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Morphometric Analysis of Kiling River Basin, North East India Using Geospatial Tools

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Abstract: *Morphometric analysis helps in studying the nature and behaviour of drainage basins. Various parameters of basin morphometry are used to recognise the characteristics of basins. It helps in understanding the physical characteristics, soil and structural properties of a river basin and largely helps in basin management. Kiling is a 7th order basin covering 1419 km² area. The rivers, Umiam and Umsiang after debouching from Meghalaya plateau, converge in Assam and flow as Kiling, which is a tributary of Kapili river. The study has demonstrated the potential use of remotely sensed data and Geographical Information Systems (GIS) in the evaluation of the linear, relief and areal morphometric parameters of the basins and in analysing their influence on the genesis and processes of landforms like drainage, and land erosion conditions.*

Key words: Geospatial technology, river basin morphometry, relief and drainage aspects

Introduction

River basins are a distinct morphometric region and have special significance to drainage pattern and geomorphology (Doornkamp and Cuchlaine, 1971; Strahler, 1957). River and their related fluvial landforms are among the most widespread features of the earth's surface (Strahler, 1957) with diversified nature. The quantitative explanation of the basin morphometry involves the linear and areal features, the channel network gradient and contributing ground slope of the drainage basin. Basin morphometry involves evaluation of streams through the measurement of zxcv678stream properties with the analysis of various drainage parameter i.e. stream order, bifurcation ratio, basin perimeter, stream length, basin area, drainage density, stream frequency, average slope, dissection index, texture ratio, circularity ratio etc. Analyses of these parameters are important to study the nature and behaviour of drainage basins. Hydrologic and geomorphic processes are the main factors responsible for formulation and development of morphometric parameter in drainage basin. Detailed study of morphometry helps in monitoring water and land resource and their management at the watershed level. The stream network within the catchment of a particular basin receives natural input of energy in the form of precipitation or sediments and has an output in the form of water and sediment discharge along the river channel. From the geomorphic point of view, the physical environment such as hill slope, river channel, stream network of the fluvial system is connected by fluvial processes which are active within the system.

The dynamics of fluvial processes within a drainage basin is controlled by geology, topography, hydrology, land use etc. in the upstream region and also in the downstream region in the form of sediment deposits and change in the base level of erosion. Remote sensing data using GIS techniques helps in identifying and interpreting such dynamic environment of river systems and its pattern of drainage and relief with their resultant landforms. Therefore, Geographical Information System and image processing technique have been adopted for identification of morphometric features and analysing their properties of Kiling river basin of north-east India. The study demonstrates the fact that integrated remote sensing and GIS-based approach is more convenient, quick and appropriate than a conventional method for morpho-dynamic assessment of medium and large-scale watershed. The study seeks to utilise the interpretation capabilities of GIS to find out the relationship between the morphometric parameters at the catchment level. GIS provides an excellent means of storing, retrieving and analysing data at the river basin level to find out their association. It also provides a powerful mechanism not only to upgrade and monitor morphometric parameters but also to permit the spatial analysis of other associated resources database.

Objective

The main objective of this paper is to evaluate the basin morphometry using conventional calculations but in a remote sensing and GIS platform using satellite data and analyse their influence on landform development processes of Kiling river basin.

Study area

Umiam and Umsiang river of Meghalaya plateau after joining together in Assam flow as Kiling which is a tributary of Kapili river. Kiling is the seventh order basin covering 1419 km^2 geographical area (Fig. 1). Geographically it is located in between 91°41′52.04″ E and 92°23′57.64″ E longitudes and 25°28′3.48″ N and 26°9′48.67″ N latitudes. The area is under sub-tropical monsoon climate, flow regime of the Kiling river is determined by south-west monsoon rainfall. The downstream of the basin consists of recent and old alluvium plain. The soil is primarily composed of silt, sand, clay, coarse sand, sandy clay, pebbles and gravel with occasional boulders. Umiam and Umsiang catchment consist of Meghalaya plateau of Pre Cambrian origin. The red hill soil comprises of red sandy clay and sandy clay loamy soil. These soils are low in nutrients and highly acidic with pH value between 6–6.5. The northern and southern part of the basin consists of the lateritic red soil of Barail series, Dihing series, Surma series, Jaintia

