.11	0.18	0.14	0.005	0.16
18	0.29	0.87	0.1	0.1	0.25	0.003	0.03
19	0.33	0.57	0.05	0.06	0.17	0.003	0.03
20	0.41	0.79	0.07	0.07	0.22	0.005	0.04
21	0.32	1.38	0.21	0.11	0.29	0.003	0.05
22	0.52	0.4	0.07	0.07	0.11	0.004	0.09
23	0.37	0.9	0.2	0.13	0.2	0.003	0.08
24	0.32	0.89	0.07	0.1	0.29	0.012	0.02
25	0.29	0.36	0.04	0.07	0.13	0.002	0.03
26	0.23	1.03	0.2	0.14	0.24	0.002	0.07
27	0.41	0.46	0.08	0.09	0.13	0.004	0.07

(Kumar et. al., 2016) and it is the number of stream segments per unit area or channel frequency.

The stream frequency of study area is 0.72 km^{-2} that is low. The Fs of sub-basins is ranging from 0.36-1.45km^{-2}, if it is directly proportional to drainage density, the stream number increases and the area is more or less affected by rainfall. Stream frequency classified into low (0-5), moderate (5-10), moderately high (10-15), high (15-20) and very high (20-25).

Elongation Ratio (Re)

The elongation ratio of the Ghaghara basin is 0.36 which indicates that the entire basin is more elongated. The elongation ratio of the Ghaghara river sub-basin ranges from 0.25- 0.5, indicates that the basin is elongated (Table 5).

Circularity Ratio (Rc)

The value of Rc varies from 0 (in a line) to 1 (in a circle) and is influenced by the length and frequency of the streams, geological structures, land use/land cover, climate, relief and slope of the basin.

The Rc of the Ghaghara basin is 0.12 which indicates that the basin is less circular. The Rc value of all the 27 sub-basins, range between 0.1 to 0.21 indicating that the sub-basins are also slightly elongated.

Form Factor (Ff)

The Ff of the intact basin is 0.11, indicating that the terrain is highly elongated and peak flow is low and duration is long. The Ff values for the sub-basins range from 0.04 to 0.21 (Table 6) for all the 27 sub-basin.

Sinuosity Index (SI)

SI of sub-basins ranges in between 0.1 and 0.15 (Table 6) that indicating the streams of all sub-basins are almost straight and structurally controlled.

Ruggedness Number (Rn)

Ruggedness number indicates the structural complexity of the terrain. If the drainage density and relief are high and the slope is steep and long then the ruggedness number is also high (Strahler, 1956; Waikar and Nilawar, 2014).

The average Rn value of entire basin is 0.007. However, the Rn value ranges from 0.002 to 0.021 for sub-basins which indicates that the entire basin is less prone to soil erosion and have low to moderate structural complexity in association with relief and drainage density (Patton and Baker, 1976).

Length of Overland Flow (Lg)

Lg is one of the most important independent variables affecting hydrologic and physiographic development of drainage basin (Ansari et. al, 2012)..

The Lg of the study area is ranges between 0.67 and 8.72 km for the sub-basins. The sub-basin-1 has Lg value of 0.67 that shows low degree of sheet erosion while the rest of the basins have higher Lg values ranging from 2.5 to 8.72km which show that sheet erosion is the prominent factor for hydrologic and physiographic development.

Rho Coefficient

The "Rho" coefficient is an important parameter relating drainage density to the physiographic development of a sub-basin which facilitates evaluation of the storage capacity of the drainage network and hence, a determinant of the ultimate degree of drainage development in a given sub-basin (Horton 1945). The Rho coefficient value in the study area ranges from 0.15- 6.01 for all sub-basins which indicates low storage capacity of the basin.

Constant of Stream Maintenance (C)

It is the inverse of drainage density. It indicates the relative size of the landform unit in a drainage basin and has a specific genetic association (Strahler, 1957).

The C of Ghaghara basin is more than 0.7 for all sub-basins which indicate that the sheet erosion is more than channel erosion.

RELIEF ASPECT

Linear and areal features have been considered as the two dimensional aspect. The third dimension introduce by the concept of relief. By measuring the vertical fall from the head of each stream segment to the point where it joins the higher order stream and dividing the total by the number of streams of that order, it is possible to obtain the average vertical fall.

Basin Relief

It is the elevation difference of the highest and lowest point of the valley floor and possesses a very significant role in surface and sub-surface water flow, permeability, development of landforms, drainages and erosional properties of the terrain.

The ranges for the sub-basins are 36m-205m that indicating the low to moderate relief for the Ghaghara basin (Table 5).

Relief Ratio

High values of relief ratio are characteristic of hilly regions whereas, low values are characteristic of pediplains and valley (Fig.5).

