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ARTICLE Fluvial Geomorphology and Basin Development of Karra Khola Basin, Hetauda, Central Nepal

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ABSTRACT

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Keywords:

Morphometric analysis Stream classification Hypsometric analysis Geomorphic development Drainage density Dissection index Natural hazards Erosion Geomorphological study of a basin is important for understanding the overall basin characteristics which are helpful for the management of water resources, construction along the river bank and natural hazard mitigation within the area. The study was carried out in the Karra Khola Basin, one of the prominent basins in the Eastern extreme of the Hetauda Dun Valley, Central Nepal, to investigate geomorphic characteristics of the main stream of the basin, categorize them into various stream types and study basin development through drainage basin's morphometric parameters. Geographical Information System (GIS) and Remote sensing techniques using satellite images were used as a tool to make the morphometric analysis of the basin along with its major 13 sub-basin and delineate stream classification following the Rosgen's Level I hierarchical inventory. The main stream of the Karra Khola is characterized as A-, B- and C-type and the tributaries segments as B- and F-type. The basin is structurally unaffected and has the permeable surface area and elongated shape. The hypsometric analysis indicates that the basin is mostly at the old stage of geomorphic development while four out of 13 sub-basin being at mature stage. The Karra Khola sub-basin have higher risk to flash flooding (Lg=0.1-0.16km). Drainage density value reveals that the basin is highly susceptible to flooding, gully erosion, etc. Similarly, dissection index value implies that the north eastern region of the basin is highly vulnerable to erosion as it at the younger stage of geomorphic development. Since the study area is highly sensitive to future natural hazards, further study and appropriate measures should be followed for safeguarding against the future risk along the Karra Khola basin and its tributaries.

1. Introduction

F luvial geomorphology is the study of river process and forms ^[1]. It deals with the study of river forms in plan and cross section that is resulted from interaction among water, sediment and channel boundaries ^[1]. This study provides the important information required for the management of water resource, construction along the river bank and natural hazard mitigation. Geomorphological studies of the drainage basin deals with the determination of various geomorphological parameters and classify the stream type. Channel width,

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depth, velocity, discharge, channel slope, roughness of channel materials, sediment load and sediment size are some major variables influencing stream pattern morphology^[2]. It is important to understand the dynamics of river in order to manage the flood plain and control bank erosions and acknowledge river stability condition^[3]. The Rosgen stream classification [4] categorizes streams according to channel morphology so that consistent, reproducible and quantitative descriptions can be made ^[5]. This classification is one of the most widely applied stream classification system^[6-7]. It involves 4 classification hierarchies of natural streams. The Level I hierarchical inventory describes geomorphic characters resulted from the integration of the basin relief, landform and valley morphology. Level 1 stream classification serves four primary functions: (1) provide initial integration of basin characteristics, valley types, and landforms with stream system morphology, (2) provide an initial framework for organizing different aspects of river morphology, (3) assist in the setting of priorities for conducting more detailed assessments and (4) correlate similar general level inventories such as fisheries habitat, river boating categories, and riparian habitat with companion river inventories^[4].

Morphometry is the measurement of shape, or geometry of any natural form- plant, animal or relief feature^[8]. The comparative evaluation of the basin in terms of various geomorphological and topographic conditions can be made from detail analysis of the morphometric parameters. Through the inference of different relief morphometric measures of drainage basin, the evolutionary history of any basin can be best understood^[9-10]. With the study of different morphometric parameters, the geomorphological stages of evolution with its erosional characteristics can also be best understood ^[11]. It incorporates quantitative study of the various components such as, stream segments, basin length, basin parameters, basin area, altitude, volume, slope, profiles of the land which indicates the nature of basin development. In recent times, remote sensing and Geographic Information System (GIS) techniques are being effectively used as tools in the evaluation of quantitative description of basin morphometry^[12-14]. Different researchers have successfully used GIS and remote sensing as a tool to evaluate morphometric parameters.

The Sub-Himalaya, Siwalik Range of Nepal is geologically young mountain range^[15-17] evolved in Tertiary Period and have been experiencing its deformation from the millions of years back to till now. The Chure Range in the Central Nepal Sub-Himalaya is the consequent event of one of youngest deformation phases in the Quaternary Period, when the Main Frontal Thrust has created upliftment of the thrust sheet ^[16-19] to its present range, therefore forming a piggy back basin, currently known as Dun valley. The upliftment of the Chure Range in the southern margin of the Dun valley created subsequent drainage basins, and among them the Karra Khola Basin is the prominent basin in the eastern extreme of the Hetauda Dun Valley. As the Karra Khola has evolved consequently to the formation of the Chure Range and generation of the subsequent north flowing tributaries, it is crucial to study the pattern of the drainage system in the Karra Khola basin and categorize them into the various stream types, and measure drainage basin's linear, areal, relief and slope aspects to characterize the basin. Therefore, in the present study, an attempt has been made to characterize the main stream of Karra Khola as per the Rosgen classification system^[4]. Along with the study of linear, areal and relief aspects of the basin geometry through morphometric means for the basin and sub-basin, their hypsometric integral values have also been computed to understand the stages of geomorphic evolution and geological development of the basin. Findings from this study would help in designing appropriate measures for the conservation of soil and water resources within the basin and sub-basin, which would eventually assist to control soil erosion, conserve water and reduce sediment discharge.