Table 1. Details of database used

Data base	Data base detail	Source
Topographical sheets	78O/10, 78O/13, 78O/14, 78O/15, 83B/4, 83B/8, 83C/1, 83C/2, 83C/3, 83C/5, at 1:50,000 scale	Office of the Survey of India, North Eastern Zone, Assam and Nagaland GDC, Guwahati (Assam). Office of the Survey of India, North Eastern Zone, Meghalaya and Arunachal Pradesh GDC, Shillong, Meghalaya
Satellite data	Shuttle Radar topography Mission (SRTM)	NASA, USA, Archive –GLCF (https://earthdata.nasa.gov/learn/articles/nasa-shuttle-radar-topography-mission-srtm-version-3-0-global-1-arc-second-data-released-over-asia-and-australia)

series of Kopili stage and Jaintia Series of Shella stage having moderate to steep slope and clayey surface with moderate erosion.

Database and methodology

The database of the study includes satellite images and secondary sources. The base map has been prepared using Survey of India (SoI) topographical sheets at 1:50,000 scale. In the present paper, the slope map is prepared from Shuttle Radar Topography Mission (SRTM) data using ArcGIS software. The whole watershed is divided into three-sub watersheds and morphometric analysis was carried out at sub watershed level. The details of database with sources are stated in Table 1. Some selected morphometric parameters of linear, areal and relief aspects are used for analysing the watershed. Table 2 shows the selected parameters and their mathematical equation with description. The data collected from the satellite and secondary sources are analyse using quantitative and computer aided techniques and prepared with thematic maps, tables, graphs using appropriate cartographic methods.

Result and discussion

Linear aspect

As per the drainage order scheme proposed by A. N. Strahler, (1964), it is found that the Kiling basin has seventh order drainage network with 6733 segments of streams, out of which 5157 segments are in the first order, 1196 in the second order, 288 in the third order, 74 in the fourth, 14 in the fifth and 3 segments are in the sixth order (Fig. 2). It is observed from the Table 3 and 4 that the numbers of stream segments are decreasing

