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Research Article

MORPHOTECTONIC ANALYSIS OF THE KHARI RIVER BASIN, EASTERN INDIA: A CASE STUDY USING MORPHOMETRIC PARAMETERS

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ABSTRACT
The aim of this work is to analyse morphometric parameters to understand the drainage characteristics and anomalies in the Khari River basin with reference to tectonics. The KRB is one of the important drainage systems in deltaic '*Rarh Bengal*' of Eastern India. Understanding of basin morphometry and its spatial variation has been carried out by quantitative analysis through SPSS software and presented in ArcGIS software. The entire drainage basin has been divided into seventeen sub-basins (coded A-Q) and there morphometric parameters have been analysed. Left and right-side basin disparity has been clear from the stream distribution which indicates right-side tile of the basin. Sub-basins B, C, F, G, K, L, and P have medium to high stream frequency, high bifurcation ratio and moderate drainage density in compare to other sub-basins. These sub-basins values are higher than reference values signify that the basins are developed in tectonically active area. Particularly sub-basins C, J, K and L, draining the downstream part of the KRB are characterised by high morphometric values, narrow elongated and centrifugal drainage pattern. Although this is low relief surface, morphometric values indicates these sub-basins have high potential in channel development and anomalies are the result of fault activity. Sub-basin F and P on the right bank, shows elongated shape of the basin and very high stream length dominated by first order are the result of right tilt of the basin.

Keywords: *River Basin, Morphometry and Tectonics*

INTRODUCTION
The earth surface is continuously modifying by fluvial systems through the transfer of water and material from upstream to downstream area with the imprint of geology, climate, and geomorphic processes over time (Knighton, 1984). The drainage basin has widely been considered as an aerial unit for the quantitative study of landforms parameters to reveal its hydrological and geological behavior (Horton, 1932 & 1945; Strahler, 1957; Schumm, 1956; Muller, 1968; Nautiyal, 1994; Leopold, *et al.*, 1964; Oguchi, 1997) including the tectonic activity (Cox, 1994; Resmi *et al.*, 2019). According to the Cox (1994), the drainage basin is a sensitive indicator of lithology, climate, and geology. Quantitative formulation of the drainage basin was introduced by Horton (1945) as an empirical relationship of landform and its controlling factors such as climate, tectonic, hydrology, soil, and vegetation characteristics. In a tectonically active region, the orientation of drainage network and anomalies in characteristics depicts the existing relationship between the fluvial processes and structural deformation (Ollier, 1981; Burbank and Anderson, 2001). Keller and Printer (1996) discussed the effects of tectonics on a drainage network to understand the development of drainage basin and structural control.

Drainage basin characteristics have been analysed as basin morphometry which refers to the measurement and analysis of landforms, developed as result of a complex interaction between surface and sub-surface processes (Keller and Pinter, 1996). In the field of tectonic geomorphology, morphometry enables to understand the hydrological behaviours, stream orientation or evolution of drainage patterns, *etc*. (Burbank and Anderson, 2001). In tectonically active area, these basin and physiographics are closely interrelated and controlled by structural activity causes of active tectonics (Holbrook and Schumm, 1999).

In this study, morphometric techniques have been categorised into linear, areal and relief aspects to understand the spatial pattern of basin characteristics and to interpret the tectonics. Measurement of areal and relief aspects are the fundamental concern to study the physiographical anomalies in basin surface which reflects the lithology, geological structural and denudational chronology of the basin (Resmi *et al.*, 2019). And the study of linear morphometry or drainage network is essential for the conceptualization of complete fluvial processes and landform evolution (Ngapna *et al.*, 2018). Hence, the prime objective of present study is focuses on the basin and drainage morphometric parameters to evaluate the regional tectonic of the Khari River basin (KRB).

Study Area

The study area, Khari River basin (KRB) is a small drainage basin area of 1208 km^2 located in the Purba Bardhaman district of West Bengal, eastern India. The Khari River is originated from the Panagarh Lateritic upland, near Budbud village and flows toward east approximately 212 km and discharge into Bhagirathi-Hugli River (Figure 1). The basin is draining the interfluves of Ajay-Damodar river system enclosed by Ajay and Damodar rivers on the north and south respectively and Bhagirathi-Hughly River on the east (Figure 1). Geomorphologically, this area belongs to the old deltaic part of Damodar para-delta (Singh *et al.*, 1998) as well as the central part of *Rarh Bengal* (Bagchi and Mukherjee, 1997). This area has been divided into three physiographical units by major relief characteristics which are bounded by counters of 36 meters and 18 meters respectively (Roy and Sahu, 2015) (Figure 1).