The relief ratio for the sub-basin ranges from 0.4 to 2 represents low to moderate relief ratio (Table 5).

DISCUSSION

The total number of streams in study area is 2898 which covers 49.33% Ist order, 24.28% IInd order, 13.65% IIIrd order, 5.84% IVth order, 5.04% Vth order and 1.96% VIth order streams. The Ist order streams are higher in numbers followed by IInd, IIIrd, IVth, Vth and VIth

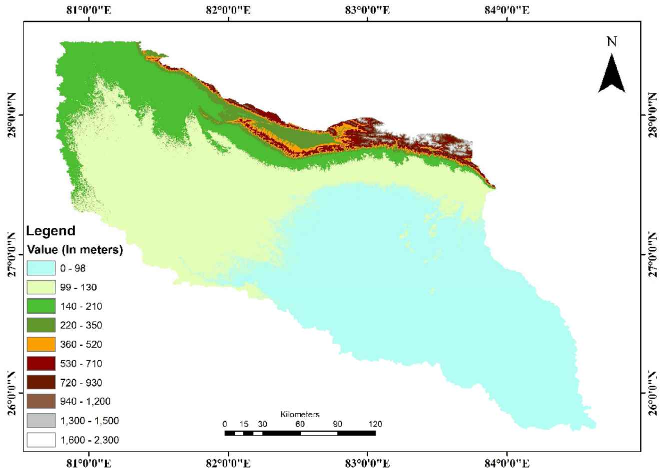

Fig.5. Releif map of Ghaghara basin

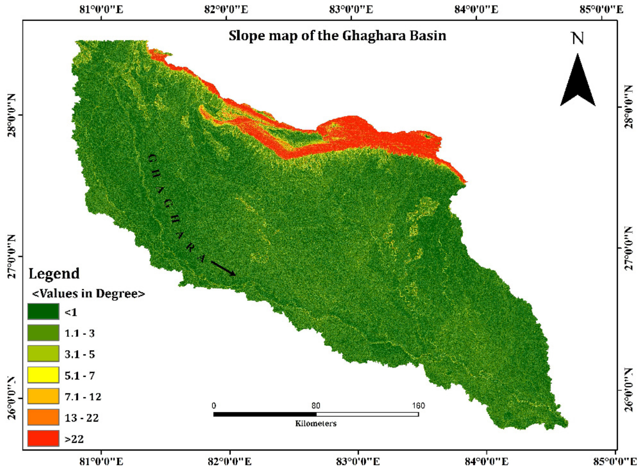

Fig.6. Slope map of Ghaghara basin

order of streams. Due to high numbers of the Ist and IInd orders in the high elevated areas, runoff is higher in these parts of the basins. The quantitative parameter provides information about the supremacy of first order stream (1844), low to moderate slope (0^o-9^o) in fluvial tract region and moderate to very steep slope in hilly terrain (9^o-58^o). The larger number of first order streams indicate uniform lithology and gentle slope gradient (Kale and Gupta, 2001, Singh and Awasthi, 2011), which shows that the major portion of precipitation flow as surface run-off. The major drainage patterns in this area are dendritic and sub-dendritic followed by trellis, herringbone, pinnate and parallel (Fig.7).

The basin morphometry is characterised by linear, aerial and relief aspects. It is found that the basin comprises VIth order streams containing 27 sub-basins. The linear aspect for all sub-basins shows a linear relationship with small deviation when plotted against the logarithmic stream numbers and stream length against stream order. This is the implication of the trend line which confirms the linear relationship of the stream number and stream length (Fig.8 a and b). Stream length ratio is showing variation between streams of different orders which may be due to variation in slope and topography. It has been observed that the length of the Vth order streams is more than the IVth order and VIth order streams which suggests a sudden change in the gradient or topography (Agarwal et al., 2018). The difference from one order to another order of stream length ratios indicates the mature stage of geomorphic development, suggesting an important relationship with runoff and erosional status of the watershed. The value of Rbm ranges from 3-5 indicates the basins may have any geological structures but do not distort the drainage pattern (Chow 1964; Nautiyal 1994; Nag, 1998) but Rbm >5 value reveals the basin is lithological and structurally controlled (Strahler, 1964) and the value of Rbm <3 means the basin has any flat region. Hence, the sub-basin 2, 4, 5, 8, 13, 14, 15, 18, 19, 20, 21, 23, 24 and 26 possess Rbm range of 3-5 sub-basins, sub-basins 1, 22 and 25 shows more than 5 Rbm value and the sub-basins 3, 6, 7, 9, 10, 11, 12, 16, 17 and 27 shows Rbm <3.