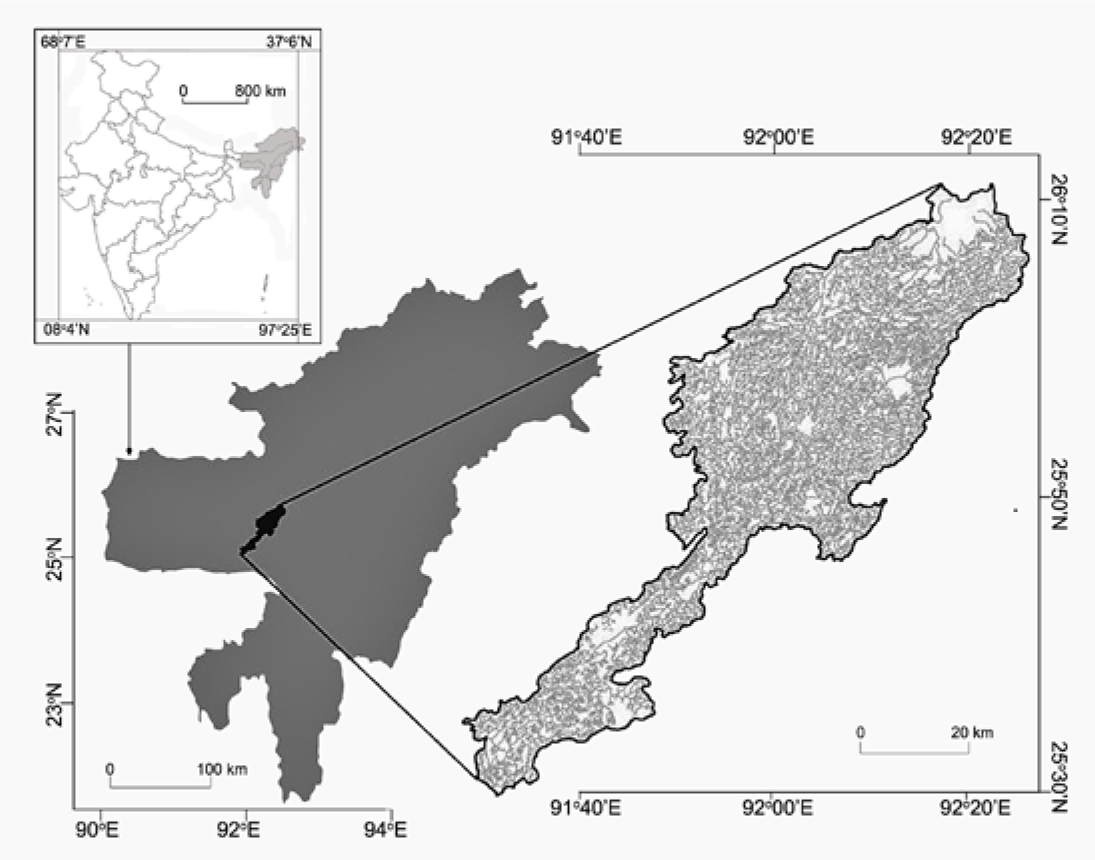

Figure 1. Location of the study area

Table 2. Morphometric parameters and their mathematical expressions

Morphometric parameter	Symbol	Mathematical expressions	
Linear aspect			
Number of streams	N		
Bifurcation ratio (Horton, 1945)	Br	$Br = Nu/N_{u+1}$	N_u is the number of streams of any given order, N_{u+1} is the number of streams in the next higher order
Basin order (Strahler, 1952)	u		
Stream length	L		
Length ratio (Horton, 1945)	R_L	$RL = Lu / L_{u-1}$	L_u is the mean stream length of a given order, L_{u-1} is mean stream length preceding lower order
Basin length	Lb		
Basin perimeter	P		
Areal aspect			
Basin area	A		
Drainage density (Horton, 1945)	Dd	$Dd = L/A$	L is Length of Stream, A is basin area
Stream frequency (Horton, 1945)	Sf	$Sf = N/A$	N is number of streams, A is area of the basin
Form factor (Horton, 1932)	Ff	$Ff = A/(Lb^2)$	A is Area of the basin, Lb is the basin length
Circulatory ratio (Miller, 1953)	Rc	$Rc=4\pi A/P^2$	A is area of the basin, P is perimeter of the basin
Elongation ratio (Schumm, 1956)	Re	$Re= (2/Lb)\times(A/\pi)^{1/2}$	Lb is the basin length, A is area of the basin
Constant of channel maintenance (Schumm, 1956)	C	$C=1/Dd$	Dd is drainage density
Relief aspect			
Basin relief	Bh	$Bh = h_{max} - h_{min}$	h_{max} is the maximum height, h_{min} is the minimum height
Relief ratio (Horton, 1945)	Rr	$Rr=H/Lb$	H is basin relief, Lb is the basin length
Ruggedness number (Strahler, 1956)	Rn	$Rn = Bh\times Dd$	Bh is basin relief, Dd is drainage density

with increasing order. Bifurcation ratio is the ratio of the number of stream segment in a given order to the number of stream of next higher order. It is a dimensionless property of drainage basin which is controlled by drainage density, lithological characteristics, basin shapes, basin area etc. High bifurcation ratio of different order signify the river flowing over tectonically active area with high overland flow and less recharge into subsurface resulting into low ground water potential (Resmi *et al.*, 2019). The bifurcation ratio of the Kiling basin ranges from 3 to 5.28. High bifurcation ratio of fourth number of order of Kiling River i.e. Umiam head stream imply tectonically active area with high over land flow consequential low permeability of sub-basin strata.

Horton gave the law of stream number of successively lower order stream segments in a given basin which tend to form a geometric series beginning with the single segment of the highest order and increasing according to constant bifurcation ratio. The regression line plotted on a semi-log graph almost validates the Horton's law of stream number. The order wise segment of Kiling river basin is shown in Table 4. The numbers of stream segment from lower order to higher order i.e. 1, 2, 3, 4, 5, 6 and 7 are 5157, 1196, 288, 74, 14, 3 and 1 respectively. The head stream Kiling is the seventh order stream. The regression equation involving a number of stream segments and stream order of Kiling basin is $\hat{y} = -647.4 \times 3551$ shown in Figure 3. The coefficient of correlation (r) between stream order and a number of stream segments is 0.75, indicating highly negative correlation between them.