2. Study Area

The study area lies in the Makwanpur District, Narayani Zone of the Province no. 3 of Nepal. According to the tectonomorphological division of the Nepal Himalaya from the south to the north, it lies in the Sub Himalaya. The study area is bounded between longitude 85°0'54"E - 85°11'24"E and latitude 27°21'15"N - 27°26'36"N .The Karra Khola watershed is an important tributary of the Rapati Nadi located in the northern face of the Churiya Hills (Figure 1). The Bhedaha Khola and the Tamune Khola lies in the north-eastern part, while Barauli Khola meets the main stem of the Karra Khola from the east. Similarly, Agrathe Khahare, Gauritar Khahare, Chisapani Khahre and Khahare Khahare are other ephemeral streams in the southern region of the study area. The basin covers an area of 99.3 sq km and has perimeter 63.39 km.



Figure 1. Location map of the Karra Khola basin

3. Geology of the Study Area

The study area lies in the Siwalik Group of Nepal Himalaya. The Main Boundary Thrust (MBT) separates the Siwalik Group from the Lesser Himalayan metasediments in the North. The Central Churia Thrust (CCT) divides the Siwalik Group into the northern and the southern belts. The Himalayan Frontal Fault (HFF) runs intermittently along the southern foot of the Churia Range. The study area comprises three lithological units namely the Upper Siwalik Subgroup, the Middle Siwalik Subgroup and the Lower Siwalik Subgroup along with the Quaternary Alluvium deposits ^[20] (Figure 2). The Lower Siwalik Subgroup is mainly made up of variegated mudstones and shales with thin interbedded layers of sandstone. The Middle Siwalik Subgroup consists mainly of medium to very coarse grained 'salt and pepper' sandstones. Upper Siwalik Subgroup primarily consists of pebble and cobble conglomerates along with minor intercalation of sandstone and mudstones. The Quaternary Alluvial Deposit in the study area is spread mostly in the central and southern regions which consist of unconsolidated, coarse to fine sediment deposits.



Figure 2. Geological map of the Karra Khola basin (After Tamrakar and Karki, 2019)

4. Materials and Method

Geographical Information System (GIS) and Remote sensing techniques using satellite images were used as a tool to study the river morphology and make the morphometric analysis of the basin. The main stream of the basin, Karra Khola was divided into 22 segments considering one wave length as one segment for the morphological study and classification of the stream type following the Rosgen Level I classification ^[4,21]. Study of the topography, geomorphology and geology was done from topographic maps, Google Earth satellite imageries, literatures and field study.

The entire basin was further delineated into 13 major sub-basin manually from the digital topomap layers (Figure 4). Then different morphometric parameters were conducted for each of these sub-basin as well. Digital Elevation Model (DEM) of 30m resolution in ArcGIS 10.4.1 was used in drainage basin analysis. Considering the drainage characteristics of the Karra Khola basin, morphometric analysis was carried out for the whole basin. Parameters such as stream number, bifurcation ratio, stream length ratio and length of overland flow were computed to understand the linear characterization of the basin.

Geometric analysis of the basin was made by computing elongation ratio, form factor and circularity ratio. For the entire basin, the relative spacing of streams per unit length was computed in grid squares ^[22]. The dissection index for the entire basin was computed using grid method ^[23]. Hypsometric analysis was carried out to figure out the period of erosion cycle of the entire basin and sub-basin.

Table 1. Different morphometric parameters computed for the present study

Parameters	References	Formulae
Stream Order (Nu)	[24]	The channels which have no any tributaries were considered 1 st order. As two 1 st order segments meet, the channel was assigned 2 nd order and so forth
Bifurcation Ratio (Rb)	[25]	$Rb = N\mu/N_{\mu+1}$ Where, $N\mu =$ number of streams of a given order and $N_{\mu+1} =$ number of streams of the next higher order
Stream Length Ratio (RL)	[26]	RL = Lu/(Lu-1) Where, Lu = mean or average length of segment of order (u), Lu-1 = mean or average length of segment of lower order (u-1)
Length of overland flow (Lg)	[26]	Lg = 1/D*2 Where D = Drainage Density
Form Factor (Rf)	[27]	$Rf = A / (L_b)^2$ Where, $L_b =$ maximum basin length
Circularity Ratio (Rc)	[24]	Rc = 4 * $\pi^* A / P^2$ Where π = 'Pi' value i.e., 3.14, A = Area of the Basin (sq. km), P ² = Square of the Perimeter (km)
Elongation Ratio (Re)	[24]	Re = $2\sqrt{(A/\pi)}/L$ Where A = Area of the Basin (sq. km)
Drainage Texture (Dt)	[28]	Dt= AS = $\frac{1}{(t+p)/2}$ AS = average spacing between two streams, t= $\frac{(t_1+t_2)/2}{\sqrt{2}}$ Where t ₁ , t ₂ = no. of intersections between the stream network and grid square diagonals, p= $\frac{(t_1+t_2+t_3+t_4)}{4}$ Where, p ₁ to p ₄ = no. of intersection between the stream network and grid square edges
Basin Relief (R)		R=H-h Where, H= Highest elevation, h= lowest elevation
Relief ratio (Rr)	[29]	Relief ratio = $H-h/L$
Dissection Index (Di)	[23]	$Di = R_r/A_r$ Where, R_R is relative relief and A_R is absolute relief
Hypsometric Integral (HI)	[30]	$E = Hsi = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}}$ Where, $Elev_{mean}$ is the weighted mean elevation of the watershed estimated from the identifiable contours of the delineated watershed; $Elev_{min}$ and $Elev_{max}$ are the minimum and maximum elevations within the watershed.