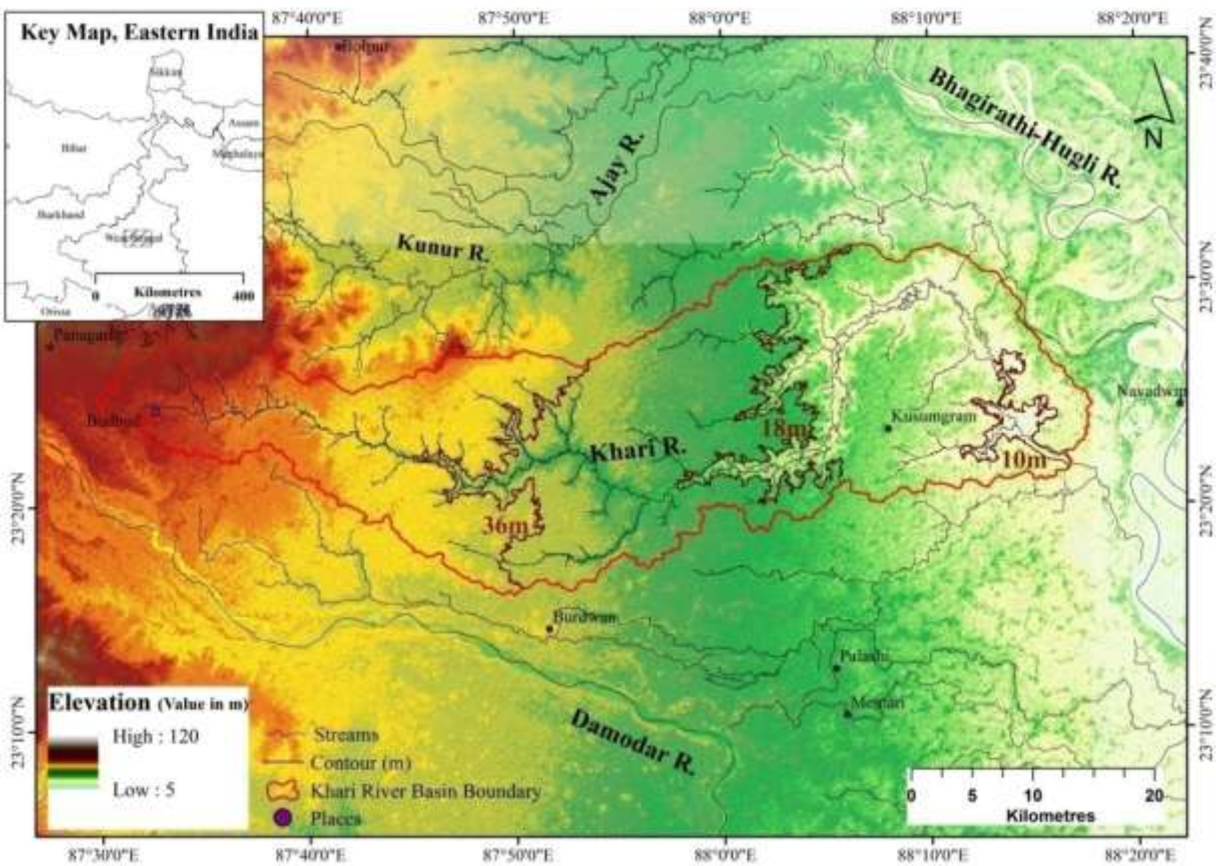

Figure 1: Location map of the study area at Ajay-Damodar interfluves and elevation map with drainage orientation of Khari River network

Surface geological formation of the KRB belongs to the Quaternary alluviums. Most of the basin part (94% of the total basin area) belongs to the older alluvium of Sijua Formation (Figure 2) which is older deltaic origin (Singh *et al.*, 1998). Pleistocene Laterite Formation covers 6% of the basin area at the western edge are in exposed condition (Figure 2). The eastern part is cover by the Panskura Formation and younger Daira Formation is dominated along the trunk stream at downstream reach (Figure 2). Structurally, the basin is located over the western continental shelf part of Western Bengal Basin between the exposed Archaean Formation on the west marked by Chotanagpur Foothill Fault (CFF) and thick Alluvial Formation of the deeper Bengal Basin on the east marked by Eocene Hinge Zone (EHZ) (Alam *et al.*, 2003). Tectonically, these two faults are more sensitive to the earthquake and the other major faults are Medinipur-Farakka Fault (MFF), Pingla Fault (PF), Garmaynan-Khandoghosh Fault (GKF), Damodar Fault (DF), Randa-Ghuni Fault (RGF) and Memari-Debogram Fault (MDF) (Figure 2). All these faults are running parallel to each other from N, NE–SW direction, excluding RGF are the cluster of same fault system (Sengupta, 1966). A tectonic stress field has been developed over the Bengal Basin due to continuous subduction of Indian plate below Eurasian and Arakan-yoma plates at a rate of ~2-4mm/year (Alam *et al.*, 2003; Roy and Sahu, 2015). These faults are reactivated by this tectonic stress during the Early Pleistocene Period (Singh *et al.*, 1998). Average magnitude of earthquakes along these faults is 4.5 *Mw* (SAI, 2001; Nath *et al.*, 2014) and very recent earthquake over GKF and CFF (http://www.imd.gov.in/pages/earthquakeprelim.php) depicts the study area is still tectonically active.

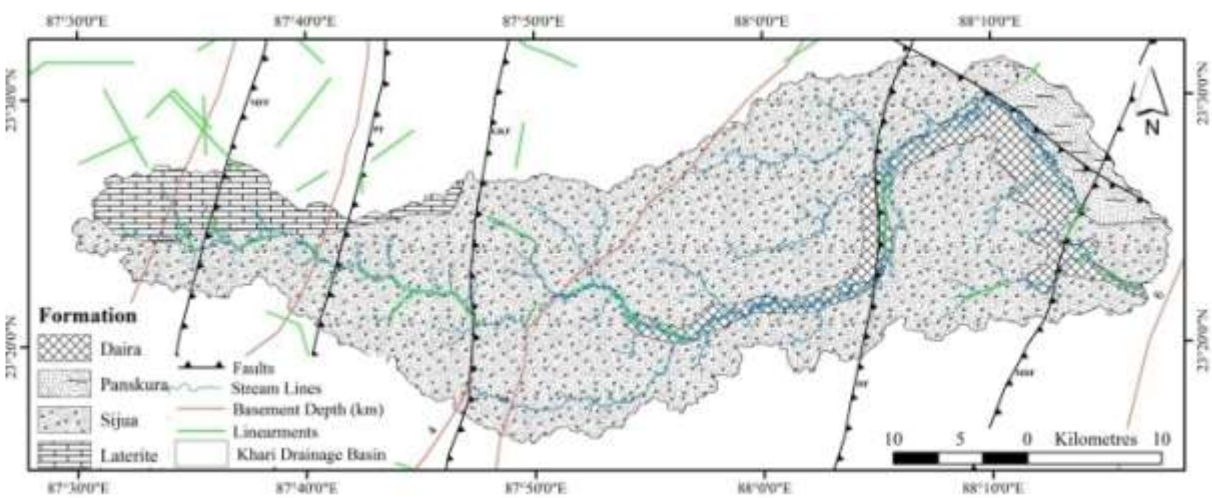

Figure 2: Surface geological formation and tectonic map of the KRB. The black linear features are faults. These are, from west to east, Medinipur-Farakka Fault (MFF), Pingla Fault (PF), Garmaynan-Khandoghosh Fault (GKF), Damodar Fault (DF), and Memari-Debogram Fault (MDF). A minor fault is running NW-SE direction along the NE corner of the basin is Randa-Ghuni Fault (RGF). The green lines are the lineaments and red lines are sediment depth lines. (The map has been prepared based on the seismotectonic atlas data of eastern India, plate no. 24, geological map of the Barddhaman district, published by Geological Survey of India; and paper of Singh *et al.*, 1998).