Analysis of cumulative length of streams (L) shows that Umiam has high stream length more than 4000 km and Umsiang sub-basin has about 2400 km. The existence of high stream length is due to structural complexity, high relief, and impermeable bedrock. Horton (1945) gave his law of stream length stated that the cumulative mean lengths of stream segment of each of the successive order in a basin tend closely to approximate a direct geometric series in which the first term is the mean length of streams of the first order. The regression line plotted on a semi-log graph in Figure 4 tends to validate his law of stream lengths as the coefficient of correlation is 0.94.

According to the law of stream length, the cumulative mean length of stream segment of successively higher order increase in the geometrical progression starting with the mean length of the first order segments with constant length ratio. The cumulative stream length of a given order is positively related to stream order. The cumulative mean stream length of Kiling river network increases as

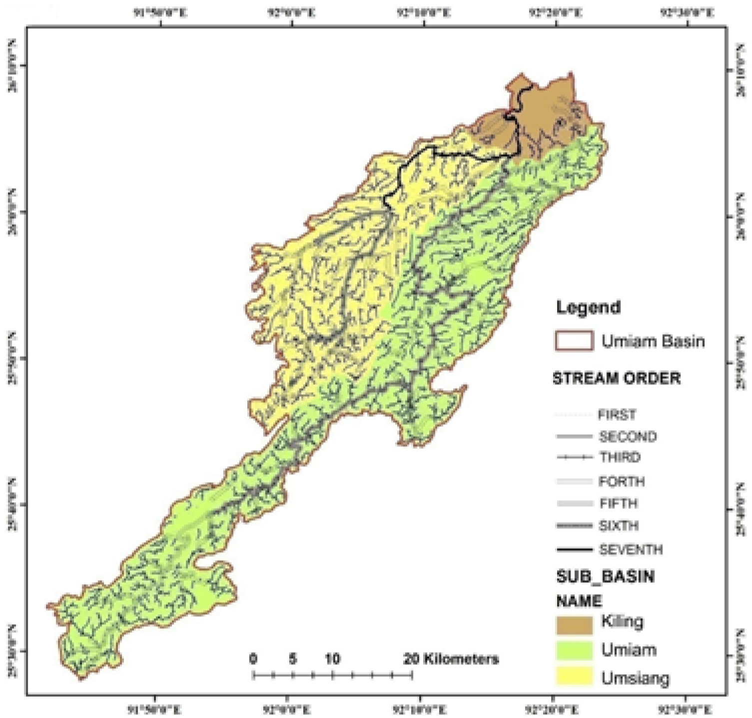

Figure 2. Stream order in the sub-basins of Kiling

Table 3. Linear and relief morphometric parameters of Kiling and its sub watershed

Name	Basin length (km)	Basin perimeter (km)	Drainage Order in (no)							No. of stream segment	Stream length (km)	Basin relief (km)	Ruggedness number	Relief ratio
			1st	2nd	3rd	4th	5th	6th	7th					
Umiam	94.5	295.8	3193	736	174	46	7	1	-	4157	2762.6	1.9	6.3	0.02
Umsiang	45.6	263.7	1856	437	108	29	8	3	1	2442	1592.4	1.2	3.7	0.03
Kiling	15.9	53.2	133	43	13	4	-	-	1	194	157.9	0.5	0.8	0.03

Table 4. Stream number and stream length of different order

Stream order	Number of stream	Bifurcation ratio	Length of stream	Mean stream length	Cumulative mean stream length	Length ratio
1st Order	5157	4.31	2737.68	0.53	0.53	
2nd Order	1196	4.15	783.92	0.65	1.18	1.22
3rd Order	288	3.89	455.49	1.58	2.76	2.43
4th Order	74	5.28	240.78	3.25	6.01	2.05
5th Order	14	4.66	115.61	8.25	14.26	2.53
6th Order	3	3	137.77	45.92	60.18	5.56
7th Order	1	-	42.77	42.77	102.95	0.93
Total	6733		4514.04			