5. Result and Discussion

5.1 River Morphology

Rosgen Level I classification is the geomorphic characterization where streams are classified on the basis of valley landforms and observable channel dimensions. The valley type present along the main stream of the Karra Khola is II, VII and VIII (Table 3). The stream segments 1st, 2nd, 3rd and 4th belong to valley type VII. The valley type along these origin segments of the main stream is moderately steep to steep with highly dissected fluvial slopes and high drainage density. The segments are deeply incised in Lower Siwalik substrate. The 5th, 6th and 7th segment belong to valley type II. The valley along these segments is colluvial side slopes and moderately steep valley slopes less than 4.0%. The remaining 15 segments belong to the valley type VIII. These are alluvial valley associated with the presence of multiple river terraces positioned laterally along broad valleys with gentle, down-elevation relief.

The average meander wavelength of the third, fourth and fifth order of river segments is respectively 0.54 km, 0.43 km and 0.598 km. The 13th segment has the highest meander wave length (1.03 km) and the 12th segment has the lowest value of meander wavelength (182.13 m) (Table 2). The meander belt width of the 5th order main stream varies from 92.8 m to 294.08 m. For the 4th order stream, it ranges from 104.32 m to 188.08 m (Table 2). The averages of the W_{blt} for 4th and 5th order stream segments are respectively 146.2 m and 179.94 m. The radius of curvature (R_c) of the main stream 4th order segment varies from 44.52 m to 145.09 m and that for the 5th order segment varies from 38.25 m to 225.05 m (Table 2). The averages for the 4th order and 5th order main stream segments are 93.57 m and 116.91 m respectively. The sinuosity of the 22 segments of the main stream varies from 1.03 to 1.56. The 6th segment is noticed as the meandering channel and the segments 1st, 2nd, 5th and 14th are straight channels. The remaining 17 segments belong to the sinuous channel. The average sinuosity of the 4th order and 5th order main stream segment of Karra Khola are 1.24 and 1.23 respectively.

Table 2. Plan-view parameter values of main stream	seg-
ments of the Karra Khola	

Segment ID	Segment Length (m)	Order	Wave Length (m)	Meander Belt Width (m)	Radius of Curvature (m)	Geological Formation
1	727.56	1	478.29	85.91	205.95	Lower Siwalik
2	559.72	2	320.14	26.64	89.20	Lower Siwalik
3	945.72	3	634.39	44.84	84.73	Lower Siwalik
4	672.53	3	460.13	60.85	169.07	Lower Siwalik
5	970.53	4	634.65	109.055 🗆	145.09	Lower Siwalik
6	720.68	4	330.41	104.32	44.52	Quaternary Mud
7	1139.55	4	339.66	188.08	91.10	Quaternary Mud
8	839.14	5	512.70	259.281 🗆	38.25	Quaternary Sand
9	2047.02	5	870.88	92.80	45.69	Quaternary Sand
10	704.14	5	317.70	134.06	107.03	Quaternary Sand
11	728.42	5	279.42	160.135 🗆	86.19	Quaternary Sand
12	611.88	5	182.13	164.351 🗆	54.90	Quaternary Sand
13	1716.35	5	1030.46	69.393 🗆	111.94	Quaternary Sand
14	431.70	5	235.11	143.86	188.87	Quaternary Sand
15	893.61	5	427.06	171.31	115.80	Quaternary Sand
16	1092.68	5	708.99	171.92	119.48	Quaternary Sand
17	1137.55	5	866.61	168.85	89.38	Quaternary Sand
18	1143.79	5	732.90	178.44	109.80	Quaternary Sand
19	969.09	5	553.18	224.982 🗆	123.39	Quaternary Sand
20	1207.68	5	675.43	264.11	131.91	Quaternary Sand
21	1680.40	5	810.83	294.08	225.05	Quaternary Sand
22	1416.16	5	773.08	289.23	205.95	Quaternary Sand

Stream Type

The stream type of the main stream Karra Khola has been classified considering all the necessary morphological characteristics. The main stream segments of the Karra Khola basin fall on A, B and C classes (Figure 3) of stream classification types. The segment of the main stream flowing from the origin through the steep terrain at the north-east boundary of the basin falls on A-type. The fifth, seventh, eighth and the thirteenth segment fall under B-type. Similarly, the remaining segments of the main stream belong to C-type stream (Table 3).