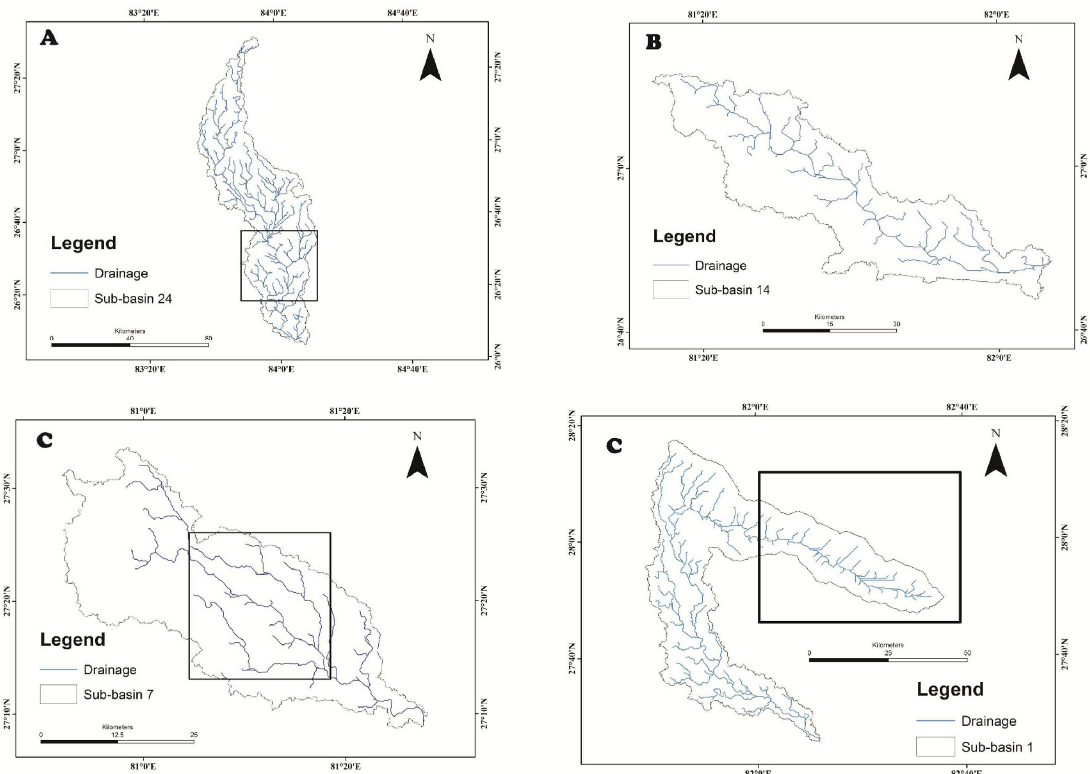

Fig.7. Different types of drainage patterns. **(a)** Trellis, **(b)** Pinnate, **(c)** Parallel and **(d)** Herringbone.

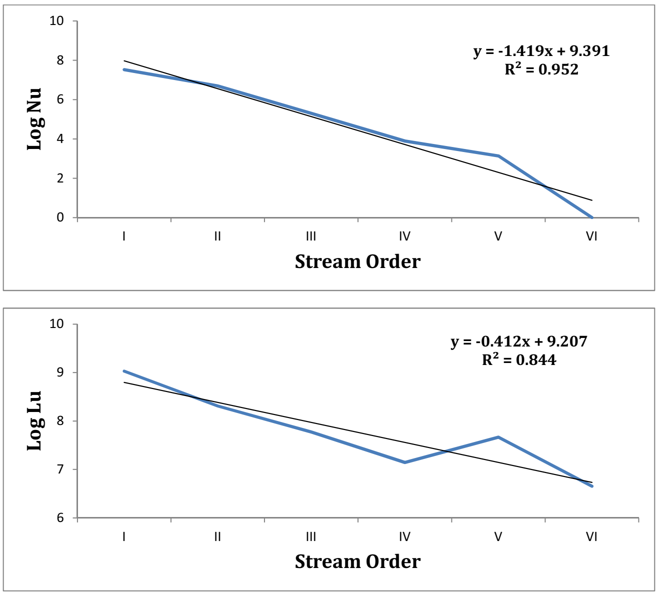

Fig.8. Graph showing relationship between **(a)** Log Nu and Stream order. **(b)** Log Lu and Stream order**.**