0.53, 0.65, 1.58, 3.25, 8.25, 45.92 and 42.77 km from the lowest order to successive higher orders of 1, 2, 3, 4, 5, 6 and 7. The estimated correlation coefficient involving the cumulative mean length of stream and stream order of Kiling basin is 0.1 i.e. highly positive correlation between them. The regression line fitted on the basis of the regression equation of positive exponential function model involving cumulative mean stream length and basin order of Kiling river basin and plotted on the semi-log graph where $\hat{y} = 15.59 \times -35.55$.

Analysis of cumulative length of streams (L) shows that Umiam has high stream length more than 4000 km and Umsiang sub-basin has about 2400 km. The existence of high stream length is due to structural complexity, high relief, and impermeable bedrock. Horton (1945) gave his law of stream length stated that the cumulative mean lengths of stream segment of each of the successive order in a basin tend closely to approximate a direct geometric series in which the first term is the mean length of streams of the first order. The regression line plotted on a semi-log graph in

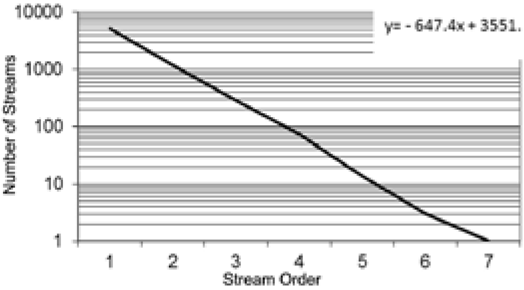

Figure 3. Relationship between stream order and number of streams

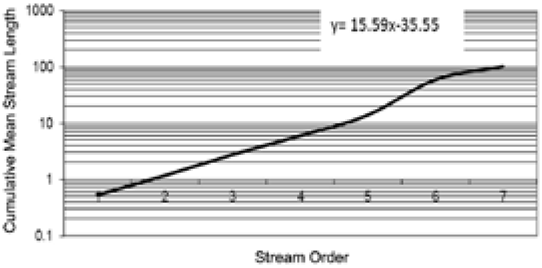

Figure 4. Relationship between stream order and cumulative mean stream length

Figure 4 tends to validate his law of stream lengths as the coefficient of correlation is 0.94.

According to the law of stream length, the cumulative mean length of stream segment of successively higher order increase in the geometrical progression starting with the mean length of the first order segments with constant length ratio. The cumulative stream length of a given order is positively related to stream order. The cumulative mean stream length of Kiling river network increases as 0.53, 0.65, 1.58, 3.25, 8.25, 45.92 and 42.77 km from the lowest order to successive higher orders of 1, 2, 3, 4, 5, 6 and 7. The estimated correlation coefficient involving the cumulative mean length of stream and stream order of Kiling basin is 0.1 i.e. highly positive correlation between them. The regression line fitted on the basis of the regression equation of positive exponential function model involving cumulative mean stream length and basin order of Kiling river basin and plotted on the semi-log graph where $\hat{y} = 15.59 \times -35.55$.

Areal aspect

The parameters considered for the present study to understand the areal aspects include basin area, basin shape, drainage density, stream frequency and constant of channel maintenance. Basin shape is a significant parameter to help in description and comparison of different forms of the drainage basin. An ideal drainage basin is dependent on the size and length of the head stream, basin perimeter, slope, basin relief, geological structure, and lithological characteristics etc.