The C-type streams are sinuous alluvial channels with well defined floodplains more width to the depth and are less entrenched compared to A- and B-types. Most of the segment of the main stream flowing through the broad multi river terraces and broad flood plain are entrenched and fall under C-type of stream. The B-type stream segments have moderate entrenchment, wide channels to the depth and are sinuous channels. The F-type channels, which are found in upstream segment of Agrathae Khahrae and Gauritar Khahare are entrenched and meandering with higher width to the depth. The A-type stream segments are narrow channels with greater degree of entrenchment, lower width to the depth, lower sinuosity and steeper slopes as compared to the other stream types.

 Table 3. Level I classification of the main stream of Karra

 Khola

Level I Classification							
Segment	Order	Valley Type	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Туре
1	1	VII	<1.4	<12	1.2	0.347	А
2	2	VII	<1.4	<12	1.2	0.103	А
3	3	VII	<1.4	<12	1.05	0.169	А
4	3	VII	<1.4	<12	1.09	0.089	А
5	4	II	>1.4	<12	1	0.061	В
6	4	II	>2.2	>12	1.56	0.001	В
7	4	II	>1.4	>40	1.16	0.021	В
8	5	VIII	1.4-2.2	>12	1.34	0.02	В
9	5	VIII	>2.2	>12	1.41	0.004	C
10	5	VIII	>2.2	>12	1.08	0.004	C
11	5	VIII	>2.2	>12	1.28	0.002	C
12	5	VIII	>2.2	>12	1.49	0.001	C
13	5	VIII	<1.4	>12	1.23	0.0001	В
14	5	VIII	>2.2	>12	1.03	0.002	C
15	5	VIII	>2.2	>12	1.11	0.001	C
16	5	VIII	>2.2	>12	1.18	0.0008	C
17	5	VIII	>2.2	>12	1.11	0.003	C
18	5	VIII	>2.2	>12	1.43	0.004	C
19	5	VIII	>2.2	>12	1.21	0.001	C
20	5	VIII	>2.2	>40	1.19	0.005	С
21	5	VIII	>2.2	>40	1.26	0069	С
22	5	VIII	>2.2	>40	1.16	0.002	C



Figure 3. Stream classification map of the Karra Khola. The letters A, B, C and F represents the stream types

5.2 Morphometric Analysis

5.2.1 Linear Aspect

The morphometric assessment helps to elaborate a primary hydrological diagnosis in order to predict approximate behavior of a watershed when it is correctly coupled with geomorphology and geology ^[31]. The stream ordering was carried out following the method proposed by ^[11]. Among 13 sub-basin I, II and X are fourth order and remaining 10 sub-basin belong to third order. The total number of streams of Karra Khola is 463 of which 344 (74.29%), 89 (19.22%), 27 (5.83%) and 3 (0.64%) streams belongs to 1st, 2nd, 3rd and 4th order, respectively. The maximum frequency was for the first order streams with the frequency decreasing as increasing stream order.

Stream length helps to reflect the surface runoff characteristic of a basin. Longer length of stream indicates flatter gradient while smaller length signifies the area with steep slopes and finer texture. The stream length of the main stream is 22.46 km. The stream length of fifth order main stream is 16.613 km. The total stream length among the sub-basin ranges from 40.47 to 9.65 km. In general, the total length of stream segment is maximum in first order streams and decreases as the stream order decreases. However, in case of the sub-basin IX, the stream length of second order streams is greater than the first order streams.



Figure 4. Major 13 sub-basin delineated for the present study

The bifurcation ratio (Rb) is the ratio of number of streams of given order (u) to its next higher order (u+1)^[26]. It denotes the water carrying capacity and related flood potentiality of a basin. The mean Rb value normally ranges from 3.0-5.0 for basins in which the drainage patterns are not distorted by geological structures^[24]. Rb value for the Karra Khola basin is 4.80 and the values for the sub-basin vary from 2.85-4.75. The higher value of Rb for the sub-basin indicates that they have the strong structural control in the drainage pattern. The lower values indicate that the sub-basin are less affected by structural disturbance^[24]. The value of bifurcation ratio for the basin

indicates that drainage pattern of the Karra Khola basin has not been affected by the structural disturbances.

The length of overland flow (Lg) of the basin is 0.18 km. The value ranges between 0.1-0.16 km among the sub-basins. The Lg value for sub-basin X is the highest (0.16) as it has least value of drainage density among the sub-basin. Similarly, the lowest value of Lg is shown by the sub-basin V (0.1). In general, the sub-basin exhibits lower value of Lg which reflects that the sub-basin have short flow paths, more runoff, and less infiltration leading to their more vulnerability to the flash flooding.

