Journal of Scientific Research
Banaras Hindu University, Varanasi
Vol. 63, 2019 : 13-24
ISSN : 0447-9483

MORPHOMETRIC INVESTIGATION OF MANDAKINI RIVER BASIN, CHITRAKOOT DISTRICT, UTTAR PRADESH, USING REMOTE SENSING AND GIS TECHNIQUES

K. Prakash, S. Singh, *C. K. Singh, A. K. Kannaujiya, P. Singh, A. Deep, and A. Gorai
Department of Geology, BHU, Varanasi
*chandrakantbhu@gmail.com

Abstract:

The Mandakini (Paishwani) river started near Itwa Khas village of Panna district, Madhya Pradesh and made confluence with the Yamuna river near Kankota village of Banda district, Uttar Pradesh. During the traverse, it covers 349.05 Km. In the topographic sheet of Survey of India (63C/16), the Mandakini (famous local name) river named as Paishwani river. The watershed of the Mandakini river envelops an area of 856.6 km^2 in the Vindhyan Supergroup. The MW (Mandakini watershed) in general, exhibits a dominantly dendritic pattern; while parallel, trellis patterns also co-exist. The MW and the sub watersheds are exhibiting mature geomorphic stage which is characterized by a relatively higher length of overland flow value. The variability in stream length ratio among successive stream orders is a reflection of differences between slope and topography and hence is an essential control on discharge and erosional stage of the watersheds. The elongated shape of the basin suggested higher hydrologic storage during floods and attenuation of effects of erosion during high discharge. Basin relief is an important factor in understanding the denudation characteristics of the basin. The larger R values are the result of the paleo and neotectonic regime of the study area.

Keywords: Morphometry of river basin; Remote sensing; Mandakini river; Central India.

Introduction

Geomorphological study of an area is the systematic morphological study of present- day landforms, related to their origin, nature, development, geologic changes recorded by the surface features and their relationship to other underlying structures [1, 2, 3, 4]. Therefore, it has become an integral part of the groundwater study of an area. The morphometric elements (measurement of landforms) also provide valuable information for groundwater condition [5, 6, 7]. The various Morphometric properties depend on various aspects like geology, tectonics, vegetation, climate and incorporate the quantitative study of the area, altitude, volume, and slope profiles of the land and drainage basin. Essentially, it measures and mathematically analyzes the configuration of the earth's surface and the shape and dimension of its landform [5, 8, 9].

The Paishwani river which is also known as Mandakini river in Chitrakoot district instigates near Itwa Khas village (24o45′ N, 80o 51' E) of Panna district, Madhya Pradesh (Fig.1). The river drains to parts of Satna district of Madhya Pradesh and Chitrakoot district of Uttar Pradesh. Near the Sati Anusuiya temple, the river is fed by underground water by several small and big springs. The river passes through various religious spots of Chitrakoot Dham before making confluence with Yamuna river near Kankota village of Banda district, Uttar Pradesh.

In the present work, efforts have been made to understand and evaluate the influence of bedrock lithology and geologic structures in the development of drainage networks through deriving morphometric parameters of drainage basins, each representing a different geologic environ.

Geology of the Area

The study area is a part of Semri Group, exposed around Chitrakoot area, Uttar Pradesh and Satna District, Madhya Pradesh. The sedimentary package of the Semri group, exposed around Chitrakoot area in Banda District, Uttar Pradesh and Satna District, Madhya Pradesh, marks the northeastern limit of the Vindhyan basin. Chitrakoot Formation, unconformably overlying the Bundelkhand Granite, caps the residual hills occurring in the northern and northwestern part of the Chitrakoot area [10,11]. The Chitrakoot Formation of the Mesoproterozoic Semri Group is exposed in and around Chitrakoot town. The normal stratigraphic sequence of Semri Group is interrupted at Lodhwara, Sangrampur, Kamtanath, Muradpur hill sections in the Chitrakoot sub- basin due to vertical and lateral facies variation [12, 13, 14]. In the SE part of the area, Tirohan Dolomite and Kaimur sandstone form a NE-SW running escarpment which is analogous to Kaimur scarp in the Son valley [11, 15]. Recent Alluvium carpets of the areas surrounding the hillocks at places.