Most popular methods of computation of basin shape are form factor, circularity ratio, and elongation ratio. Analysis of form factor estimates that Umiam and Umsiang sub-basin have low form factor of 0.09 and 0.23 respectively indicating high side flow for longer duration and low main flow for shorter duration causing high peak flows in a shorter

Table 5. Areal morphometric parameters of Kiling and its sub watershed

Name	Area (km^2)	Drainage density ($km\ km^{-2}$)	Stream frequency ($Seg\ km^{-2}$)	Form factor	Elongation ratio	Circulatory ratio	Constant of Channel Maintenance ($km^2\ km^{-1}$)
Umiam	825.61	3.346	5.03	0.09	0.34	0.11	0.298
Umsiang	490.04	3.249	3.24	0.23	0.54	0.08	0.307
Kiling	104.24	1.514	1.86	0.41	0.72	0.46	0.660

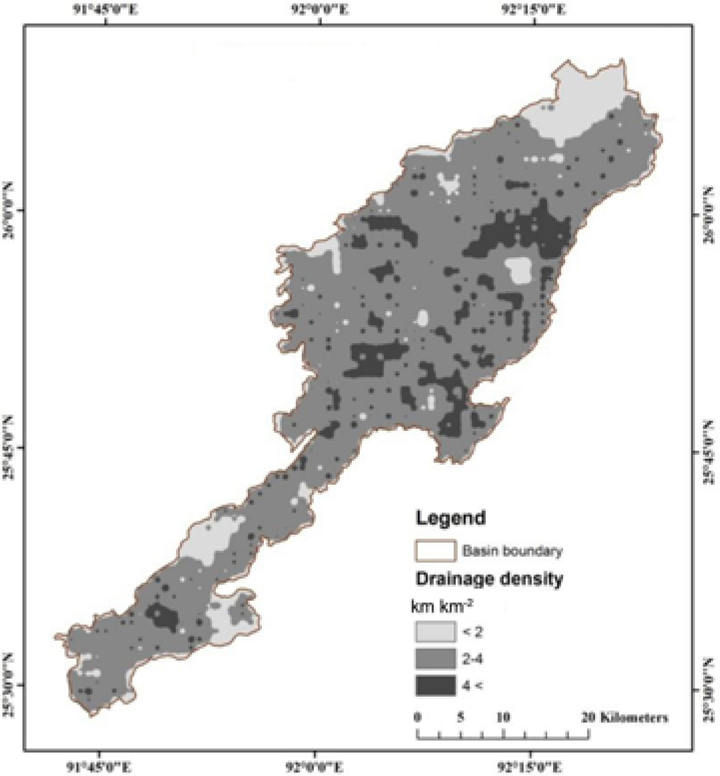

Figure 5. Drainage density of Kiling river basin

duration. Circulatory ratio values of 0.11 for Umiam and 0.08 for Umsiang indicate that the shape of the basin is elongated and as a result, it can be inferred that the sub-basin shape is of low runoff discharge and highly permeable sub soil conditions. The elongated basins are easier to manage during a flood (Kuntamalla *et al.*, 2018). Umiam and Umsiang have a lower value of elongation ratio 0.34 and 0.54 respectively indicating elongated longer duration flow watersheds. The downstream of Umiam, locally known as Kiling has comparatively higher form factor, circularity and elongated ratio of 0.44, 0.46 and 0.72 respectively than its upstream sources. It indicates that the Kiling low-lying area is circular in shape and gets a scope for uniform infiltration and takes time to reach excess water at basin outlet, which further depends on existing geology, slope and land cover.

Drainage density of a river basin refers to the total number of stream length per unit area. The density of stream network has long been recognized as topographic characteristic of fundamental significance. It provides a link between forms attributes of a drainage basin in many ways and processes along the stream courses. The drainage density of Kiling and Umsiang sub-basin varies 1.5 km km^{-2} to 3.3 km km^{-2} representing low drainage density and highly permeable subsurface material, under dense vegetation cover and low relief. It is observed from Figure 5 that the drainage density of the basin is not uniform throughout. The drainage density of entire Kiling river basin has been categorised into extremely low drainage density (below 2 km km^{-2}), moderate (2–4 km km^{-2}) and high (above 4 km km^{-2}). More than 14 % of the total area has low drainage density and 72 % of the total area falls in the category of medium drainage density; whereas only 12.59% of the total area has high drainage density. The high drainage density in Umiam catchment may be due to the presence of impermeable subsurface material, high relief and runoff potential.

