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Morphometric Evaluation using Geospatial Technology in the Kunur River Basin of West Bengal

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Abstract: *The topographic, network and hydrological parameters of the micro-watersheds of Kunur River Basin (KRB) has been analysed to understand the behaviour of the Kunur stream. The morphometric approach involving the analysis of multi-thematic and spatio-temporal parameters have largely helped in the logical assessment of hydrological character of the basin. The KRB is a fifth order basin with dendritic to sub-dendritic drainage pattern. Morphological study substantiated by statistical and geo-spatial techniques was used in analysing the morphometric characteristics of KRB. The analysis helped to establish relationships between the morphometric characteristics of the drainage basin and its hydro-geologic parameters. The study also attempts to investigate the causes behind the high-intensity floods in KRB. The hydro-geologic analysis provides information about the characteristics of groundwater recharging in the basin and recommends that any plan for water resource management in the KRB, should include the construction of recharging ponds and caution should be maintained during prolonged periods of heavy precipitation.*

Introduction

Drainage basin is the most fundamental unit of investigation in terms of geometric characteristics of fluvial landscape. Morphometry is mathematical analysis of the drainage basin where channel network plays a vital role in understanding the hydro-geomorphological behaviour of the drainage basin. Morphometry also expresses the interrelationship between geomorphology, geology and prevailing climate of the catchment under study. Documentation of basin characteristics using morphometric techniques was well known since early nineteenth century in various parts of the world (Horton, 1932, 1945; Strahler, 1952, 1957, 1964; Miller, 1953; Schumm, 1956; Morisawa, 1985; Shreve, 1967; Scheidegger, 1967; Smart, 1968; Gardiner and Park, 1978). In India, drainage basin analysis using morphometric techniques has been done by different scholars in various parts of the country (Reddy *et al*., 2004; Thakkar and Dhiman, 2007; Ahmed and Khan, 2013; Dash *et al*.; 2013). However, there are few systematic studies carried out on Kunur River Basin (KRB) itself (Roy, 2013; Bandyopadhyay *et al*., 2014) and none of the studies so far done on KRB has actually attempted a correlation among the various morphometric parameters. A remarkable study has been done on KRB by considering the entropy model which revealed the stage of evolution of the KRB (Bandyopadhyay *et al* 2014).

The geomorphometric analysis includes quantitative measurement and analysis of linear (stream order, stream number, stream length, stream length ratio, bifurcation ratio) and areal aspects (drainage density, stream frequency, drainage texture, length of overland ratio, constant of channel maintenance, elongation ratio, circulatory ratio, form factor, shape factor) of the drainage basin. The GIS platform was used for digital extraction of morphometric parameters from digital elevation models (SRTM DEM, 2006) Statistical analysis aids in reducing the correlation complexity and helping us in minimizing the error in the drainage basin research. The basic steps involved in morphometric analysis are defining, measuring and analyzing the quantitative indices related to flow plane geometry of KRB. The present study examines the morphometric characteristics of KRB and its implementation.

Geographical setting of Kunur river basin

The Kunur river originates near Banshgara (elevation 100 m) in the Faridpur area of Bardhhaman district (Fig. 1). The Kunur River (23˚25´N to 23˚40´N and 87˚15´E to 87˚54´E) is a fifth order, non-perennial, monsoon-dominated river traversing a total distance of 112 km before merging with river Ajay at Kogram (Plate 1D) as its right bank tributary. Majority of the river course falls within the canal command area of Damodar river Basin covering 277 villages and three urban areas, located partly or fully within the basin. The KRB extends over an area of about 826.50 km^2 with a perimeter of 174 km having an elongated and asymmetrical shape. The basin is dominated by semi-dendritic and sub parallel drainage pattern and basin elevation varies from <43 m to 100 m from mean sea level.

The landscape of KRB shows great diversity in terms of physiographic, geological and pedological conditions. A fault zone runs through Jalangi-Debagram and Barddhaman-West Ghatal area, which is possibly reflected in the SSW–NNE course of the Kunur river near Mongolkot (Bandyopadhyay *et al.,* 2014). The morphometric and channel network analysis plays an important role in understanding the geo-hydrological behaviour of drainage basin.