Sub-basin	5	Stream Le	ngth Rati	0	Mean RI	Stream Order				Bifurcation Ratio	Length of Overland Flow
Sub-basin	RL1	RL2	RL3	RL4		1 st	2 nd	3 rd	4 th		
Ι	-	1.08	2.83	0.74	1.55	38	13	4	1	3.39	0.14
II	-	1.38	3.15	1.67	2.07	44	11	3	1	3.55	0.12
III	-	1.78	4.96	0	3.37	15	2	1	0	4.75	0.13
IV	-	1.49	2.33	0	1.91	11	3	1	0	3.33	0.13
V	-	2.30	0.67	0	1.48	10	3	1	0	3.16	0.10
VI	-	1.32	7.08	0	4.2	11	3	1	0	3.33	0.14
VII	-	1.92	2.49	0	2.21	15	5	1	0	4	0.11
VIII	-	0.97	8.69	0.04	3.23	16	5	2	0	2.85	0.14
IX	-	4.67	0.20	7.81	4.23	27	8	3	0	3.02	0.13
X	-	2.47	2.2	1.86	2.17	23	6	2	1	2.94	0.16
XI	-	2.96	5.25	0	4.1	15	4	1	0	3.87	0.15
XII	-	1.10	10.2	0	5.67	32	4	3	0	4.66	0.13
XIII	-	2.29	0.60	0	1.44	20	5	1	0	4.5	0.14

Table 4. Linear parameters values of 13 sub-basin

5.2.2 Basin Geometry

The elongation ratio (Re) of the basin is the ratio of diameter of a circle having same area as of the basin to the maximum basin length^[25]. Re value for the entire basin is 0.60 and for sub-basin it varies from 0.45 to 0.71 (Table 5). The sub-basin I, V and XIII are less elongated indicating their high susceptibility to erosion and sediment load. Similarly, the sub-basin namely II, III, IV, VI, VII, VIII, IX and X are categorized as elongated. The remaining sub-basin XI and XII are categorized as more elongated showing high infiltration capacity and low runoff characteristic of the basin.

Form factor (Rf) is the ratio of the area of the basin to the square of basin length^[27]. Smaller th e Rf, more elongated is the basin indicating lower peakflow with longer duration. Higher the value more circular is the basin indicating high peak flow in shorter duration^[32]. Rf for the basin is 0.28 and in case of sub-basins it ranges from 0.16-0.4. This low Rf value of basin and sub-basin conforms their elongated shape with lower peak flows of longer duration than the average.

Circulatory ratio (Rc) is the ratio between the area of the basin to the area of a circle having the same perimeter^[24]. It indicates geomorphological stages of development of any basin. Rc varies between 0 to 1. High, medium and low Rc value signifies old, mature and young stage of geomorphic development. Rc value of the Karra Khola basin is 0.31 referring to the elongated shape of the basin. For the sub-basins, Rc ranges between 0.3-0.66. Sub-basin II, IV, V, VII and XIII show high Rc value implying the old stage of geomorphic development of the sub-basin. The remaining watersheds having Rc value less than 0.5 are categorized as low Rc value indicating the mature geomorphological adjustment and less peak flow characteristic of the sub-basin. The analysis from the shape parameters (Re, Rf and Rc) clearly indicates an elongated shape of the sub-basins which in turn has an effect on their discharge characteristics.

Drainage density (Dd) is the ratio of total stream length in a given basin to the total area of the basin. Dd value of the basin is 2.77 km/sq. km. It indicates that the basin is poorly drained with a slow hydrologic response. Surface runoff is not rapidly removed from the watershed making it highly susceptible to flooding, gully erosion, etc. The drainage density among the sub-basin range from 2.98-4.67 indicating their coarse drainage system and somewhat permeable nature of their sub strata.

Table 5. Geomorphometric and relief parameter values of13 sub-basin

Sub- Basin	Form Factor (Rf)	Circulatory Index (Rc)	Drainage Texture (T)	Elongation Ratio (Re)	Drainage Density (Dd)	Drainage Texture (T)	Relief Ratio
Ι	0.39	0.49	3.23	0.70	3.46	3.23	0.07
II	0.30	0.53	4.35	0.6	3.92	4.35	0.16
III	0.20	0.42	2.08	0.51	3.84	2.08	0.16
IV	0.34	0.61	1.83	0.66	3.67	1.83	0.06
V	0.40	0.66	2.41	0.71	4.67	2.41	0.16
VI	0.20	0.36	1.5	0.51	3.52	1.5	0.05
VII	0.37	0.63	2.87	0.69	4.20	2.87	0.12
VIII	0.26	0.40	2.02	0.57	3.36	2.02	0.05
IX	0.28	0.41	2.41	0.60	3.75	2.41	0.05
Х	0.20	0.43	2.37	0.51	2.98	2.37	0.04
XI	0.16	0.35	1.38	0.45	3.23	1.38	0.05
XII	0.17	0.30	2.03	0.46	3.57	2.03	0.05
XIII	0.39	0.64	2.33	0.71	3.52	2.33	0.08