Stream frequency refers to the number of streams per unit area. The quantitative analysis of stream frequency helps in classification of the drainage basin, prediction of processes particularly the length of overland flow, runoff, sedimentation, denudation etc. It also gives an idea about the geological structure, topographic controls, hydrological factors are paramount significant in the evolution of terrain characteristics of a drainage basin. The low stream frequency of Kiling and Umsiang sub-basin are 1.86 and 3.24 respectively signifies highly permeable soil, vegetation cover and low relief whereas Umiam basin has a high range of stream frequency representing an impermeable subsurface material, sparse vegetation, and high relief. The stream frequency of entire Kiling varies from 2 to 16 segments of river per square kilometer (Fig. 6). The stream frequency of the entire river basin have been grouped into five categories (Table 8) of stream frequency i.e. very low stream frequency (below 3 segments/km^2), low stream frequency (3–6 segment/km^2), moderate stream frequency (6–9 segment km^{-2}), high stream frequency (9–12 segment km^{-2}) and very high stream frequency (more than 12 segment km^{-2}).

The inverse of drainage density or constant of channel maintenance (C) is a property of landform development. It depends on the rock type, permeability, climatic regime, vegetation cover, and relief as well as duration of erosion (Schumm, 1956). The inverse of drainage density denotes the relative size of landform units in basin and has a specific genetic connotation (Strahler, 1957). It is observed from the table 4 that both the sub-basin Umiam and Umsiang of Kiling have low C value 0.29 km^2 km^{-1} and 0.30 km^2 km^{-1} respectively which expresses that the sub-basins of Kiling are under the influence of high structural disturbance, low permeability, steep to very steep slope and high surface runoff. The downstream of Kiling also have low C value 0.46 km^2 km^{-1} but it is higher than catchment means less structural disturbances and less runoff condition.

Relief aspect

Basin relief aspect plays an important role in drainage development, surface and subsurface water flow, permeability, landform development, and erosion properties of the terrain. Under relief aspect of basin morphometry the parameters like basin relief, ruggedness number, slope helps in analysing the relief characteristics of Kiling basin. In the state of Meghalaya, the maximum of altitude of Umiam catchment is Shillong

Table 6. Spatial distribution of stream frequency

Stream frequency (streams km^{-2})	Category	Area in km^2	Area in %
< 3	Very Low	130.57	9.19
3-6	Low	372.75	26.25
6-9	Moderate	737.56	51.94
9-12	High	171.06	12.04
12 <	Very High	7.95	0.56