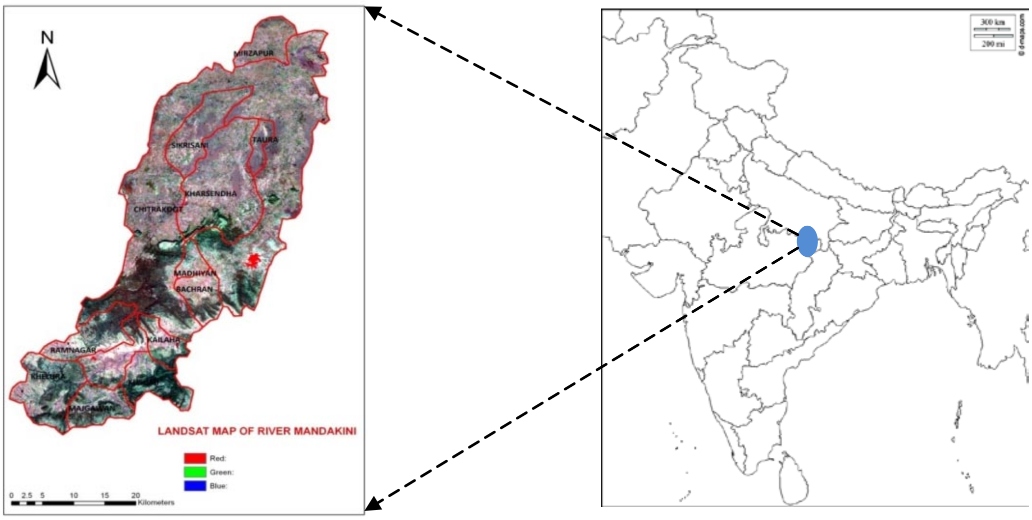

Fig. 1 Location map of the Mandakini river basin.

Methodology

The drainage extraction and stream ordering are done by ARC GIS-10. For this purpose, Landsat images are downloaded through GLCF of USGS. All downloaded images are stacked with keeping their background values zero. For mainstream, tributaries and basin, shapefile of drainage, drainage lines and basins are made in the Arc Catalog. The delineation of Mandakini Watershed (MW) and its fourth order sub watersheds, stream ordering is done on the scale of 1:50,000 by Landsat 7 (ETM+) Imaginary which is further supported by SOI topographic maps. The stream network and elevation contours were on screen digitized and prepared a geodatabase in ARC GIS10 platform. Based on the drainage network and contour data, MW has been divided into 11 fourth order sub-watersheds. The drainage channels were characterized according to their corresponding drainage order. The basic parameters such as basin area, perimeter, length etc. were extracted from the geodatabase, and others are derived from mathematical equations.

Result and Discussion

The data on the perimeter of MW (349.05 km) and that of 11 fourth order sub-watersheds are given in table1. Among the sub watersheds, SW9 has the largest P (67.03 km), registering a large basin area (200.08km^2), while the perimeter of the SW8 (20.28km) is the smallest of all. The MW in general, exhibits a dominantly dendritic pattern; while parallel, trellis patterns also co-exist. The parallel pattern occurs in the Chitrakoot region due to the structural deformation present in the form of sets of fractures and joints. The lower order drainages are almost parallel to each other. River terraces are also developed in downstream indicates dissection of fluvial sediments of floodplains deposited along the valley floor. River terraces are formed due to the rejuvenation of the channel which is evidenced by valley deepening in the area. In upstream the straight channel segments bend near right angles which are the result of lineament intersection.

The classification of streams based on the number and type of tributary junctions has proven to be a useful indicator of stream size, discharge, and of the river basin [9, 16, 17]. Stream ordering with specific numbers and other details have been shown in Fig.2. MW is designated as a 6th order watershed. The present study is confined to fourth order sub-watersheds.

The stream length ratio of 11 SW (0.2 to 0.4) was also found to be varying inconsistently. This variation could be easily explained as the downstream extension of the higher order stream or upward extension of tributaries or inception. The modification in the mean stream length ratio is a marker of the amends in the slope and topography, which in turn establish the maturity of the basin. The stream length ratio is also reported to have a vital role in surface flow discharge and sedimentation stage of the basin.