MATERIALS AND METHODS

The KRB has been considered as a geomorphic unit to study the tectonic activity. Hierarchy of the KRB drainage network (Figure 3, after Strahler's classification, 1964) has been delineated from Aerial Being Map of recent view of 'Google Image' of 0.30-0.33meters spatial resolution using QGIS 'Open Layer Plug-in Tool'. Then the delineated drainage network was rectified with drainage map digitized from the Survey of India (SOI) topographical map of 1:50000. In order to analyse the drainage characteristics of the KRB linear, areal and relief morphometric parameters have been calculated from the extracted data set. Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global DEM of 30 meters spatial resolution and height from topographical maps (contours, sport heights, bench marks, and relative heights) were used to prepare the surface elevation map (SEM) using ArcGIS. The SEM has been used to calculate the areal and relief data sets. The relief aspects have been calculated dividing the basin into 1 km × 1 km small grid through the 'Hawths tool' application in ArcGIS. The basin has been classified into seventeen sub-basins with coded from A-Q for comparative analysis and better understanding of tectonics (Figure 3). The sub-basin A is extreme headwater region of Khari drainage system, whereas, sub-basins B, C, D, J, K, L, and N are draining in the left side of basin and E, F, G, H, M, O, P and Q are in the right side of basin (Figure 3). D and N sub-basins are characterized by surface runoff with only one first order stream. Sub-basin Q has no tributary and sub-basin M is dominate by paleochannels of the Khari trunk stream. Therefore, subbasins Q and M are not considered for the morphometric analysis. Major basin properties of sub-basins have been presented in table 1.

Total sixteen morphometric parameters (Table 2) were applied for drainage and basin analysis, which are divided into three groups; (i) six linear morphometric parameters were computed viz. stream order, stream number, bifurcation ratio, mean bifurcation ratio, stream length ratio and stream gradient ratio, (ii) eight areal parameters were calculated viz. stream frequency, drainage density, form factor, elongation ratio, circularity ratio, compactness coefficient, constant of channel maintenance and length of overland flow, and (iii) two relief parameters were also computed viz. relative relief and absolute ratio. These morphometric parameters have been calculated by ArcGIS and analysed in SPSS statistical software. The relationships among the drainage sub-basins have been interpreted by the linear properties and the areal deformation understood by interpretation of areal and relief properties to constrain the tectonics role. Present study has been also investigated the streams orientation, drainage patterns and structural linear features, such as lineaments to assay the relationship between stream orientation and tectonic nature of the study basin (Ribolini and Spagnolo, 2008). The lineaments have been extracted from bhuvan, https://bhuvanapp1.nrsc.gov.in/gwis/gwis.php# (prepared by Bhuvan-Indian geo-platform of ISRO on 1:50000 scale), through a web based mapping techniques tool in QGIS, dated on 8th April 2019. Using geometry calculator in ArcGIS, stream starting and ending coordinates have been calculated for estimation of flow direction. Rose diagrams of flow direction were prepared in RockWorks geological software using the calculated stream coordinates for first, second and third orders and for lineament orientation.

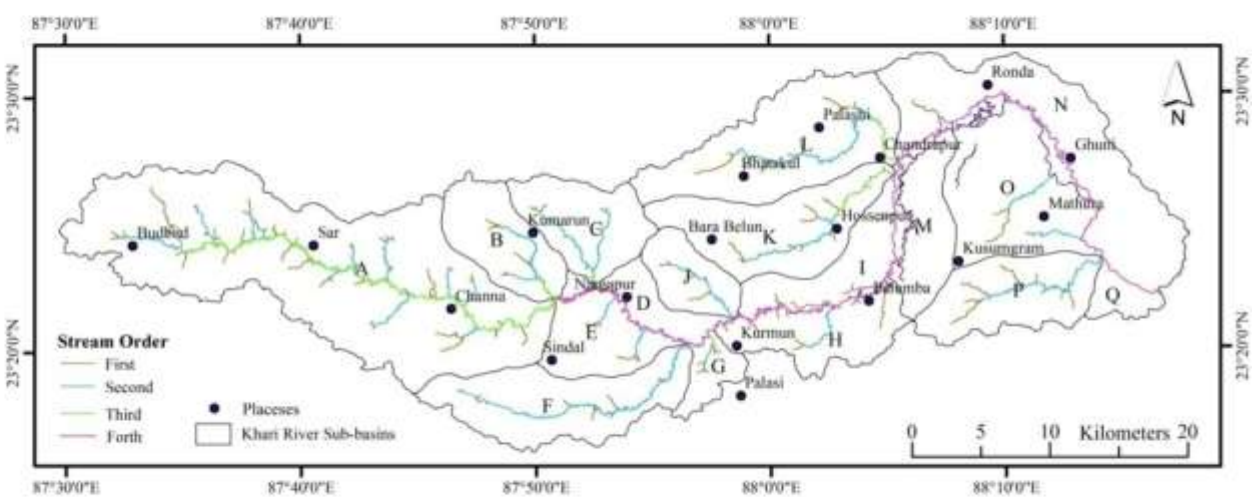

Figure 3: Drainage network hierarchy and sub-basins of the KRB. A-Q are the codes of the respective sub-basins

Table 1: Morphometric properties of sub-basins of the Khari River basin. Sub-basins in brown colour are the eastern most head water basin. Sub-basins marked in black colour are the left bank tributaries and green colour sub-basins are right bank tributaries.