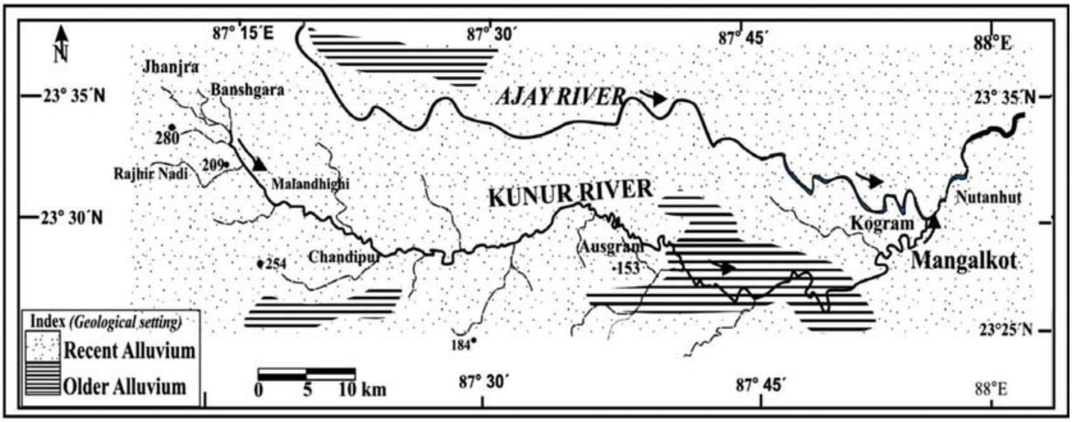

Figure 1. Location map and geological setting of the Kunur River Basin.

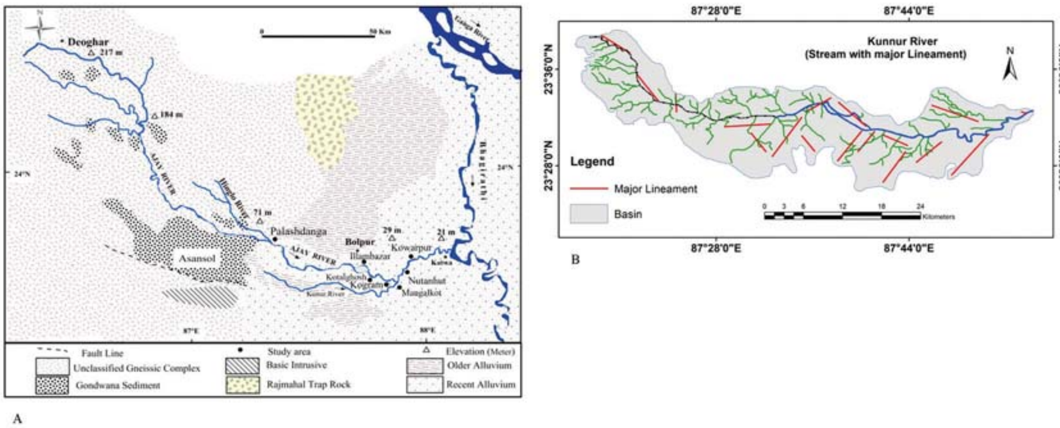

Figure 2. (A) Geological map of the study area with entire Ajay river system (modified after Bhattacharya, 1972. (B) Lineament map of the Kunur basin (GSI, 2015).

Objectives

The main objectives of the present study are:

- To evaluate the morphometric parameters of Kunur drainage basin
- To understand the impact of the morphometric parameters on the fluvial environment of KRB.

Database and methods

Survey of India topographical sheets of various editions with 1:50,000 RF were used to create a base map. The morphometric data regarding hierarchy of the drainage network, drainage length, drainage basin area and perimeter were extracted from the base map using TNT MIPS (version Basic-2014) which is a RS and GIS integrated software. Statistical software like Grapher 9 and photo editing software like Coral Draw Graphic Suite 11 and Adobe Photoshop CS6 were also used.

Morphometric parameters of drainage networks such as the bifurcation ratio, drainage density, stream frequency, texture ratio, basin relief, ruggedness number and time of concentration were evaluated with established mathematical equations (Table-1). The drainage network was extracted from a DEM (fig 2) generated from digitising the contours of topographical maps and prepared the contours of 10-m intervals using the Hydrology toolset in GIS environment. SRTM DEM is also used to derive and calculate morphometric parameters as well as drainage network for the understanding of geo-hydrological conditions of the KRB. The precision of the DEM affects the accuracy of the extracted drainage network. Stream orders of drainage networks derived from

Table 1. Data base used for morphometric analysis of Kunur river basin.

Type of Material/data	Details	Source
Topographical maps	73M/6, 73M/10, 73M/11, 73M/14, 73M/15 with scale 1:50,000	Survey of India (1971–72)
Geological map	Geological Map of Ajay Valley	A.K. Bhattacharya, (1972)
SRTM (Shuttle Radar Topography Mission) data, 2006	Digital Elevation Model (DEM) of 3 arc sec (approximately 90 m resolution)	http://strm.csi.cgiar.org

topographic maps were entered manually whilst those derived from the DEM were assigned automatically in GIS. Quantitative analysis has been done based on Survey of