The Bifurcation ratio is the ratio between the numbers of streams of any given order to the number in the next lower order [18]. This is considered to be an important parameter that articulates the degree of the ramification of the drainage network and a significant indicator of the geological condition of the basin [8, 9]. The bifurcation ratio of the study area varies more or less gradually ranging from 1.5 to 4.11 (Table 1), ascribed to the mountainous or highly dissected basin areas [16] and the network formed in the homogenous rocks (with least/minimum structural disturbances). The closer range, in the variations of mean bifurcation ratio of the sub-watersheds (SW1, SW6, SW7, SW9; SW2, SW3, SW4, SW5, and SW11) is attributed to the geometrical similarities among the watersheds. The Rb of the successive stream orders (in SW1, SW6 and SW7), with the much larger spread, is interpreted as a predominant outcome for geological attributes [19]. The general trend of the bifurcation ratios confirms that the Rb values within a region decrease with increase in order [20]. The deviation from the above hypothesis in the sub- watersheds (SW1, SW6, SW7, SW3, SW10 and SW11) indicates that the geology and relief have affected the branching of streams.

The variability in RI among successive stream orders is a reflection of differences between slope and topography and hence is an important control on discharge and erosional stage of the watersheds [21]. Though the RI between successive orders of streams in the sub-watersheds does not obey any empirical rule or follow any systematic variations, some anomalous value are observed in few sub-watersheds of upstream. The anomaly may be interpreted as a sign of disequilibrium in the drainage system.

The Rho coefficient (ρ) is relating drainage density to physiographic evolution of a watershed useful to evaluate drainage development in a watershed [16]. The Rho values in the MW and sub watersheds span for 0.07 to 0.37. SW11 having the largest value of 0.37 while SW1, SW2, SW3, SW4, SW5, SW6, SW7, SW8, SW9, SW11 having the second higher values suggesting higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

TABLE I. LINEAR, AREAL AND RELIEF PARAMETERS OF THE MANDAKINI RIVER BASIN.

Linear and Areal Parameters

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	MB
Perimeter	30.49	41.18	33.94	45.71	47.03	28.91	20.22	67.30	24.81	33.22	48.80	349.0
Basin length (km)	11.51	13.22	8.96	12.92	17.02	10.54	5.93	24.63	10.13	8.63	19.04	81.05
Area (sqkm)	39.36	67.06	59.39	105.4	74.76	47.88	21.73	20.08	23.63	51.99	86.4	856.6
Drainage Density(Dd)	1.22	1.24	1.12	1.27	1.19	1.30	1.24	1.13	1.90	1.18	1.28	2.25
Stream Frequency (Fs)	0.91	0.95	0.91	0.93	0.83	0.92	1.06	0.81	1.02	0.87	0.89	1.63
Texture (T)	1.16	1.18	1.02	1.18	0.99	1.19	1.31	0.91	1.93	1.02	1.14	3.67
Length of overland flow (Lg)	0.61	0.62	0.56	0.64	0.59	0.65	0.62	0.57	0.95	0.59	0.64	1.13
Circulatory ratio (c)	0.82	0.81	0.89	0.79	0.84	0.77	0.81	0.88	0.53	0.847	0.78	0.44
Form factor (Ff)	0.29	0.38	0.74	0.63	0.26	0.43	0.62	0.33	0.23	0.69	0.23	0.13
Elongation Ratio (Re)	0.61	0.69	0.97	0.89	0.57	0.74	0.89	0.14	0.54	0.94	0.55	0.41
Length of overland flow Lg	0.61	0.62	0.56	0.63	0.59	0.65	0.62	0.56	0.95	0.59	0.64	428.3
Bifurcation Ratio (Rb)	1.90	2.22	2.03	2.52	2.22	1.93	1.60	3.08	1.54	2.03	2.68	4.11
Stream Length ratio(Rl)	0.41	0.42	0.35	0.26	0.41	0.30	0.21	0.24	0.34	0.34	0.99	0.76
rho coefficient (*p*)	0.22	0.19	0.18	0.11	0.18	0.15	0.13	0.07	0.22	0.18	0.37	0.18