5.2.3 Relief Aspect

The relief of the basin is 875 m and the value for the sub-basin varies from 190 m to 860 m. The sub-basin II has the highest relief value and the sub-basin VI has least relief. The relief value per 1 km square grid has been classified as extremely low (0-15°), moderately low (15°- 30°), low (30° - 60°), moderate (60° - 120°), moderately high $(120^{\circ}-240^{\circ})$ and high $(>240^{\circ})$ categories (Figure 5). North eastern region of the basin mostly shows maximum difference in the highest and lowest elevation present because of the varying topography. The moderately low to low relief is present in the central region of the basin indicating the presence of flat to very gentle topography. Surrounding this region lies the area with moderate relief. The relief ratio of the whole basin is 0.05 and the values for the sub-basin ranges from 0.05 to 0.16 (Table 5). The sub-basin II, III, V and VII shows higher value of Rh because of having higher elevation, smaller drainage area and size. It indicates the presence of steep slopes in these sub-basin and their proneness to erosional activity. The remaining sub-basin have the lower value of Rh because of low degree of slope.

The drainage texture (Dt) of the Karra Khola basin as whole is 7.30 and the value for all sub-basins ranges from 1.38 to 4.35 (Table 5). The sub-basin II has the highest value, while XI has the lowest drainage texture value. The drainage texture map shows that most area of the basin has moderate drainage texture. The eastern and western boundary exhibits very coarse drainage texture (Figure 6). The Dt value is fine in some areas in the mid-east, mid-central and western region of the basin. In the central region, the places around Agrathe, Shikharpani and Chisapani show coarse to very coarse drainage texture. The areas showing finer drainage texture value have the greater potentiality to the erosion.



Figure 5. Basin relief map of the Karra Khola basin



Figure 6. Drainage texture map of the study area

5.2.4 Dissection Index (Di)

Dissection index expresses the ratio of the maximum basin relief to the maximum absolute relief. It indicates the nature and magnitude of dissection of terrain. It defines the roughness of a surface developed by numerous valleys. The value of Di derived for each grid squares vary between 0 and 1. The values thus obtained are has been classified into five categories: (1) extremely low (0-0.1), (2) low (0.1-0.2), (3) moderate (0.2-0.3), (iv) high (0.3-0.4) and (v) very high (more than 0.4). Most parts of the basin shows extremely low (0-0.1) value while the least part has very high (>0.4)

value (Figure 7). Extremely low index is observed for the terrain which has flat terraces, low reliefs and covered by alluvium deposit. The north-eastern edge of the basin shows higher value of Di near Sano Gadhi which indicate their higher risk for erosion to occur. The middle part of the basin shows the least value because of the presence of wide and flat topography. The spatial distribution map of the Di of the basin shows the variation of the values within the basin. The spatial variation of the index value helps to determine that the region with very high index is at younger stage of erosion cycle. Likely, the central region of the basin is at older stage of the erosion cycle.



Figure 7. Dissection index map of the Karra Khola basin

5.2.5 Hypsometric Integral (HI)

Hypsometric Curves (HC) and hypsometric integrals (HI) are important indicators of watershed conditions ^[33]. It

helps to understand the degree of dissection and stage of cycle of erosion. Hypsometric curve is obtained by plotting the relative area along the abscissa and relative elevation along the ordinate. The relative area is obtained as a



Figure 8. The hypsometric curves of each sub-basin with relative area on horizontal axis and relative height on vertical axis

ratio of the area above a particular contour to the total area of the watershed encompassing the outlet. The relative elevation is calculated as the ratio of the height of a given contour (h) from the base plane to the maximum basin elevation (H). The resulting curve starts at the top left corner at 1.0 and ends at the bottom right corner at 1.0. The hypsometric integral is equivalent to the ratio of the area under the curve to the area of the entire square formed by covering it (Figure 8).

The HI value for the entire basin ranges from 0.176-0.386 (Table 6). The hypsometric integral values, relative

elevation and relative area value with corresponding contour values have been calculated for the basin and 13 sub-basin. The sub-basin have been classified as young (>0.6), mature (0.3-0.6) and old (<0.3) stage of the erosion cycle according to their values for the hypsometric integral. The sub-basin II, IV, V and VI are at equilibrium or mature stage and heading towards the peneplanation or deteriorating stage. This indicates that the soil erosion from these sub-basin were primarily derived from the incision of channel beds, down slope movement of topsoil and bedrock material, washout of soil mass and cutting of stream banks. It is understood that the hydrologic response of the sub-basin attaining the mature stages will have slow rate of erosion^[33] unless there are very high intense storms leading to high runoff peaks. The remaining sub-basin namely, I, III, VII, VIII, IX, X, XI, XII and XIII are at old stage of the erosion cycle.