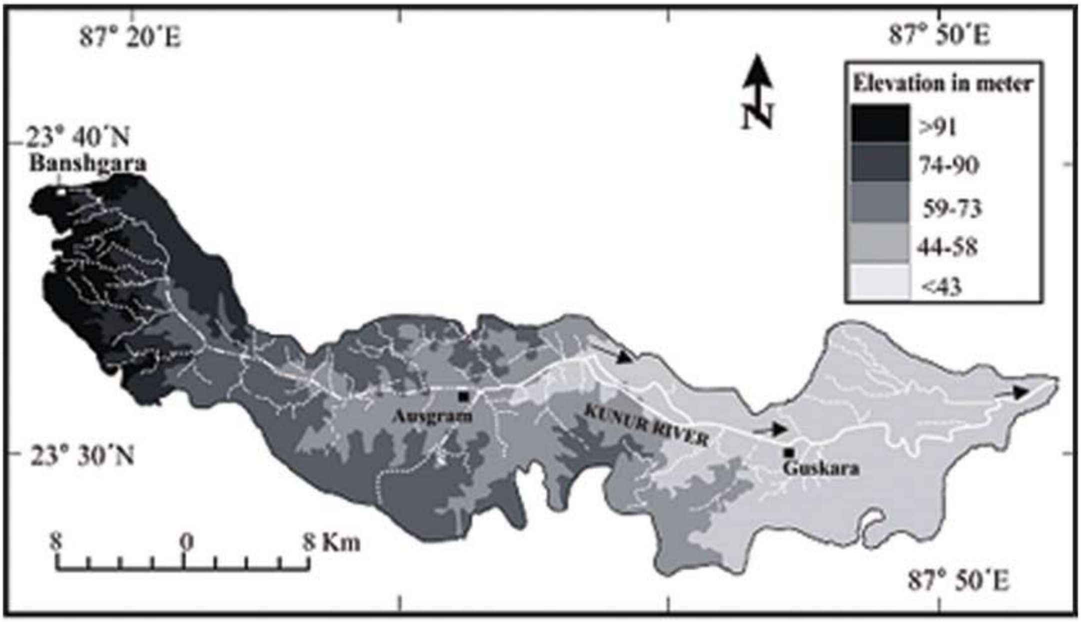

Figure 3. Elevation map of the Kunur River Basin based on SRTM DEM (2006).

Table 2. Methodology adopted for computation of morphometric parameters.

Morphometric parameters	Formulae	Abbreviation	References
Linear Aspects			
Stream Order (U)			Strahler (1964)
Stream Number (Nu)		Nu = Total number of streams	Horton (1945)
Stream length (Lu)	The average length of streams of different orders in a drainage basin tends closely to approximate a direct geometric ratio.	Lu = Total length of stream	Horton (1945)
Mean stream length (Lsm)	Lsm = Lu/Nu	Lu = stream length	
Nu = stream Number	Strahler (1964)		
Stream length ratio (Rl)	RL = Lu/Lu1	Lu=Total stream length of order, Lu1=Total stream length of its next lower order	Horton (1945)
Bifurcation Ratio (Rb)	Rb = Nu/Nu1	Nu1 = No of segments of the next higher order	Schumm (1956)

Continued

Areal Aspects			
Drainage Density (Dd)	Dd = Lu/A	Lu = Total stream length of order, A = Area	Horton (1932)
Stream Frequency (Fs)	Nu/A	Nu = Total no of streams, A = Area	Horton (1932)
Drainage Texture (Rt)	Rt = nu/p	Nu = Total no of streams; p = perimeter of the basin	Horton (1945)
Length of over land ratio (Lg)	Lg = 1/2Dd	Dd = Drainage density	Horton (1945)
Constant of channel Maintenance (C)	1/Dd	Dd = Drainage density	Schumm (1956)
Circulatory Ratio (Rc)	Rc = 4*πA/p2	A = Area, p = perimeter of the basin	Miller (1953)
Form Factor (Rf)	Rf = A/L2	A = Area, L = Basin length	Horton (1945)
Elongation Ratio	2*√(A/π)/Lb	A = Area, Lb = Basin length	Schumm (1956)

India Toposheet and SRTM DEM (2006)

Results and discussion

Quantitative description of drainage network and basin characteristics has been carried out for the KRB. The study emphasises the use of satellite remote sensing for morphometric analysis and the results are discussed below.

Linear Aspects

Stream order, stream length, mean stream length, stream length ratio and bifurcation ratio are linear aspects that were determined and results have been given in Table 2.

Stream Order (U)

Stream order is not only the index of size and scale of the drainage basin, but also can approximate the amount of stream flow within the basin. It is perhaps the first step in drainage basin analysis. The KRB is a fifth order drainage basin (Fig. 4) as derived from the SRTM DEM (2006) following Strahler's (1964) stream ordering system (Table 2). The lower order streams originate from heterogeneous geological formations. The frequency of right bank tributaries is more in comparison to the left bank tributaries. The left bank tributaries are draining through unclassified gneissic complex and the right bank lower order steams have cut their valleys through old and recent alluvium deposit. Geology plays a vital role in the development of the drainage system in KRB.