Relief Parameters											
Basin relief (m)	346	417	382	234	311	239	195	514	168	149	165	352 (average)
Relief ratio(Rr)	30.06	31.54	42.63	18.11	18.27	22.67	32.88	20.86	6.71	5.67	8.66	4.34
Ruggedness number (Rn)	422.12	517.08	427.84	297.18	370.09	310.7	241.8	580.82	199.2	157.82	211.2	792
Gradient Ratio (Rg)	1035.2	1242.5	1070.4	1195.3	1169.7	816.37	585.07	832.38	368.46	324.80	477.08	1231.0
Melton ruggedness ratio (MRn)	55.150	50.921	49.56	22.79	35.96	34.53	41.83	36.27	23.98	19.79	17.75	12.02

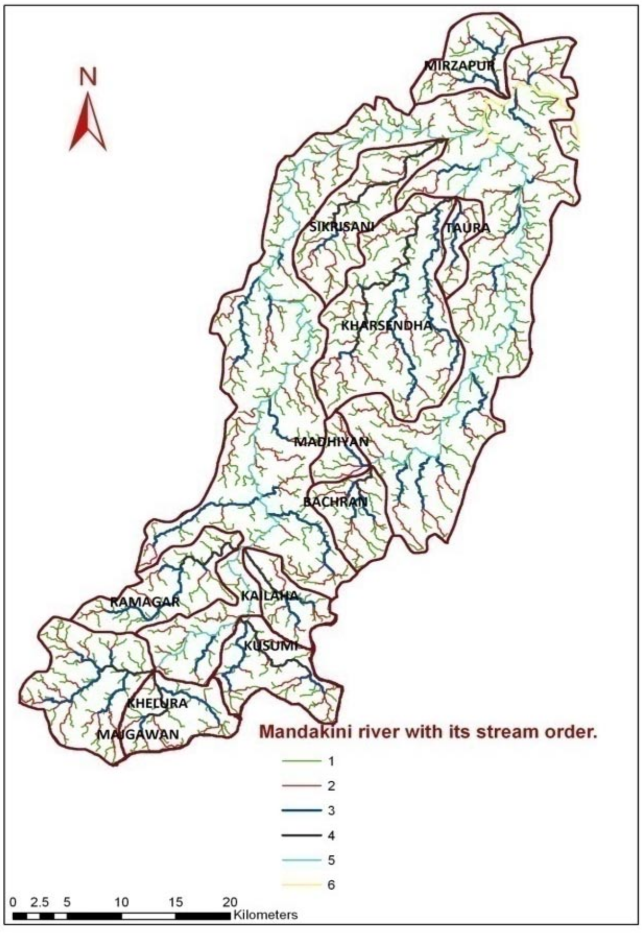

Fig. 2 Mandakini river basin and eleven sub-basins with 3rd and 4th order streams of the main watershed of Mandakini river in and around Chitrakoot area

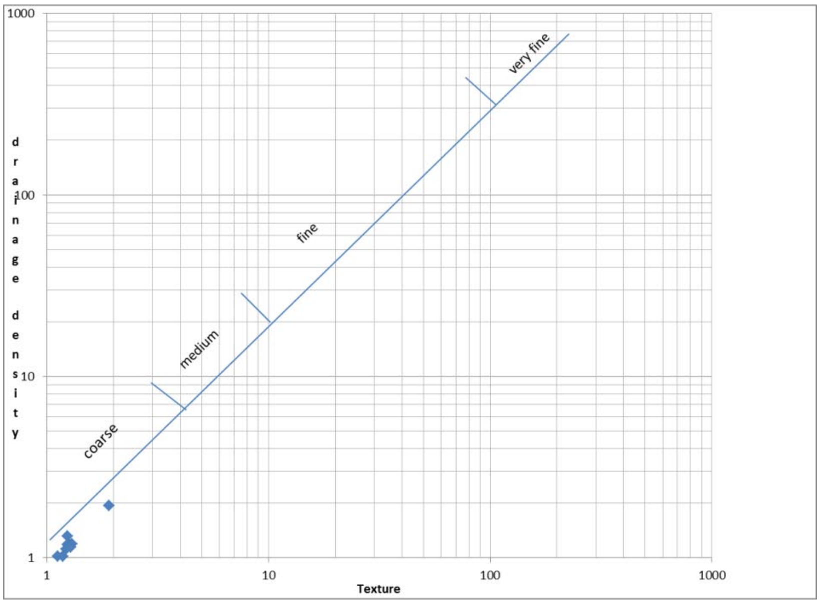

Fig. 3 Drainage density vs drainage texture ratio graph.