The basin morphometry is trustworthy to forecast activity during heavy rainfall that may produce unusual run-off and create floods (Perucca and Angilieri, 2010 and Kumar et. al., 2018). The timing of discharge events in the form of break time has also been related to the basin morphometric characteristics (Kennedy and Watt 1967, Bali et. al, 2012). Increase in drainage density suggests increasing flood peaks. Similarly, the decrease in drainage density may reflect decreasing flood volumes (Pallard et al. 2009). The value of drainage density for the sub-basins of the Ghaghara basin ranges between 0.3 and 0.58/km. The high drainage (2-3km^{-1} and above 3km^{-1}) density shows high runoff and low percolation (Agarwal et al, 2018). Low Dd occurs in the regions of highly resistant and permeable sub soil material with dense vegetated cover and low relief; whereas high Dd is prevalent in the region of weak impermeable sub surface materials which are sparsely vegetated and show high relief in the study area (Sreedevi et. al, 2009). Therefore, the low values of drainage density upto 1km^{-1} in this basin shows poor drainage density which suggests low runoff and high percolation in the area due to different lithological controls. If the stream frequency is directly proportional to drainage density, the stream population increases and the area is more or less affected by rainfall and temperature (Dikpal et al., 2017). Higher stream frequency (Fs) suggests poor infiltration and higher relief while lower stream frequency suggests higher permeability of bed rocks and low relief in the area. The low stream frequency of sub-basins (0.23 to 1.45/km) reflects that the drainage texture mainly depends on the lithology of the sub-basins. The drainage texture (T) of the Ghaghara river basin indicates very coarse drainage texture under the significant value of T<2. This shows more runoff in the sub-basins. The less value of drainage density, stream frequency and drainage texture, imply that surface runoff is not properly drained from the basin, making the downstream portion more susceptible to flooding Angillieri, 2008).

In the prospect of discharge and run-off, a circular basin appears to be more efficient than an elongated basin (Singh and Singh 1997). The Re values generally ranges between 0.6 and 1.0 over a wide variety of climatic and geologic types. Values near to 1.0 are the characteristics of the region of very low relief area; while, values in the range of 0.6-0.8 usually occur in areas of high relief and steep ground slope (Strahler, 1964). The elongation ratio (Re <0.5) of the study area indicates that sub-basins are elongated except sub-basins 21, 23 (Re=0.5-0.6). Value of sinuosity index <1 indicates that the sub-basin possesses straight drainage system. The high value of Rbm and Re and less value of SI, indicate that the drainage system of the entire sub-basin flows through some structural setup and showing elongation in the south-eastern direction. The elongated nature of the river basin has an implication on both hydrologic and the geomorphic processes. The flow of water in elongated basins takes longer time for distribution and is susceptible to erosion and sediment load (Angillieri, 2008).

The Rc is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. The low circularity ratio value (Rc <0.7) of the basin is corroborates by the Miller's range, which indicates that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition (Pareta and Pareta, 2012). The circulatory ratio of the Ghaghara river sub-basins range between 0.06 and 0.21 represent the elongated nature of the sub-basins, based on the values of Rc as circular (>0.9), oval (0.9 to 0.8) and less elongated (<0.7). The entire sub-basin has low attributes of Rn <0.18 and Rf value (0-0.6) indicating that it is slightly elongated and flatted peak flow with longer duration. Lg reveals the erosional capacity of the terrain and indicate >0.7km for the sub-basins, indicates that the sheet erosion is prevalent more than channel erosion except in sub-basin-1 (Lg=0.67km). Constant of stream maintenance (>0.5km^2/km) indicating the least erodible capacity of river in an area and showing inverse relationship with drainage density which means low drainage density has high stream erosion capacity and high drainage density has low stream erosion capacity.

CONCLUSIONS

The morphometric analyses of the Ghaghara river basin provide insights to the hydrological behaviour, basin evolutionary history and maturity of the terrain. The following conclusions can be drawn:

1. In the present study area of the Ghaghara basin, the main channel is of 6^{th} order stream with the total stream length of 18974km. It is a lithologically and structurally controlled basin with an asymmetrical drainage arrangement showing dendritic to sub-dendritic drainage pattern followed by pinnate herringbone and finally concluding with parallel to sub-parallel drainages in the flow regime. The varying drainage density and very coarse drainage texture indicates erratic permeability and low effect of natural phenomena.
2. The basin is more or less elongated and shows an early stage of maturity. The basin relief is low to moderate that gives evidence to water flow capability, permeability, drainage developments and erosional properties of the surface. The relief value in the northern side of the basin is characterised by high runoff and high velocity for erosion but low storage capacity whereas the Southern side of basin shows low runoff and low velocity of erosion but high water storage capacity.
3. The channel is linear/sinuous with least erodible for the soil surface. However, sheet erosion is common than the channel erosion. The region has highly fertile soil and has high ground water potential. The landform characteristic of the region can be boon to support natural hydrodynamic reserves in terms of sustainable development of the society.

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