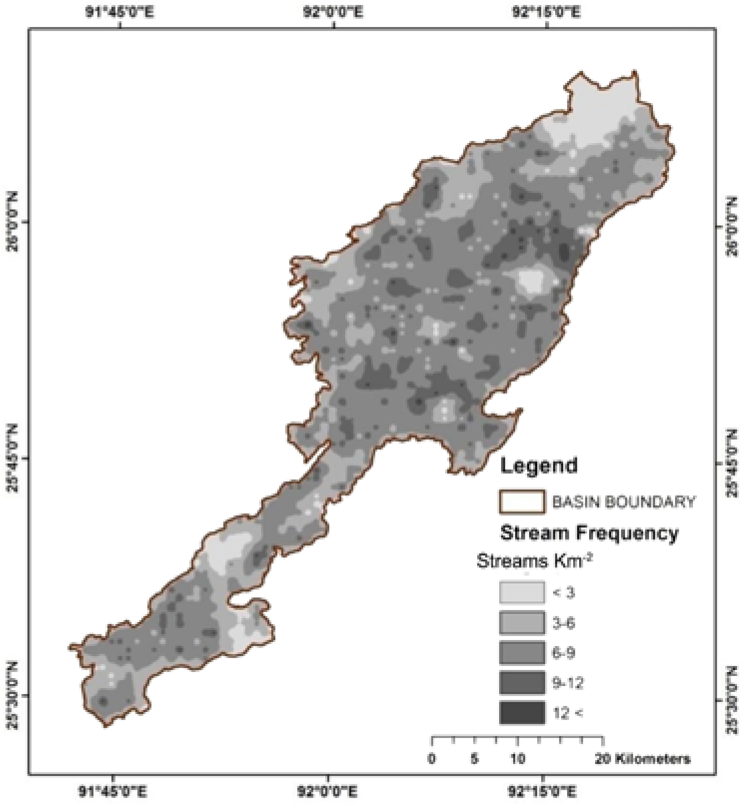

Figure 6. Drainage frequency in Kiling river basin

peak about 1964 m above mean sea level and height at the meeting point of Kapili, a tributary of Brahmaputra in Assam is about 59 m above mean sea level. The relative relief of Kiling river basin is 1905 m. The basin relief of Umiam and Umsiang are found 1890 m and 1150 m respectively. The ruggedness number of Umiam sub-basin is 6.32 indicates the highly structural complexity of the terrain and highly susceptible to erosion. While the ruggedness number of low-lying area of the basin is only 0.80 that assign low probability of erosive power of river.

The estimated slope of Kiling river basin varies from 0° to 68°. The spatial distribution of slope of the basin has been grouped into five categories (Fig. 7). From figure 5, the watershed can be subdivided into level slope (0°–2°), gentle slope (2°–5°), moderate slope (5°–15°), steep slope (15°–30°) and very steep slope (30°–68°). Less than 2% of the total area lies in the very steep slope category.

Only 44.48% of the total area comes under the category of moderate slope (5°–15°). 30.41% of the total area of the Kiling river basin is under level to gentle slope category which indicates that Kiling river basin is uneven and a very typical spatial pattern of the slope is observed. It is formed by various tectonic and denudational forces.

Conclusion

It can be concluded that the detailed quantitative morphometric analysis at the sub-basin level enables to understand the relationships among the different aspect of the drainage pattern and their influence on landform processes, drainage, and soil erosion

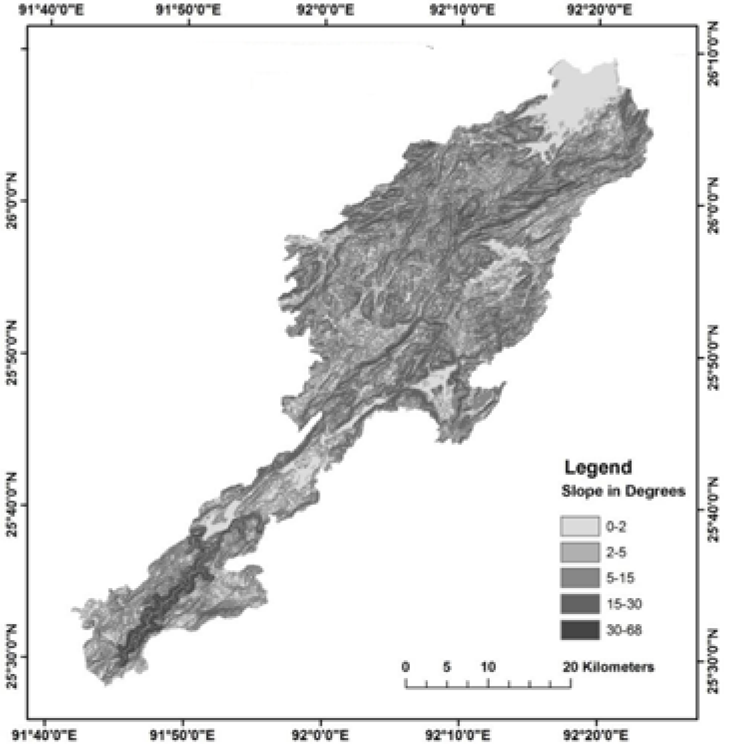

Figure 7. Stream order in the sub-basins of Kiling

properties. Kiling basin is a seventh order river basin and elongated in shape. The Killing river basin is characterised by low discharge of runoff with flow for longer duration and highly permeable subsoil condition. The catchment is also associated with low to medium drainage density with steep slopes that specify highly permeable subsurface material under dense vegetation condition. The relief aspects of the Kiling basin prove that the catchment is characterised by highly structural complex terrain and vulnerable to soil erosion. As a result, the structure, slope and flow regime have a great implication on the processes of landform development. The morphometric parameters evaluated using geospatial tools helps to develop a better understanding on the nature of landforms and their processes, along with drainage pattern characteristics for watershed area planning and management.

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