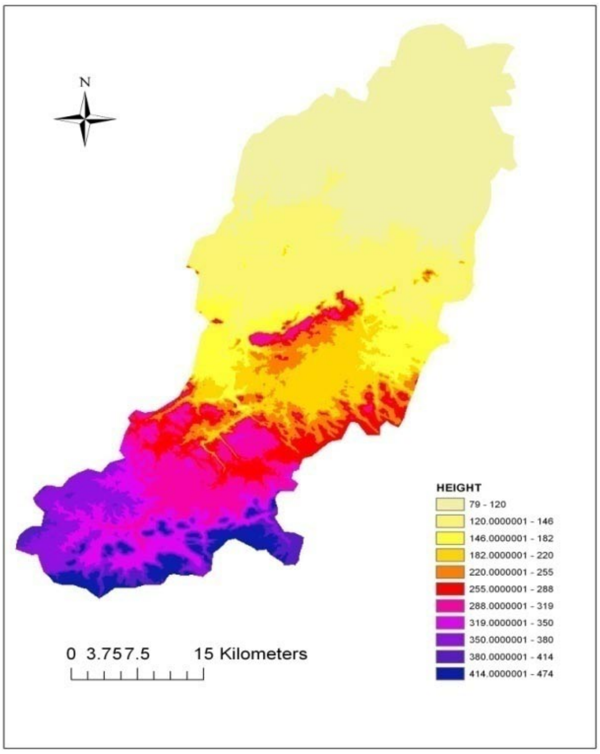

Fig. 4 Digital Elevation Model of Mandakini river basins.

The drainage density (Dd) is a sensitive parameter to the erosional advances and presents a linkage between form attributes of a watershed and process operating along the stream course [22, 23]. He Dd of MW Basin is 2.25 (table 1) and the other sub-basins have low drainage density. This value satisfies the lithology as MW is comprised of sedimentary terrane having high infiltration capacity with the seasonal flooded area. The stream frequency (Fs) for MW is 1.63 km^2 and it has a strong positive correlation with Dd values (r=0.71 at 0.001 level).

The drainage texture (T) is a measure of relative channel spacing in a fluvial dissected terrain, which is significantly influenced by climate, vegetation, lithology, soil type, relief, of the watershed [24]. The T values of MW and other sub-basins are given in table1. The MW has moderate texture and the other Sub-basins like SW1, SW2, SW3, SW4, SW5, SW6, SW7, SW8, SW9, SW10 have coarse-grained texture (Fig.3).

Length of overland flow (Lg) is the length of transverse of water over the ground before it gets concentrated into definite stream channels which affect both hydrologic and physiographic development of the drainage basins [16, 25]. The MW reports an Lg value of 1.13, whereas all other sub-watershed is varying between 0.56 and 0.95. The MW and the sub-watersheds are in a mature geomorphic stage characterized by a relatively higher Lg value.

The values of constant channel maintenance (C) of 11 sub-watersheds range between 0.5 and 0.8 and MW having 0.4. Most of the watersheds with low values of C indicate the region with close dissection and moderately influenced by structural deformation.

The form factor (Ff) is a parameter used to predict the flow intensity of a defined area and this has a direct linkage to peak discharge [9, 16, 23]. The Ff of MW is 0.130 and that of 11 watershed range between 0.2 and 0.6. But Ff values for SW7 having 0.73 and SW11 having 0.69 are relatively larger values (Ff >0.50) indicating rather low peaks but of shorter duration, while the other has comparatively low values (<0.30) implying a more elongate plan view of watersheds and suggesting consequent flatter peak of long duration.