Sub-basin	HI	Stage of erosion cycle		
Ι	0.18	old		
II	0.302	mature		
III	0.282	old		
IV	0.386	mature		
V	0.317	mature		
VI	0.34	mature		
VII	0.18	old		
VIII	0.217	old		
IX	0.225	old		
Х	0.224	old		
XI	0.225	old		
XII	0.285	old		
XIII	0.176	old		

Table 6. Hypsometric Integral value for 13 sub-basin

6. Conclusion

The main stream of the Karra Khola originates from the north-eastern hills within the basin and stretches for about 22.35 km and meets the Rapti River at the western extreme of the basin. The stream segments of the Karra Khola falls on A, B, C and F classes. First to fourth order segments flowing through the substrate of the Lower Siwalik sub-group fall on A- and B-type. Similarly, B-type streams of fourth order are developed at segments flowing through the substrate of Quaternary Mud deposit. The fifth order B- and C-type streams are developed in the Quaternary Sand substrate. F-type stream are developed towards upstream segment of Agrathe Khahare and Gauritar Khahare on the substrate of Quaternary Gravel deposit.

Morphometric analysis of a drainage basin is a better approach towards unraveling various aspects of basin characteristics and its development. GIS and remote sensing procedures can be successfully applied for computing different morphometric parameters. The Karra Khola basin is 5th order basin mostly populated by 1st and 2nd order streams. It is an elongated basin along with most of its sub-basin indicating their high runoff feature. Rb value of the sub-basins conforms that they are unaffected by the structural disturbance. Sub-basin are characterized with short flow paths, more run off and less infiltration indicating their vulnerability to flash flooding. The drainage density values of the basin reveal the surface area of the basin is permeable; marking its high susceptibility to flooding, gully erosion, etc. The basin has very coarse texture mainly in the eastern territory along with north-east, south-west region and towards the confluence of the main stream Karra Khola and Rapti Nadi. The central portion of the basin executes very fine, fine and moderate drainage texture. Dissection index value implies that the north eastern regions of the basin are at younger state of erosion cycle and are at higher risk for erosion to occur, while the central region of the basin is at older stage of geomorphic development. Hypsometric analysis was helpful to visualize the erosional stage of basin and sub-basin with quantitative interpretation. It reflected that the basin and most of its sub-basin are at the old stage of geomorphic development process. The study clearly elucidates that the Karra Khola basin is at a greater threat future natural calamities such as flash flood, erosion, etc. The information and findings condensed under this study can be valuable to guide researchers, planners, developers and decision makers for adopting suitable soil erosion and flood disaster risk reduction measures in the Karra Khola basin, a major tributary of Rapti Nadi.

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References

- Lewin, J., Brewer, A. P.. Sedimentary Process/ Fluvial Geomorphology. Encyclopedia of Geology, 2005: 650-663.
- [2] Leopold, L. B., Wolman, M. G., Miller, J. P., Fluvial Process in geomorphology. Freeman, San Francisco, CA, 1964: 522.
- [3] Shrestha, P., Tamrakar, N. K.. Morphology and classification of the main stem Bagmati River, Central Nepal. Bulletin of the Department of Geology, Tribhuvan University, Kathmandu, Nepal, 2012, 15: 23-34. https://doi.org/10.3126/bdg.v15i0.7415.
- [4] Rosgen, D. L. A classification of natural rivers. Cantena, 1994, 22: 169-199. https://doi.org/10.1016/0341-8162(94)90001-9
- [5] Qazi, H. A., Ashok, P. K.. Hydology, geomorphology and Rosgen Classification of Doodhganga stream in

Journal of Geological Research | Volume 02 | Issue 04 | October 2020

Kashmir Himalaya, India. International Journal of Water Resources and Environmental Engineering, 2011, 3: 57-65.

- [6] Buffington, J. M., Montgomery D, R. Geomorphic classification of rivers. Treatise on Geomorphology, 2013, 9: 730-767.
- [7] Juracek, K. E., Fitzpatrick, F. A., Limitations and implications of stream classification. Journal of the American Water Resource Association, 2003, 39: 659-670.

https://doi.org/10.1111/j.1752-1688.2003.tb03683.x

- [8] Strahler, A. N. Physical Geography. 3rd edition, John Willey and Sons, New York, 1969: 535.
- [9] Sharma, S., Sarma, J. N. Drainage analysis in a part of the Brahmaputra valley in Sivasagar district, Assam, India, to detect the role of nontectonic activity. Journal of Indian Society of Remote Sensing, 2013, 41, 4: 895-904.

https://doi.org/10.1007/s13201-019-1118-2

- [10] Mahala, A.. The significance of morphometric analysis to understand the hydrological and morphological characteristics in two different morpho-climatic settings. Applied Water Science, 2020, 10: 33. https://doi.org/10.1007/s13201-019-1118-2
- [11] Strahler, A. Dynamic basis of geomorphology. Geological Society of America Bulletin, 1952, 63: 923-938. http://dx.doi.org/10.1130/00167606(1952)63[11 17:HAAOET]2.0.CO;2.
- [12] Nautiyal, M. D. Morphometric analysis of drainage basin using aerial photographs; a case study of Khairkuli basin. District Dehradun. W. P. Journal of Indian Society of Remote Sensing, 1994, 22, 4: 251-261.

https://doi.org/10.1007/BF03026526

[13] Biswas, S., Sudhakar, S., Desai, V. R.. Prioritisation of subwatersheds based on morphometric analysis of drainage basin: a remote sensing and GIS approach. Journal of Indian Society of Remote Sensing, 199, 27: 155.