Sub-basins Name	u = Stream Order	N_u = Total no of stream segments of 'u' order				A = Area of the basin (km^2)	L_u = Total length of streams of order 'u' (km)				L = Basin maximum length (km)	P = Perimeter (Km)	H = Maximum elevation (m)	h = Minimum elevation (m)	a = Elevation of stream at source point (m)	b = Elevation of stream at confluence point (m)	l = Actual length of the stream (km)	Straight Line Length (km)	Stream Gradient (m/km)
		1st	2nd	3rd	Total		1st	2nd	3rd	Total									
A	3	57	12	1	70	295.34	45.56	40.52	67	153.06	34.96	106.4	73	27	58.7	29.5	47.63	32.54	0.613
B	3	7	2	1	10	48.68	5.71	12.33	3.85	21.89	10.89	30.03	56	29	41.2	30	14.89	7.56	0.752
C	3	9	2	1	12	51.53	3.8	16.28	2.39	22.47	9.86	31.41	45	25	38	26.2	12.42	7.03	0.95
D	1	1	0	0	1	25.31	0.45	0	0	0.45	8.0	49.35	34	19	26.3	24.5	0.45	0.4	4.5
E	2	6	2	0	8	41.59	4.41	6.9	0	11.31	7.75	40.31	36	20	30.4	20.6	5.9	2.9	1.16
F	2	13	1	0	14	82.13	6.68	31.18	0	37.86	20.2	52.16	41	20	37.3	20	31.22	16.91	0.554
G	3	6	2	1	9	16.55	3.27	2.64	1.22	7.13	6.75	23.43	29	20	27.9	21.6	4.24	2.83	1.48
H	2	9	2	0	11	50.79	10.24	7.34	0	17.58	8.65	51.16	28	15	25.6	13.4	6.34	4.16	1.92
I	2	5	1	0	6	41.65	8.19	0.69	0	8.88	12.5	53.32	25	13	15.3	13.2	1.69	1.31	1.24
J	2	5	1	0	6	29.55	4.35	10.31	0	14.66	8.5	22.37	34	19	31	19.5	11.16	6.81	1.03
K	3	12	2	1	15	78.7	11.52	13.98	9.1	34.6	17.71	45.29	33	13	26.6	12.5	23.76	12.95	0.593
L	3	10	2	1	13	107.82	13.65	24.55	5.9	44.1	19.26	53.9	34	12	30.7	11.8	32.21	14.76	0.586
M	0	0	0	0	0	48.24	0	0	0	0	12.25	40.3	20	12	-	-	-	-	-
N	1	1	0	0	1	120.66	3.5	0	0	3.5042	25.0	90.86	20	9	15.4	10.6	3.5	2.41	1.37
O	2	4	2	0	6	96.45	6.39	10.87	0	17.26	12.1	52.89	16	8	17.6	9.4	7.67	6.8	1.07
P	2	8	1	0	9	60.66	14.61	17.2	0	31.81	15.27	36.96	19	8	17.3	8	20.84	11.96	0.446
Q	0	0	0	0	0	13.11	0	0	0	0	4.93	18.41	15	9	-	-	-	-	-

Table 2: Basin morphometric parameters used to evaluate the Khari River Basin

Aspect of Analysis	Morphometric parameters	Equation/Formula	Followed by	Threshold value and Interpretation
Linear aspect	Stream Order (u)	Stream hierarchy	Strahler (1964)	Indicates the empirical relationship of stream order with different parameters of drainage composition such as number, length, slope and basin area.
	Stream Number (Nu)	Nu ¼ N1þN2þ … Nn	Horton (1945)	Indicates the numbers of stream of segments of each order and evolves as inverse geometric sequence with order number. Nu/Basin area > 0.2, structural control.
	Stream Length Ratio (S_{tr})	$S_{tr} = L_u / L_{u-1}$	Horton (1945)	Indicates the development of the late youth stage of geomorphic streams that can be related to fault emplacements or reactivations.
	Bifurcation Ratio (R_b)	$R_b = N_u / N_{u-1}$	Schumm (1956)	R_b normally varying from 3.0-5.0 in drainage indicates natural drainage system within homogenous rock and higher or lower the value expresses irregularities of drainage basin development under lithological and structural variation controls.
	Mean Bifurcation Ratio (B_R)	B_R = Average of R_b	Strahler (1957)	
	Stream gradient Ratio (S_g)	$S_g = (a-b)/l$	Sreedevi *et al.*, (2005)	Indicates the ratio of drop of stream elevation with per unit horizontal distance. Higher the S_g is High slope and lower the S_g is gentle slope of stream that's indicates the stream power.
Aerial aspect	Stream Frequency (S_f)	$S_f = \sum N_u/A$ (no./k^2)	Horton (1945)	Indicates the number of stream segments successively present in unit area informs on responses of watershed to runoff processes.
	Drainage Density (D_d)	$D_d = \sum L_u/A$ (km/km^2)	Horton (1945)	Drainage density primarily influenced by lithological condition, provides quantitative reflection of dissections, landform typologies, geneses under lithology, tectonics and climate variations.
	Form Factor (F_f)	$F_f = A/L^2$	Horton (1945)	The value 0.7857 indicates a compact massive circular basin, and in case of lover value (0.5) indicates typify narrow elongated watershed.
	Elongation Ratio (E_r)	$E_r = 1.128\sqrt{(A/L)}$	Schumm (1956)	Indicates various shape of watershed, circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7) and more elongated (<0.5).
	Circularity Ratio (C_r)	C_r = 4paiA/P^2	Strahler (1957)	Defines circular character of watershed. Lower values below 1 indicate oval-shaped or elongated form.
	Compactness Coefficient (C_c)	$C_c = 0.2821\ P/A^{0.5}$	Gravelius (1914)	Indicates the ratio of perimeter of watershed to circumference of a circle whose area is equal to the drainage basin used for inter-basin comparison.
	Constant of Channel Maintenance (C_m)	$C_m = 1/D_d$	Schumm (1956)	Indicates the dynamic equilibrium stage of watershed and constitutes an important climate history indicator.
	Length of Overland Flow (L_o)	$L_o = 1/2\ D_d$	Horton (1945)	Informs on variables affecting both the hydrologic and physiographic development of drainage basins and channel evolutions.
Relief aspect	Relative Relief (R_r)	$R_r = B_r/L$	Schumm (1956)	The value > 0.5 indicates high relative relief and < 0.5 indicates low relative relief
	Absolute Relief (A_r)	A_r = H-h	Schumm (1961)	Indicates the amplitude of erosion in relation to maximum elevation of the area

Where, Nu = Total no of stream segments of 'u' order; A = Area of the basin (km2); Lu = Total length of streams of order 'u' (km); Lu-1 = Total stream length of its next higher order; Nu-1 = Total no of stream segments of its next higher order; L = Basin maximum length (km); P = Perimeter (Km); H = Maximum elevation (m); h = Minimum elevation (m); a = Elevation of stream at source point (m); b = Elevation of stream at confluence point (m); l = Actual length of the stream (m); K = A proportional constant; s = Slop of the stream.