Stream Number (Nu)

In general, the number of the stream segments decreases as the order increases. The higher stream number indicates lesser permeability and infiltration. The computed stream number (Nu) and revealed that total number of streams in the watershed is 283. Out of which 209 are 1st order, 55 streams are of 2nd order, 16 streams are of 3rd order and only 2 streams are of 4th order (Table 3). A plot of log of stream number against stream order for KRB is represented in Figure 5A. High R^2 (Explained variance = 98%) values suggest that the best fitted model is exponential regression which explains the relation between stream order and stream number.

Mean Stream Length (Lsm)

The mean stream length of a basin is a dimensional property revealing the characteristics of a drainage network and its contributing basin surfaces. In general mean length of channel segments of a given order is greater than that of the next lower order but less than the next higher order. Mean stream length of Kunur basin reveals an increasing trend with the increase in stream order.

STREAM LENGTH (LU)

Stream length is one of the most significant hydrological parameter of basin analysis. Stream length is relatively small in the upper catchment area than lower catchment area of KRB due to the difference in gradient. Smaller lengths are characteristic of areas with higher slope and finer texture whereas longer lengths of streams are generally indicative of lower gradient. Near the source of the Kunur river the elevation is 100 m and near its confluence the elevation is around 30 m.

STREAM LENGTH RATIO (RL)

Stream length ratio (RL) may be defined as the ratio of the mean length of an order to the next lower order of stream segment. The stream length ratio of the KRB ranges from 0.23 to 0.54. The stream length ratio between streams of different orders reveals variations which may be attributed to variation in slope and topography.

BIFURCATION RATIO (RB)

The Bifurcation Ratio (Rb) has been calculated after Strahler (1964) and a unique trend can be seen in case of KRB. Up to the 3rd order streams the Rb value ranges between 3.44 and 3.88, (Fig. 2) which is not unusual for any river basin. But the value of Rb increases abruptly to 8 in case of 4th order streams of KRB (Table 3). It is because the 4th order streams of KRB are draining through older and recent alluvial tract from where a considerable number of rills, gullies and ravines are meeting with Kunur. The mean value of Rb for the entire KRB is 4.31, which indicates the possibility of geological heterogeneity in the region.

Areal Aspects

DRAINAGE DENSITY (DD)

The Dd is the ratio of cumulative length of channel segments for all orders within a basin to the basin area, which is expressed in terms km^{-km2}. Drainage density (DD) indicates the extent of landform dissection and generally, DD increases with decreasing infiltration capacity of the underlying rocks and decreasing transmissivity of the soil. Drainage density is related to lithology, runoff potential, infiltration capacity, surface roughness, climatic conditions and vegetative

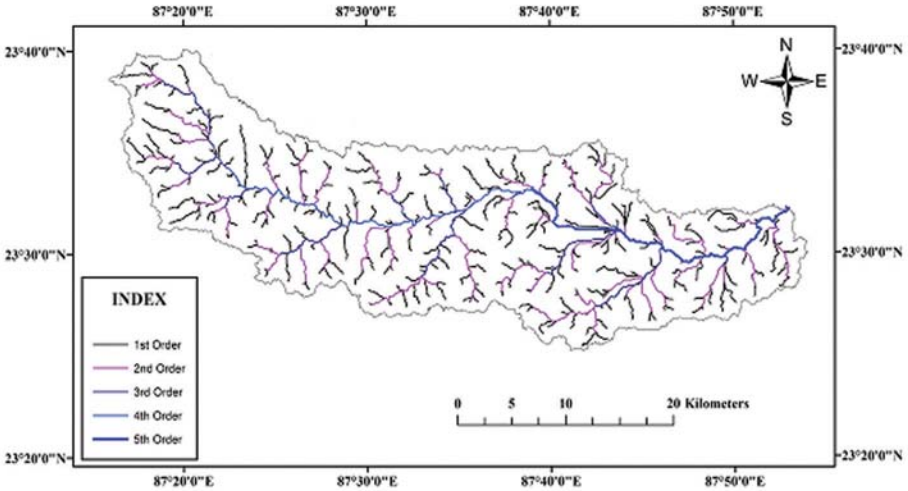

Figure 4. Stream ordering of the Kunur river basin (after Strahler, 1952).

Table 3. Calculation for Stream length Ratio and Bifurcation Ratio.