https://doi.org/10.1007/BF02991569

[14] Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N., Jini, K. V.. Geographical information system-based morphometric analysis of Bharathapuzha river basin, Kerala, India. Applied Water Science, 2013, 3: 467-477.

https://doi.org/10.1007/s13201-013-0095-0

- [15] Tokuoka, T. The Churai (Siwalik) Group in West Central Nepal. Bulletin of the Department of Geology, Tribhuvan University, 1992, 22: 75-88.
- [16] Tokuoka, T., Takayasu, K., Yoshida, M., and Hisatomi, K.. The Churia (Siwalik) Group of the Arung Khola area, west-central Nepal. Memoirs of the Fac-

ulty of Science, Department of Geology, Shimane University, 1986, 22: 135-210.

- [17] Kizaki, K.. An outline of Himalayan upheaval. Jagadamba Prakashan, Kathmandu, 1994: 127.
- [18] Critelli, S., Ingersoll, R. V.. Sandstone petrology and provenance of the Siwalik Group (northwest Pakistan and western-southeastern Nepal). Journal of Sedimentary Research, 1994, A64: 815823. https://doi.org/10.1306/D4267ED3-2B26-11D7-8648000102C1865D
- [19] DeCelles, P. G., Gehrels, G. E., Quade, J., Ojha, T. P., Kapp, P. A., Upreti, B. N., 1998. Neogene foreland basin deposits, erosional unroofing, and the kinematic history of the Himalayan fold-thrust belt, western Nepal. Geological Society of America Bulletin, 1998, 110: 2-21. https://doi.org/10.1130/0016-7606(1998)110%

https://doi.org/10.1130/0016-7606(1998)110% 3C0002:NFBDEU%3E2.3.CO;2

- [20] Tamrakar, N. K., Karki, B. Geomorphometric properties and variability of sediment delivery ratio and specific sediment yield among sub-basin of Karra River basin, Central Nepal, Sub Himalaya, Journal of Nepal Geological Society, 2019, 59: 19-37. http://dx.doi.org/10.1130/0016-7606(1945)56%5b275: EDOSAT%5d2.0.CO;2
- [21] Rosgen, D. L. Applied River Morphology. Wildland Hydrology, Pagosa Springs, Colorado, 1996: 378.
- [22] Singh, S. A geomorphological study of small drainage basin of Ranchi plateau, DPhil thesis, Geology Department, Allahabad University, 1978.
- [23] Dov. Nir. 1957. The ratio of relative and absolute altitudes of Mt. Carmel, a contribution to the problem of relief analysis and relief classification. Geographical Review, 1957, 47: 564-569.
- [24] Strahler, A. N. Quantitative geomorphology of drainage basins and channel networks. In: Chow, V. T. (Ed), Handbook of applied hydrology, McGraw-Hill, New York, 1964: 439-476.
- [25] Schumms, S. A. Evaluation of drainage systems and slopes in Badlands of Perth Amboy, New Jersey. Geological Society of America Bulletin, 1956, 67: 597-646. http://dx.doi.org/10.1130/0016-7606(1956)67[597: EODSAS]2.0.CO;2
- [26] Horton, R. E. Erosional development of streams and their drainage density: hydrophysical approach to quantitative geomorphology. Geological Society of America Bulletin, 1945, 56: 275-370. http://dx.doi.org/10.1130/0016-7606(1945)56% 5b275:EDOSAT%5d2.0.CO;2
- [27] Horton, R. E. Drainage basin characteristics. Transactions American Geophysical Union, 1932, 13: 61-

350.

https://doi.org/10.1029/TR013i001p00350

- [28] Singh, V. P. A morphometric study of terrain of Patlands of the Chotanagpur region, PhD thesis, Awadh University, Faizabad, 1984: 184-210.
- [29] Schumm, S. A. Sinuosity of alluvial rivers in the great plains. Bulletin of Geological Society of America, 1963, 74: 1089-1100. https://doi.org/10.1130/0016-7606(1963)74[1089:SO AROT]2.0.CO;2
- [30] Pike, R. J., Wilson, S. E. Elevation-relief ratio, hypsometric integral and geomorphic area-altitude analysis. Geological Society of America Bulletin, 1971,

82: 1079-1084.

http://dx.doi.org/10.1130/0016-7606(1971)82[1079 :ERHIAG]2.0.CO;2

- [31] Bali, R., Agarwal, K. K., Ali, S. N., Rastogi, S. K., Krishna, K. Drainage morphometry of Himalayan Glacio-fluvial basin, India: hydrologic and neotectonic implications. Environmental Earth Sciences, 2011, 66(4): 1163-1174.
- [32] Esper, A. M. Y. Morphometric analysis of Colanguil River Basin and flash flood hazard, San Juan, Argentina. Environmental Geology, 2008, 55: 107-111.
- [33] Ritter, D. F., Kochel, R. C., Miller, J. R. Process geomorphology. McGraw Hill, Boston, 2002: 560.