RESULT AND DISCUSSION

Linear aspect

The KRB is a 4th order basin with 157 first order streams, 33 second order, 06 third orders and 01 fourth order stream. Total stream length of the basin is about 537 km with an average stream density of 0.44 km/km^2, where first, second, third and fourth order streams covers almost 27%, 36%, 17% and 20% of the stream length respectively. Bifurcation ratios of the KRB between 1st- 2nd, 2nd-3rd and 3rd-4th order streams are 4.76, 5.5, and 6 respectively. The mean bifurcation ratio of the basin is 5.42, which is the higher than any other rivers of the *Rarh Bengal* (Roy and Sahu, 2015), reveals the presence of structural control on drainage network development (Strahler, 1964). Linear parameters of the sub-basins are summarised in table 1. Figure 4 represents the relationship between stream-number, stream-length and stream-orders which are negative exponential trend and natural extension of drainage network (Horton, 1954). The stream numbers as well as stream length are higher on the left side of the basin (Figure and table) which indicates that the left side of the KRB is potential surface of drainage development and the trunk stream has been migrated towards the right (Resmi *et al.*, 2019). Sub-basin A is characterised by highest Nu = 70 and Lu = 153.06 km (Table 1). Sub-basins B, C, F, H, K and L are associated with comparatively higher Nu (>10) and sub-basin E, G, I, J, O and P are characterised by lower Nu (<10) (Table 1). First and second order mean stream length of sub-basins H, I, J, K, L, O, P (>1 km) and sub-basins C, F, J, K, L, P (>7 km) are respectively very high (Table 1). Among these, J, K, L and P sub-basins stream length ratio are relatively higher which indicates the faster channel elongation process causes of high stream gradient and more channelized flow (Resmi *et al.*, 2019) due to diversity in sub-basins slope and erosional stages of these basins. These sub-basins are draining the downstream part of the basin in two opposite side of the Damodar fault. Mean bifurcation ration of the left-hand sub-basins are comparatively high (Figure 6a). This higher mean bifurcation ratio and S_g (Table 1) of these downstream sub-basins also indicates structural or tectonics control on hydrological pattern and regional drainage branching (Verstappen, 1983; Ngapna *et al.*, 2018).

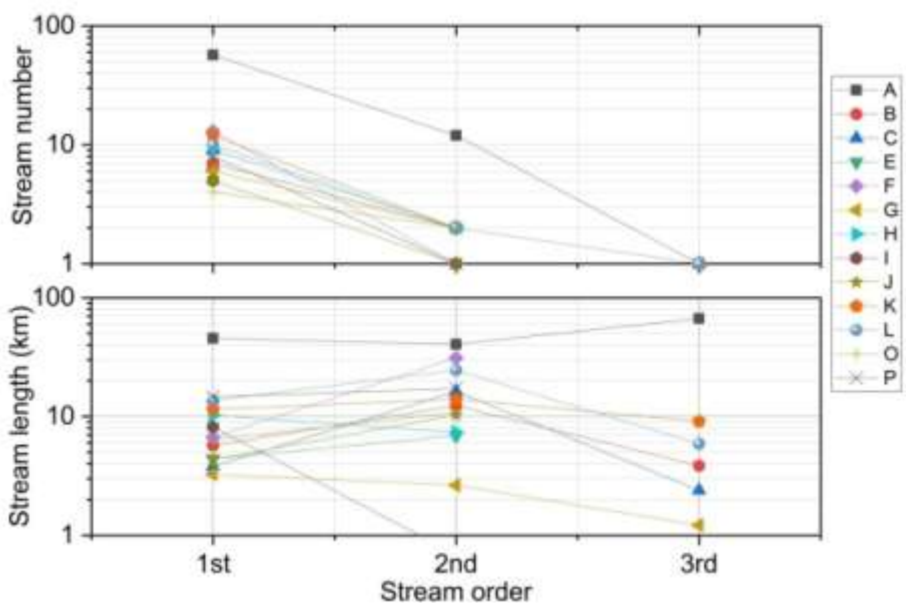

Figure 4 Relationship between stream number, stream length and stream orders of the KRB.

Sinuosity index and stream gradient

Sinuosity index (SI) and stream gradient are two important indicators of channel pattern to analysis the active tectonics (Gradiner, 1990). The average SI value of the KRB trunk stream is 2.41 (Table 3) which indicates the river is highly sinuous and meandering in nature. According to Barman et al. (2018) the SI value of the same stream was 2.34 in 1972. The increasing sinuosity signifies the active and oscillating nature of the Khari River. The sub-basins wise SI values varies from 1.13 (sub-basin D) to 2.18 (sub-basin L) (Table 3). Sub-basins B, C, E, F, G, H, J, K, L and P are meandering in nature with high SI values (SI = >1.5), whereas, sub-basins A, I and N are sinuous (SI = 1.25-1.5), and sub-basins D and O are almost straight (SI = <1.25) in nature (Table 3). Sinuous basins I and N are having catchment with one first order interior link and dominated by surface runoff or paleochannel flow. The Khari Trunk stream gradient is 0.38 m/km. and sub-basins range between 0.40 m/km (sub-basin D) to 1.92 m/km (sub-basin H) (Table 3). Analyses of SI and stream gradient helps in understand the effect of topographic characteristics on channel course (Bhatt *et al.*, 2008). Over the region, a negative correlation (r = – 0.58) has been observed between SI and stream gradient (Figure 5). This also indicates lower stream power is the cause of increasing stream sinuosity of the KRB and sub-basins (Leopold *et al.*, 1964).

Table 3: Sinuosity index and stream gradient index of the KRB and sub-basins

Sub-basin	Actual length (km)	Straight Line length (km)	Sinuosity index (SI)	Stream gradient (m/km)	Remarks
A	47.63	32.54	1.46	0.61	Sinuous stream
B	14.89	7.56	1.97	0.75	Meandering stream
C	12.42	7.03	1.77	0.95	Meandering stream
D	0.45	0.4	1.13	0.40	Straight stream
E	5.9	2.9	2.03	1.16	Meandering stream
F	31.22	16.91	1.84	0.56	Meandering stream
G	4.24	2.83	1.5	1.48	Meandering stream
H	6.34	4.16	1.52	1.92	Meandering stream
I	1.69	1.31	1.29	1.24	Sinuous stream
J	11.16	6.81	1.64	1.03	Meandering stream
K	23.76	12.95	1.83	0.60	Meandering stream
L	32.21	14.76	2.18	0.59	Meandering stream
N	3.5	2.41	1.45	1.37	Sinuous stream
O	7.67	6.8	1.13	1.07	Straight stream
P	20.84	11.96	1.74	0.45	Meandering stream
Trunk stream	183.56	76.23	2.41	0.38	Meandering stream

Areal aspect

The KRB is a narrow elongated basin with an elongation ratio (E_r) of 0.48 and circulatory ratio (C_r) of 0.27. Basin maximum length is 81.90 km and maximum width is 21.68 km. The basin is 3.75 times longer than its width and wider in its downstream direction. This non-circularity nature of the KRB is also clear from the form factor (F_f=0.18) which is much lower than the reference value (Figure 6c). It has also been clear from the values of F_f, E_r and C_r that sub-basins F, J, K, L and P are narrow elongated (Figure 6c, d and e). All these sub-basins are draining the downstream and wider part of the basin. Such planimetric shape of the KRB and of these sub-basins in alluvium surface is points out the tectonic activity (Strahler, 1964; Schumm, 1965 and 1986). Average D_d of the KRB is 0.44 km/km^2 and sub-basins ranges between 0.178 to 0.581 km/km^2 (Figure 7d). Though, overall D_d of are very low, sub-basins, basin A, J and P are relatively high with value of D_d = >0.50 and basin B, C, F, G and K belong