Stream order	No of segments	Total length(km)	Mean length(km)	Stream length ratio (Rl)	Bifurcation ratio (Rb)
1st	209	203.67	0.97	-	
2nd	55	99.44	1.81	0.54	3.8
3rd	16	75.24	4.70	0.39	3.44
4th	2	40.77	20.39	0.23	8
5th	1	64.62	64.62	0.32	2
Total	283	483.74	92.49	0.37	4.31

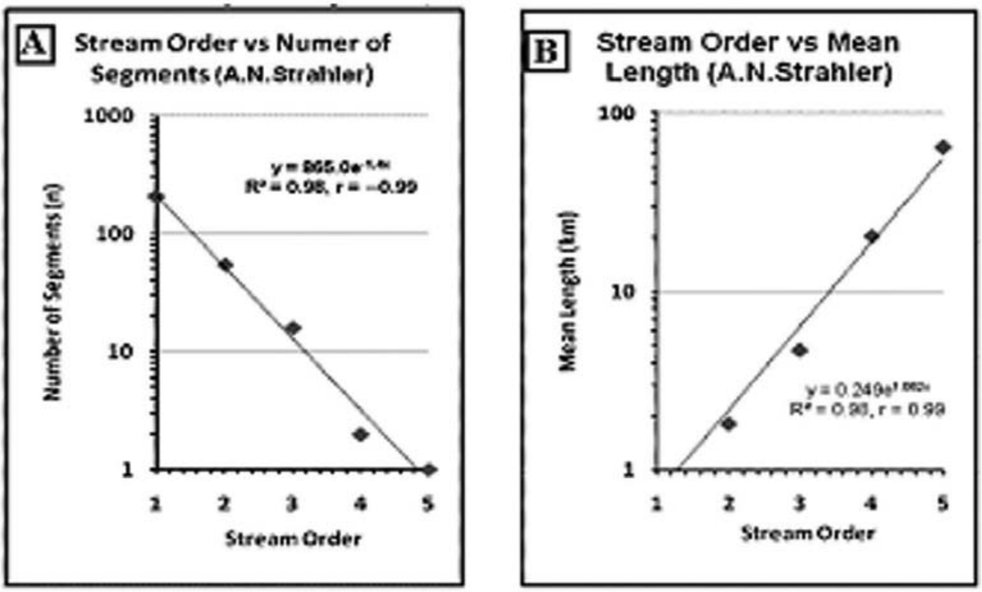

Figure 5. (A) Relation between logarithm of number of stream segments with stream order in the Kunur River Basin. (B) Stream order vs. mean stream length plot of the Kunur River Basin. The regression line is of positive exponential function model.

cover of the basin (Verstappen, 1983; and Reddy *et al*., 2004). For steep slopes an inverse correlation has been modelled by Montgomery and Dietrich (1992). Out of which only surface roughness has no significant correlation with drainage density. KRB has low drainage density 0.52 km^{-km2} which is indicative of permeable sub surface material, moderate vegetative cover and low to moderate relief.

Plate 1. (A) Upper reaches of the Kunur river in the Faridpur forest area near Bansgara, Barddhaman District. (B and C) Data generation during field visit. (D) Kunur-Ajay confluence near Nutanhat, Barddhaman, West Bengal

Drainage Texture (RT)

Drainage texture (RT) is another important drainage parameter in morphometric analysis. The KRB shows significant diversity in terms of physiography, lithology and pedological conditions experiencing different geomorphic processes. Generally, it is observed that during the monsoon period the KRB experiences high discharge. Drainage Texture (RT) depends upon drainage density along with climate, rainfall, vegetation, lithology, soil type and infiltration capacity. In its upper reaches, the Kunur river flows over a more or less homogenous area in terms of the above mentioned parameters and the Rt value is 1.22. But the lower reaches of KRB show an abrupt change in Rt value (>0.66), which means that here there is strong lithological control. The mean grain size varies between 0.2–0.5 mm. The mean value of Rt (1.68) designate that the KRB has medium to coarse drainage texture.

Stream Frequency (Fs)

Stream frequency (Fs) or channel frequency as the ratio of total number of stream segments of all orders to the basin area. Low Fs values indicate permeable sub-surface material and low relief, whereas higher values are the characteristic of impermeable, resistant sub-surface material, sparse vegetation and high relief. The average stream frequency of the KRB is 0.31 which indicates that the basin has high hydrological potential.

Drainage Intensity (DI)

Faniran (1968) defines drainage intensity (DI), as the ratio of stream frequency to the drainage density. This study shows a low drainage intensity of 0.60 for the KRB watershed. Such low drainage intensity implies that drainage density and stream frequency have little effect on the extent to which the surface has been lowered by agents of denudation. With low values of drainage density, stream frequency and drainage intensity, surface runoff is not likely to drain quickly from the watershed, making it highly susceptible to flooding, gully erosion and landslides.

Infiltration Number (If)

The infiltration number of a watershed is defined as the product of drainage density and stream frequency and gives an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration rate and the higher will be the runoff. Infiltration number of the KRB is 0.16, which indicates that runoff will be very high and the infiltration capacity very low.