Basin relief (R) is a parameter that determines the stream gradient and influences flood pattern and volume of sediment that can be transported and also useful to understanding the denudation characteristics of the river basin [26, 27]. The MW is endowed with the R value of 352 m (Fig.4), while that of 11 sub watersheds are given in table 1.

Relief ratio (Rr) is a dimensionless height to length ratio i.e. basin relief and basin length and widely accepted as an effective measure of gradient aspects of the watersheds [28, 29]. The Rr of MW is 4.34 while SW9,SW10,SW11 having the low values indicating the exposure of basement rocks as small ridges and mounds with lower slope values, while SW1, SW2, SW3, SW4, SW5, SW6, SW7, SW8 have high values indicating steeper slopes and higher relief underlain by resistant rocks.

The ruggedness number (Rn) for MW is 792 and that of 11 sub watersheds are tabulated in table1. The high Rn of MW and SW9 imply that these tracts are more prone to soil erosion and have moderate intrinsic structural complexity in association with the basin. Gradient ratio (Rg) is an indicator of channel slope which enables assessment of the runoff volume. MW has Rg value of 1231.The large Rg values indicate the hilly nature of the terrain. The melton ruggedness number (MRn) is a slope index that provides a specialized representation of relief ruggedness within the watershed.

Conclusions

The relevance of morphometric analysis reveals that there are total 1399 numbers of streams grooved with each other from order 1st to 6, spread over 856.6 km^2 area of the catchment in Upper Vindhyan terrain (Chitrakoot Formation). Detailed study of the Mandakini river basin gives valuable direction for surface runoff and helps for natural resource improvement and management. Bifurcation ratio indicates that the drainage has covered by impermeable subsurface and high mountainous relief. Circulatory ratio, elongation ratio shows watershed have high slope and high peak flow. Texture ratio provides thought about infiltration capacity and relief aspect of terrain.

Thus study shows that morphometric analysis using GIS technique helps to understand complete terrain parameters which lead to finalize watershed development planning and management with respect to water conservation. The huge morphometric data provided by the present study may be of immense application for the future infrastructure development and resource management of the Chitrakoot region.

Acknowledgements

The authors are thankful to the Head, Department of Geology, Banaras Hindu University, Varanasi and for providing the facility for the above work. Financial support from DST (SERB) Project No. P07/673 is thankfully acknowledged by K. Prakash. Financial support from UGC [UGC-Ref.No.:453/(CSIR-UGC)] is thankfully acknowledged by Prinsi Singh and Akash Deep is also thankful to CSIR (Sr.No. 1121721217, Ref.No. 17/12/2017(ii) EU-V) for financial support.

References

[1] Angillieri EYM (2012) Morphometric characterization of the Carrizal basin applied to the evaluation of flash floods hazards, San Juan, Argentina. Quat Int 253:74–79.

[2] Clark C (1966) Morphometry from maps. Essay in geomorphology. Elsevier publication company, New York, pp 235–274.

[3] Altaf F, Meraj G, Romshoo AS (2013) Morphometric analysis to infer the hydrological behaviour of Lidder Watershed, Western Himalaya, India. Geography J 2013:1–14.

[4] Chow VT (1964) Handbook of applied hydrology. McGraw-Hill, New York.

[5] Prakash K, Mohanty T, Singh S, Chaubey K, Prakash P (2016a) Drainage morphometry of the Dhasan river basin, Bundelkhand craton, central India using remote sensing and GIS techniques. J Geomat 10:21–132.

[6] Prakash K, Singh S, Shukla UK (2016b) Morphometric changes of the Varuna river basin, Varanasi district, Uttar Pradesh. J Geom 10:48–54.

[7] Prakash K, Mohanty T, Pati JK, Singh S, Chaubey K (2017) Morphotectonics of the Jamini River basin, Bundelkhand Craton, Central India; using remote sensing and GIS technique. Appl Water Sci 7:3767–3782.

[8] Prakash K, Singh S, Mohanty T, Chaubey K, Singh CK (2017c) Morphometric assessment of Gomati river basin, middle Ganga plain, Uttar Pradesh, North India. Spat Inf Res 25:449–458.