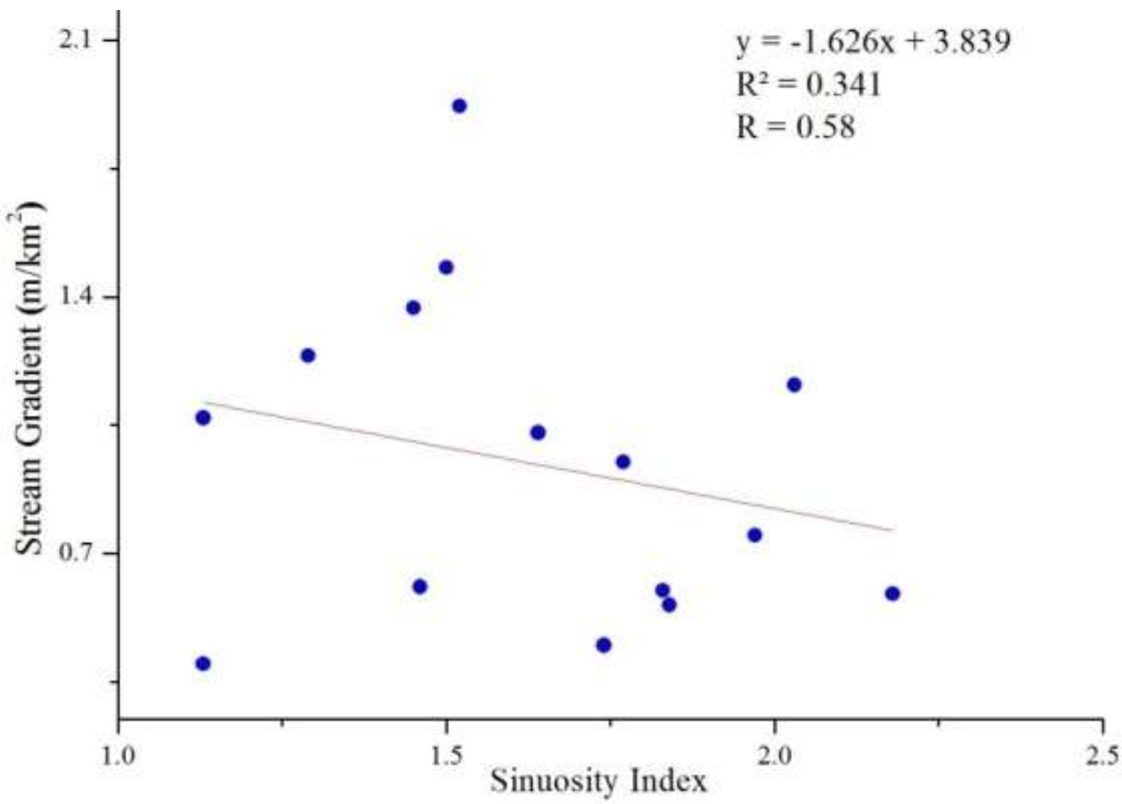

Figure 5: Scatter plot of stream gradient and sinuosity of the KRB and sub-basins

near to this value (Figure 7d). This low D_d implies low channelized flow as a result of high rate of infiltration causes of alluvium surface and/or high surface run-off causes of younger basin (Ramalingam and Santhakumar, 2001). Stream frequency of the KRB is 0.163 no./km2 and sub-basins ranges between 0.062 to 0.544 no./km2 (Figure 6b). The sub-basins at the central part of the Khari basin shows relatively moderate Sf that leads to more surface run-off which, are also elongated. However, in sub-basin specific analysis, sub-basin B, C, J, K, L, and P are represents the higher values that probably indicating the high rate of channel initiation. Mean compactness coefficient (C_c) of the KRB is 1.685 and highest value has been observed in sub-basin I with Cc=2.331 (Figure 6f). The constant of channel maintenance (C_m) and length of overland flow (L_o) are ranges between C_c = 1.721 to Cc = 5.617 and Lo = 0.861 to L_o = 2.809 respectively (Figure 6g and h). All these values are indicates low energy surface of the KRB and its hydrology and morphology controlled by humid environment and tectonics (Ngapna *et al.*, 2018).