Length of Over Land Flow (Lg)

The length of overland flow (Lg) may be defined as the length of water flow over the ground before it gets concentrated into defined channels and is considered as one of the most important independent variables affecting hydrologic and geomorphic evolution of drainage basins. The average length of overland flow is approximately half the average distance between stream channels and is therefore approximately equals to half of reciprocal of drainage density. Drainage density is an approximate measure of the length of overland flow. For basins of comparable relief, the hydrologic response of a stream network should be directly related to drainage density because with increasing drainage density the path length of overland flow decreases while hill slope angle increases (Schumm, 1956).

The value of Length of Overland Flow of the KRB is 0.96. The value is equals to half of the constant of channel maintenance. The value of (Lg) is high and it indicates that erosion and dissection potentials are low in Kunur basin.

Basin Geometry

Area of a basin (A) and perimeter (P) are the two important parameters in quantitative morphology. The area and perimeter of the basin is computed by vectorising the basin from Survey of India topographical sheets. The total area of the basin is found to be 826.50 km^2. Areal aspects such as circulatory ratio, form factor, constant of channel maintenance etc. have important bearing on channel and network parameters.

Circulatory Ratio (Rc)

Circularity ratio (Rc) has been defined as the ratio of the area of the basin (A) to the area of a circle having the same circumference as the perimeter (P) of the basin. Circularity ratio (Rc) is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate, relief and slope of the basin. The circularity ratio of the KRB is 0.41. This value indicates the lack of circularity.

Form Factor (Rf)

Form Factor (Rf) is expressed as the ratio of the basin area to the square of the basin length (Horton, 1945). Larger values of Rf indicate sharp rise in peak flows of short duration whereas, smaller values of Rf imply more flatter peak flows of longer duration. The latter situation is usually observed in elongated basins. The hydrological behaviour of KRB is characterised by Rf value of 0.18 and flashy flow with sharp hydrograph peak.

Wandering Ratio (Rw)

According to Smart and Surkan (1967), wandering ratio is defined as the ratio of the length of the mainstream to the valley length. Valley length is the straight-line distance between outlet of the basin and the farthest point on the ridge. In the present study, the wandering ratio of the KRB watershed is 1.01.

Fitness Ratio (Rf)

As per Melton (1957), the ratio of main

channel length to the length of the watershed perimeter is Fitness Ratio (Rf), which is a measure of topographic fitness. The fitness ratio for KRB watershed is 0.51.

Lemniscate's (k)

Table 4. Morphometric characteristics of the Kunur river basin and the results.

Morphometric parameters	Result	Remark
Stream Number (N_U)	283	Medium
Stream order (U)	5	Medium
Mean stream length (L_{SM})	1.71(km)	Low
Bifurcation Ratio (R_B)	4.31	Geological control on the river
Stream length (L_U)	483.74 (km)	Low
Stream length ratio (R_L)	0.37	Low
Drainage Density (D_D)	0.52 (km km^{-2})	Low
Stream Frequency (Fs)	0.31	Very low
Drainage Texture (R_T)	1.68	Coarse drainage texture
Circulatory Ratio (R_C)	0.41	Lack of circularity
Form Factor (R_F)	0.18	Narrow Elongated
Elongation Ratio	0.84	Elongated
Length of over land flow (L_G)	0.96	Reciprocal of drainage density
Constant of channel Maintenance (C)	1.92	High structural disturbance

Chorely *et al.* (1957) express the Lemniscates value to determine the slope of the basin. In the Formula $k = Lb^2 / 4\times A$. Where, Lb is the basin length (km) and A is the area of the basin (km^2). The Lemniscates (k) value for the watershed is 1.40, which shows that the KRB watershed occupies maximum area in its regions of inception with large number of streams of higher order.

Constant of Channel Maintenance(C)

The Constant of Channel Maintenance (C) measures the amount of watershed surface area in $feet^2$ required to sustain one linear foot of channel. It is calculated as the reciprocal of drainage density and the unit of measurement is $feet^{2\ -ft}$. It has dimensions of length and therefore increases in magnitude as the scale of the landform units increases. In short, it The Constant of Channel Maintenance of the KRB is 1.92. This low value indicates high structural disturbances, low permeability, steep to very steep slopes and high surface runoff.