[9] Prakash, K, Rawat, D., Singh, S., K. Chaubey, S. Kanhaiya, T. Mohanty. (2019) Morphometric analysis using SRTM and GIS in synergy with depiction: a case study of the Karmanasa River basin, North central India. Appl Water Sci 9: 13. https://doi.org/10.1007/s13201-018-0887-3.

[10] Banerjee A. K. and Singh LI. J. M. (1981) Paleogeography and sedimentation of Vindhyans in eastern Rajasthan, Misc. Publ. Geol. Surv. India 50,89-94.

[11] Anbarasu K. (2001) Acritarch from Mesoproterozoic Chitrakoot Formation, Semri group, Chitrakoot Area, Central India, Jour. Geol. Soc. India 57,179-183.

[12] Banerjee A. and Banerjee D. M. (2010) Modal analysis and geochemistry of two sandstones of the Bhander Group (Late Neoproterozoic) in parts of the Central Indian Vindhyan basin and their bearing on tire provenance and tectonics, J. Earth Syst. Sci. 119, 825- 839.

[13] Bhattacharyya A. (1996) Recent advances in Vindhyan Geology, Mem. Geol. Soc. India 36,331p.

[14] Bose P.K., Sarkar S., Chakraborty S. and Banerjee S. (2001) Overview of the Meso-toNeoproterozoie evolution of the Vindhyan basin, central India. Sedimentary Geology 141-142,395-419.

[15] Chakraborty P. P., Dey S. and Mohanti S. P. (2010) Proterozoic platform sequences of Peninsular India: Implications towards basin evolution and supercontinent assembly, J. Asian Earth Sci. 39,589-607.

[16] Horton, R.E. (1945). Erosional development of streams and their drainage basins hydrophysical approach to quantitative morphology. Geological Society of America Bulletin, 56 (3), pp. 275-370.

[17] Singh S, Kanhaiya S, Singh A, Chaubey K (2018) Drainage network characteristics of the Ghaghghar River Basin (GRB), Son Valley, India. Geol Ecol Landsc. https ://doi.org/10.1080/24749 508.2018.15256 70.

[18] Strahler, A.N. (1964). Quantitative geomorphology of drainage basin and channel networks. In: V.T.Chow, ed. Handbook of applied hydrology. New York: McGraw Hill Book, pp. 4-76.

[19] Strahler, A.N. (1952). Hypsometric – area–altitude. Analysis of erosional topography. Geological Society of America Bulletin 63, pp. 1117–1142.

[20] Guarnieri, P. and C. Pirrotta (2008). The response of drainage basin to the late Quaternary tectonics in the Sicilian side of the Messina Strait (NE Sicily). Geomorphology 95, pp. 260– 273.

[21] Sreedevi, P.D., K. Subrahmanyam and S. Ahmed (2004). The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environmental Geology, 47, pp. 412-420.

[22] Strahler, A.N. (1958). Dimensional analysis applied to fluvially eroded landforms. Geological Society of America Bulletin, 69, pp. 279-300.

[23] Gregory KJ, Walling DE (1973) Drainage basin. Form and process: A geomorphological approach. Edward Arnold, London.

[24] Smith, K.G. (1950). Standards for grading texture of erosional topography. American Journal of Science, 248, pp. 655-668.

[25] Vijith H, Satheesh R (2006) GIS-based morphometric analysis of two major upland sub-watersheds of Meenachil river in Kerala. J Indian Soc Remote Sens 34:181–185.

[26] Hadley, R.F. and S.A. Schumm (1961). Sediment sources and drainage basin characteristics in upper Cheyenne river basin. USGS water supply paper, US Geological Survey, 1531-B.

[27] Sreedevi, P.D., K. Subrahmanyam and S. Ahmed (2004). The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environmental Geology, 47, pp. 412-420.

[28] Schumm, S.A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin, 67, pp. 597- 646.

[29] Singh, C. K. (2014). Active deformations extracted from drainage geomorphology- a case study from Southern Sonbhadra district, Central India. Journal of Geological Society of India, 84, pp. 569-578.