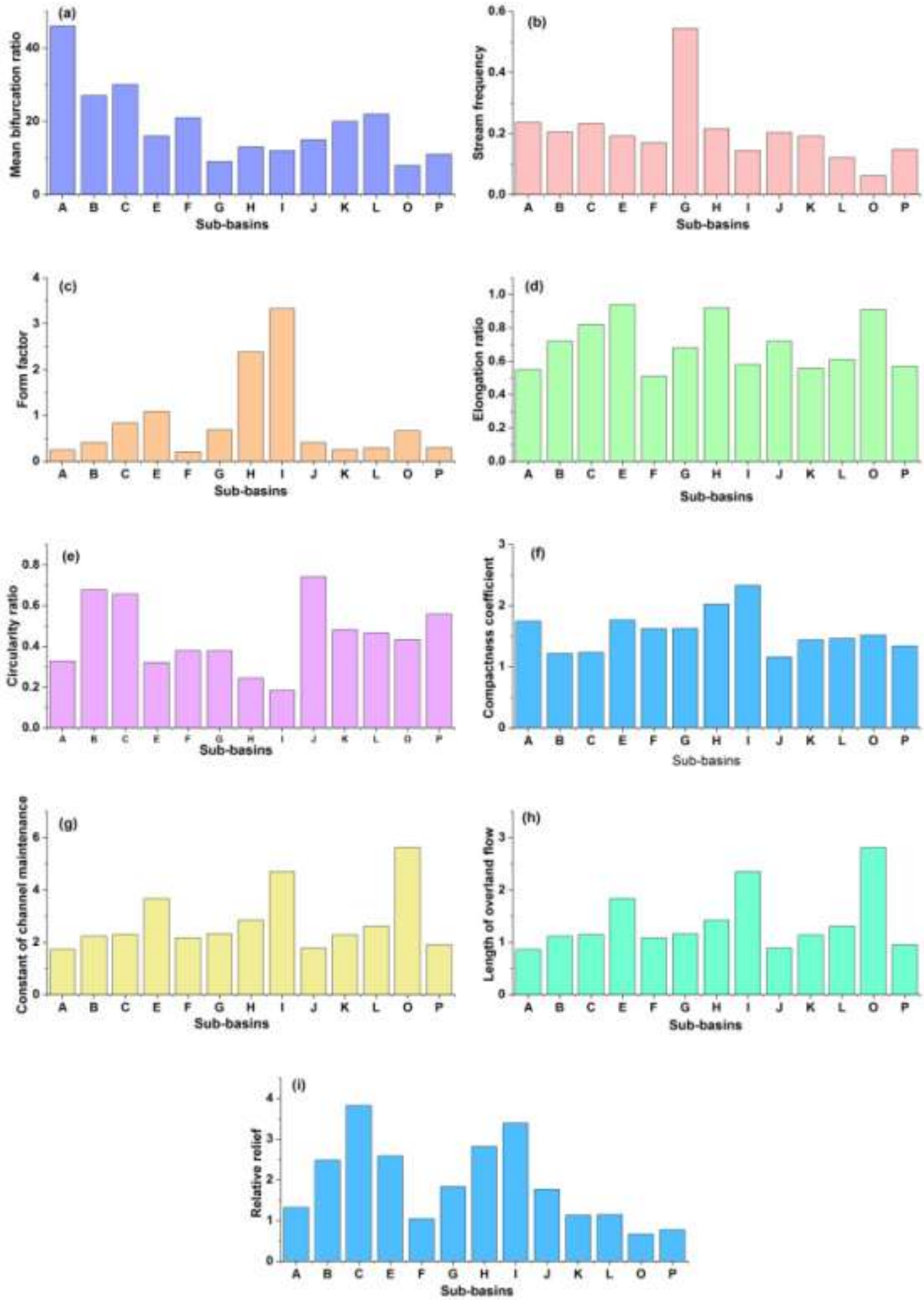

Figure 6: Sub-basin wise analysis of (a) mean bifurcation ratio, (b) stream frequency, (c) form factor, (d) elongation ratio, (e) circularity ratio, (f) compactness coefficient, (g) constant of channel maintenance, (h) length of overland flow, and (i) relative relief.

Relief aspect

Measurement of relief aspect highlights the potential energy of the drainage basin. Maximum elevation of the Khari basin is 75 meters and minimum is 5.8 meters. An extensive area (33%) of the downstream basin lies between 20 meters and 20 meters contours. This part of the basin indicates anomalies in areal aspects. Absolute relief of the basin is high at western part and considerably very low at eastern part (Figure 7a), which clearly indicates west to east ward basin slope. The relative relief (R_r) of the KRB is range from 1.07 meters to 8.4 meters (Figure 7b) with the basin average value of R_r = 2.09 which covers approximately 50% of basin area. Figure 7b suggests that the basin is characterised by very low relief condition and downstream part particularly, sub-basins F, E, K, L, O and P are flat surface with alternative high pockets of R_r along the trunk stream. Sub-basin specific Rr varies between 0.661 - 3.817 (Table 6i). The lower Rr values are associated with first and second order streams in source region of sub-basins (Figure 7b and 8b). An area of high R_r (R_r > 6.0) has been marked at NW part of sub-basin A and an another high observed along the trunk stream in sub-basin D, near Nargapur village (Figure 7b). This high R_r is the area of incised valley, submerge every year during flood (Figure 8c and e). Unpaired terrace, exposed lateritic formation and extremely low R_r in two side of this valley are indication of active down cutting and regional warping of land due tectonic activity (Figure 8a and d). Surface slope of the KRB ranges from 0.02° to 2.08°, with basin average of 0.54° (Figure 6c). Approximately, 80% of the basin area comes under the very gentle slopping and the remaining portion of basin is under moderate or steep slopping. The steep slope has been observed at the extreme NW part of KRB and in some patches along the trunk stream between Channa to Chandrapur village (Figure 6c). These patches are coincides with the regional high R_r indicating the surface anomalies.

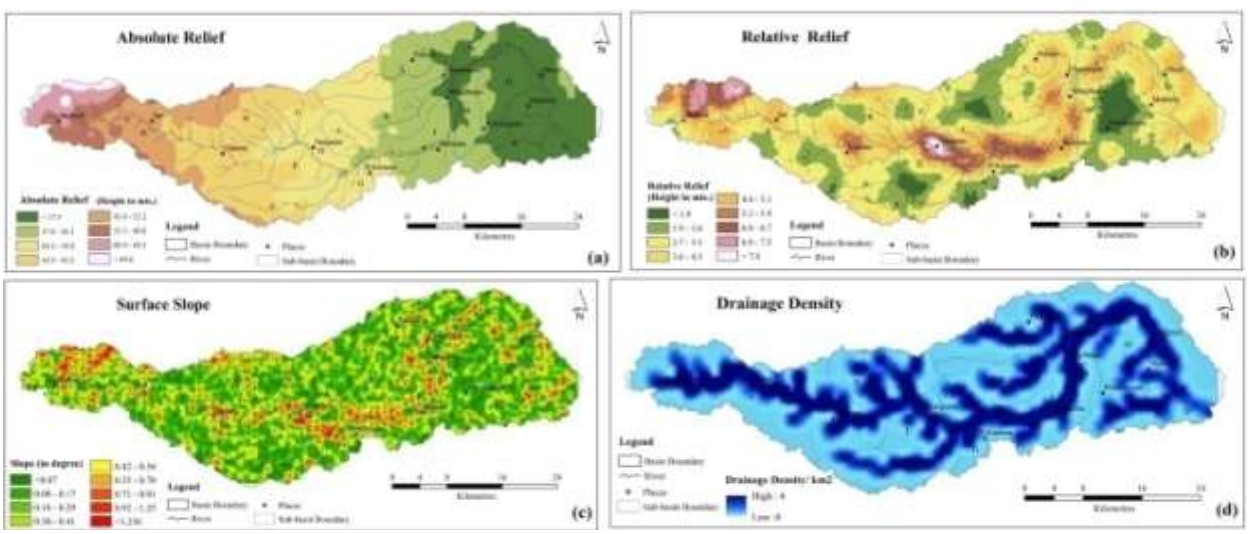

Figure 7: Thematic representation of (a) absolute relief, (b) relative relief, (c) surface slope and (d) drainage density of the KRB.