Implications of Basin Parameters

Deciphering the controlling factors

The basic parameters of KRB provide information about the dominance of first order stream (209), high surface run off, mature stage of topography, low sediment production and high infiltration rate. All streams and their drainage network originating in the alluvium shows a linear relationship with a small deviation when logarithmic stream number is plotted against the stream order (Fig. 5A). It shows that this river basin obeys Horton's laws, which confirms the linear relationships between stream number and stream order, and mean stream length and stream order. The river network (order and stream number), slope and surface relief tend to reach a steady state, when the channel morphology is adjusted to transmit the sediment and excess flow, based on lithology, climate, rainfall and other relevant parameters of the basin (Horton, 1945; Strahler, 1952; Mesa, 2006). From the results of morphometric analyses and mapping, it could be inferred that the frequency of the right hand tributaries are more in comparison to the left bank. The right bank tributaries drained through pre-Quaternary rocks and the left bank lower order steams flow through alluvium deposit (Fig. 2A). Therefore, lithology plays a vital role on the drainage system of KRB. The stream length ratio (RL) between streams of different orders varies from 0.30 to 0.55 and this may be attributed to variation in slope and topography. Conspicuous result of bifurcation ratio (8.0) has been found in case of fourth-order stream in KRB. It is because the fourth order streams are draining through older and recent alluvial tract from where a considerable number of rills, gullies, kandar (yazoo stream) and paleo-channels are meeting the main stream.

The value of circulatory ratio (0.41) and e elongation ratio (0.84) indicates that the catchment of Kunur is elongated and skewed in SE direction having dendritic drainage pattern. The area is characterised by moderate to low relief (Fig. 3) and the drainage system is lithologically and structurally controlled which is confirmed by Bandyopadhyay *et al.* (2014). In this region. KRB has the drainage density of 0.52 km km^{-2}. The low drainage density and moderate to fine texture may be the result of lithological control.

Hydrological inferences

The derived morphometric parameters provide information about low relief (50-20 m), low stream length ratio (0.37), low surface runoff, high infiltration rate, low stream power for erosion, low sediment transport, low water storage capacity and concentration of peak discharge in the distal part of this basin. The larger number of first order streams indicate uniform lithology and gentle slope gradient (Kale and Gupta, 2001). Precipitation during monsoon season in the catchment area initially increases the subsurface infiltration which increases the groundwater table and after some time the infiltration decreases which increases the surface runoff. The gentle slope gradient, low surface runoff and high infiltration rate is favourable for building up the hydraulic gradient suitable for groundwater recharge. Groundwater recharging is a natural and continuous process in the basin during monsoon season. According to Niyogi (1985), the unconsolidated Quaternary deposits, *i.e.* older and recent alluvium (Fig. 1) have high groundwater recharge potentiality and large yield prospect (>150 m^3 hr^{-1}) which confirms the present inferences.

In many parts of the basin groundwater is depleting fast as evidenced by installation of pumps. Therefore ponds/trench/ pits should be made to facilitate the recharging of aquifers during precipitation. The upper part of this basin is characterised by dominance of coal mining activities having impact on the fluvial environment so water resource planning should be made accordingly. The length of overland flow (Lg) indicates shorter path for the concentration of flow which explains that the peak discharge takes place in the middle and downstream part of the river. It has been observed that whenever rainfall is high in the catchment area there is flood in the downstream part of the basin in the years 1978, 1995, 1999, 2000 and 2005 (Niyogi, 1987). This indicates that caution should be taken and flood mitigation planning should be made during periods of prolonged heavy precipitation. Desiltation of the channel, diversion canals, and construction of embankment capable of holding the peak discharge of the river are suggestive measures.

Conclusions

The present study indicates that remote sensing and GIS is an efficient tool in delineation, analysis and updating morphometric and hydrological parameters of a drainage basin. Based on the analyses, the Kunur Basin has been classified as fifth order basin which gives the basic idea about the nature of drainage. The quantitative analysis of linear and aerial parameters helped to establish relationships between the drainage basin and hydro-geomorphic parameters. The study reveals that Geoinformatics-based approach in quantitative evaluation of drainage parameters and their influence on landforms characteristics at the basin level are more appropriate than the conventional methods. This is essential to understand terrain and hydrological parameters, which helps in better understanding of the land form, their processes, drainage management and evolution of groundwater potential for watershed planning and management. This will be useful for soil and water conservation and is a positive scientific contribution for the people of Kunur River Basin area. This work will be useful for natural resources management for sustainable development at the basin scale.

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References

Ali, S.A. and Khan, N. (2013). Evaluation Of Morphometric Parameters- A Remote Sensing And Gis Based Approach. . *International Journal Of Geomatics And Geoscience*, 03(01): 20–27.

Bandyopadhay, S., Sinha, S., Jana, N. C. and Ghosh, D. (2014). Entropy Application to Evaluate the Stability of Landscape in Kunur River Basin,West Bengal,India. *Current Science*, 104(11): 1842–1853.

Bhattacharya A.K (1972), A Study of the Ajay River Sediments. In Baghi, K.G. (ed) *The Bhagirathi-Hooghly Basin*, Calcutta University: 18–32.