Stream and lineament orientation

Analysis of Drainage network helps to evaluate the existence relationship between spatial orientation of streams and tectonic structure (Resmi *et al.*, 2019). Although orientation of drainage evolve as complex interaction of structure, processes, stage and anthropogenic activity, in a region of less anthropogenic modification drainage network depicts the geological and tectonic nature of that region (Masoud and Koike, 2006; Ribolini and Spagnolo, 2008). A structural lineament is an expression of geological structure which is the weaker section of the surface. The drainage network run through these weaker parts have a spatial pattern and channel characteristics that provide good geological and tectonic record

(Sahazad *et al.*, 2009). In the KRB, we have been examined the orientation of streams and mean flow direction with lineament location and orientation (Figure 9).

Figure 8: Ground evidences of tectonic signature; (a) Exposed Pleistocene laterite formation on river bank near Nargapur, (b) flat surface near Ramngar which is the source region of radial drainage pattern at left bank of trunk stream, (c) incised channel near the upstream of Nargapur, (d) paleochannel of Khari with unpaired terrace near Nargapur at right side, and (e) flooding of Khari river near Narjapur.

The trunk stream which is draining the western part of the basin and sub-basin A initially flows from west to east but, near the Sar the stream turned ~45° towards SE and continued up to the downstream of Channa (Figure 9). In the middle portion between Channa and Nargapur the trunk stream flowing from W to E and take another sharp ~90° clockwise turn at upstream of Nagarpur. Near Kurmun this SE ward flow direction turned anticlockwise to flow eastward. Near Malumba the trunk stream take abruptly ~90° anticlockwise turn and flowing towards north up to Chandrapur, from where the flow direction is NE ward for the next 16 km (Figure 9). These major flow turns are the area where one lineament ends and new lineament starts and the lineaments orientation coincides with the stream flow direction and orientation (Figure 9). However, the Khari River basin and all sub-basins illustrating a dendritic drainage pattern, the main stream of sub-basins F, J, K, L and P are flowing parallel with trunk stream and in same flow direction (Figure 9). The mean flow direction and rose diagram of 1st, 2nd and 3rd orders stream orientation shows an approximately NW to SE trend which are similar to the NW to SE trend of lineaments (Figure 9). The lineaments length is varying between 1.12 km to 6.02 km and the average length is 2.69 km. Some lineaments are oriented SW to NE direction, particularly from the middle and lower part of the basin where trunk stream take anticlockwise turn towards NE. The orientation of trunk stream and lineament trends helps to understand the relationship between channel deflection and tectonics

(Resmi *et al.*, 2019). Although, the different order streams of the Khari River are drain into higher order from all direction, the preferential flow orientation of streams is likely to be tectonic controlled.

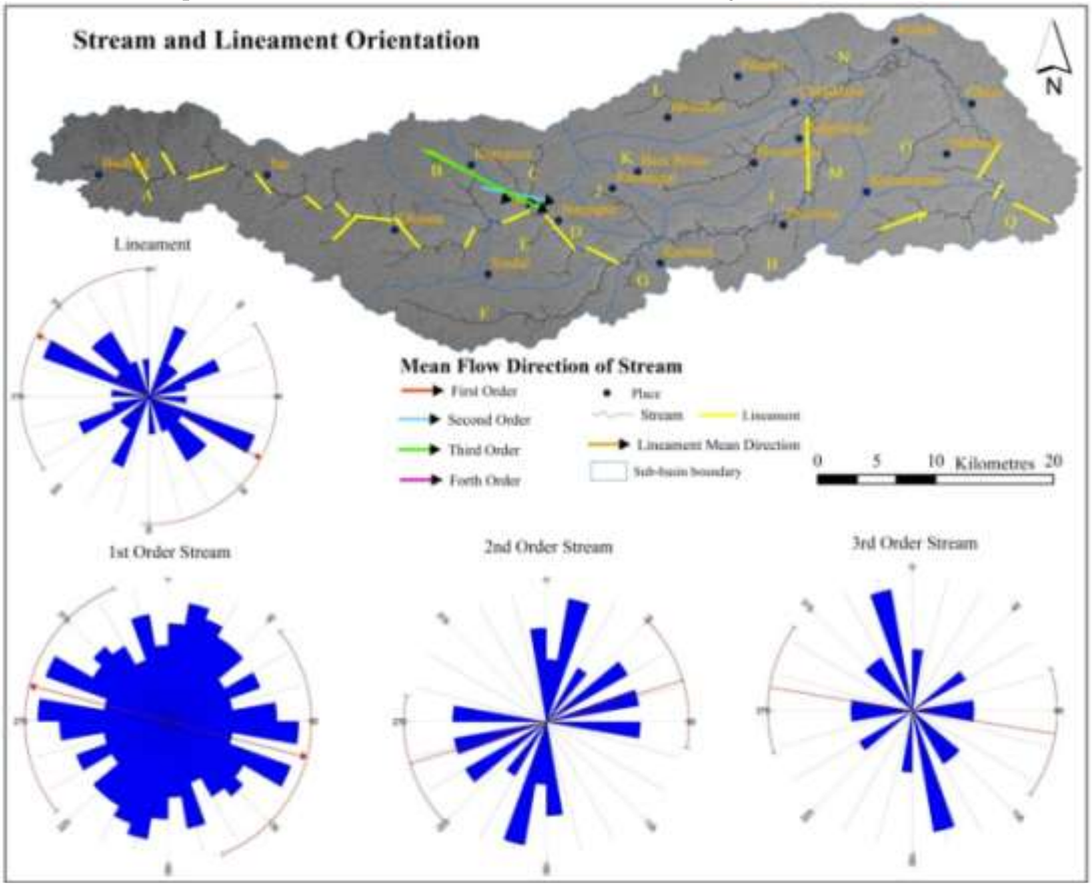

Figure 9: Drainage network of Khari River basin with mean flow direction of streams and correspondent rose diagram of stream flow direction of first, second, third and lineament direction.

CONCLUSION

After details analysis of morphometric parameters coupled with stream orientation and lineament arrangement, we can conclude that the basin has been influenced by tectonic activity. Because, the high bifurcation ratio along with low form factor and narrow elongation basin shapes in alluvium plain implies the geological control and tectonic activity on the drainage development. Left and right-basin stream disparity and drainage pattern deformation reveals the basin has been influenced by lateral tilt. Linear arrangement of stream and deflection of the master stream are the result of fault activity and lineament guiding. Although, the downstream part of the basin is very low relative relief maximum anomalies of morphometric parameters have been observed in this part along the two opposite side of Damodar fault and strike flow orientation of stream are the result of tectonic activity.

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