Chorley, R., Donald, E.M. and Pogorzelski, H. (1957). New Standard For Estimating Drainage Basin Shape. *American Journal of Science 255*, 138–141.

Dash, P., Aggarwal, S.P. and Verma, N. (2013). Correlation Based Morphometric Analysis To Understand Drainage Basin Evolution: A Case Study of Sirsa River Basin, Western Himalaya, India. *Scientific Annals 0f Alexandru Ioan Cuza*, 51(9): 35–38.

Faniran, A. (1968) The Index of Drainage Intensity—A Provisional New Drainage Factor. Australian Journal of Science, 31: 328–330.

Gardiner, V. and Park, C.C. (1978) Drainage basin morphometry: review and assessment, *Progress In Physical Geography*, 2(1): 1–35.

GSI: Geological Society of India (2015) *Quaternary geology and geomorphology of Ajay basin, Birbhum and Bardhaman districts, West Bengal with special reference to geoenvironmental studies*, Quaternary Geology and Geomorphology Division, Eastern Region, Calcutta, 2nd Ed: 1–57.

Horton, R. (1932). Drainage Basin Characteristics. *Transactions of American Geophysical Union*, 13: 350–361.

Horton, R.E. (1945) Erosional Development Of Streams And Their Drainage Basin: Hydrological Approach to Quantitative Morphology, *Geological Society of America Bulletin*, 56: 275–370.

Kale, V.S. and Gupta, A. (2001*) Introduction to Geomorphology*. Orient Longman Limited: 285p.

Melton, M.A. (1957) An analysis of the relations among elements of climate, surface properties and geomorphology, *Project NR 389042*, *Technical Report 11*, Columbia University, New York, 102p.

Mesa, L.M. (2006) Morphometric analysis of a subtropical Andean basin (Tucuma´n, Argentina), *Environmental Geology*, 50: 1235–1242.

Miller, V.C. (1953) A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee. Department of Geology Columbia University, New York: 389-402.

Montgomery, D.R. And. Dietrich, W.E. (1992) Channel Initiation and the Problem of Landscape Scale, *Science*, American Association for the Advancement of Science, 255: 826–830.

Morisawa, M. (1985). *Rivers Form and Processes.* New York, Longman Group Limited: 222p.

Niyogi, M. (1985) Groundwater Resources of the Ajay Basin. In: Mukhopadhyay S.C. (ed) *Geographical Mosaic*, Modern Book Agency Pvt. Limited, Calcutta: 165–183.

Niyogi, M. (1987) Flood frequency and magnitude analyses in the Ajay Basin. *Indian Journal of Landscape System and Ecological Studies*, 10(1): 22–29.

Reddy, G.P.Obi., Maji, A.K. and Gajbhiye, K.S. (2004) Drainage Morphometry and its Influence on Landform Characteristics in a Basaltic Terrain, Central India – A Remote Sensing and GIS Approach,. *International Journal of Applied Earth Observation and Geoinformation*, 6(1):1–16.

Roy, S. (2013) Combined Techniques in Fluvial Geomorphology: An Application of Sampling and GIS for Quantitative Analysis of the Kunur River Basin, Middle Barddhaman, West Bengal. *International Journal of Remote Sensing and GIS*, 2(2): 61–73.

Scheidegger, A.E. (1967) A Complete Thermodynamics Analogy for Landscape Evolution. *Bulletin of the International Association of Scientific Hydrology*: 57–62.

Schumn, S.A. (1956) Evolution of Drainage System and Slopes in Badlands at Perth Amboy. New Jersey. *Geological Society of America Bulletin*, 67: 597–646.

Shreve, R.L. (1967) Infinite Topologically Random Channel Networks, *Journal of Geology*, 75: 178–186.

Smart, J.S., and Surkan, A.J. (1967) The relation between mainstream length and area in drainage basins. Water Resource Research, 3(4): 963–973.

Strahler, A.N. (1952) Hypsometric (area-altitude) analysis of erosional topography, *Geological Society of America Bulletin*, 63: 1117–1142.

Strahler, A.N. (1957) Quantatitative Analysis of Watershed Geomorphology. *Transactions of American Geophysical Union*, 38: 913–920.

Strahler, A.N. (1964) Quantitative Geomorphology of Drainage Basin and Channel Networks. In Chow, V.T. (ed). *Handbookof Applied Hydrology, Mcgraw Hill Book Company,Newyork*: 4–11.

Thakkar, A.K. and Dhiman, S.D. (2007) Morphometric Analysis and Prioritization of Miniwatersheds in Mohr Watershed, Gujarat Using Remote Sensing and Gis Techniques. *Journal of the Indian Society of Remote Sensing*, 35(4): 313–321.

Verstappen, H.T. (1983) *Applied Geomorphology: Geomorphological Surveys for Environmental Development*, Amsterdam: Elsevier Science Ltd: 450p.

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