Morphometric Analysis of Sekmai River 3rd Order Watershed, using Geographical Information System (GIS)

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Abstract: The present study aims to quantitative analysis of morphometric parameters of the Sekmai River 3rd order watersheds using Geographical Information System (GIS) and DEM data. Sekmai basin covers an area of 380.32 km2. GIS data was used for the evaluation of linear, areal and relief aspects of morphometric parameters. The study area is designated as sixth-order drainage basin and it is mostly dominated by the lower order of streams with drainage density value (1.14 - 7.11) km/km^2 which exhibit gentle to steep slope terrain, dense to sparse vegetation of permeable to impermeable geological material with low to high infiltration surface run-off. The mean bifurcation ratio is 3.42 and the value of the sub-basin varies from 2 to 6.25 which reveal drainage networks formed on the homogenous rock with the influences of geologic structures on the stream network and the higher values indicates that the area has structurally distorted. Length of overland flow suggests that the majority of the watersheds have moderate flow-paths following local ground slope, reflecting more run-offs and less infiltration due to the impermeable lithology supported by high drainage density. The results of the present drainage morphometry may be helpful in better understanding the watershed characteristics and serve as a basis for improvement in the planning, management, and decision making to ensure sustainable use of watershed resources.

Keywords: Morphometry, Drainage density, Bifurcation ratio, Length of overland flow, GIS, DEM.

Introduction: The measurement and mathematical analysis of the configuration of the earth's surface shape, and dimensions of its landforms are termed as morphometry (Clarke, 1966). Morphometry is the most commonly used technique in drainage basin analysis, as morphometry forms an ideal areal unit for interpretation and analysis of fluvially generated landforms and is an example of an open system. The present studies involve measurement and evaluation of various stream properties viz. linear, areal and relief aspects which provide the quantitative information on the geometry of a fluvial system that can be correlated with the hydrologic conditions (Rao, 1984). The morphometric parameters are very important for watershed planning since it gives an idea about the watershed characteristics in terms of slope, topography, soil condition runoff characteristics surface water potential, etc. The development of landforms and drainage networks depends on the bedrock lithology, associated geological structures, and slope.

In recent years, many researchers and geoscientists from different fields have approached the quantitative analysis of drainage basin morphology was given by the first pioneer in this field Horton (1945). The Horton's law of stream lengths suggested that the geometric relationship existed between the numbers of the stream segments in successive stream orders. The law of basin areas reveals that the mean basin area of successive ordered stream formed a linear relationship when graphed. The Horton's laws were further modified and developed by several geomorphologist, most notably by Strahler (1952, 1957, 1958, and 1964), Schumm (1956), Morisawa (1957, 1958), Schiedeggar (1965), Shreve (1967), Gregory (1966, 1968), Gregory and Walling (1973). Subsequently, different characteristics of various morphometric analysis using remote sensing and GIS such as Ziaur R. A. et al. (2011), Koshak N., et al. (2012), carried out GIS-based morphometric analysis. Sreedevi et al. (2009), applied GIS and SRTM data for morphometric analysis of watershed. Anantha R.V., (2014), used ASTER DEM data and GIS techniques for drainage basin analysis for characterization of 3rd order watershed. Pareta et al. (2011), applied GIS and ASTER DEM data for quantitative morphometric analysis of a watershed of the Yamuna Basin.

Geographical Information System (GIS), techniques have been used for assessing various terrain and morphometric parameters of the drainage basins and watershed as they provide a flexible environment and a powerful tool for the manipulation and analysis of the spatial information, particularly for the future identification and extraction of the information for better understanding (Vijith, 2006). It also provides a powerful mechanism not only to upgrade and monitor morphometric parameters but also to permit spatial analysis of other associated resource database.

The morphometric analysis describes the basin processes and compares basin characteristics and it gives the history of a drainage basin. A watershed is an important part of the management of natural resources like land and water and for mitigation of the impact of natural disasters for achieving sustainable development. The morphometric assessment helps to involve a primary hydrological identification in order to calculate the approximate behavior of a watershed if correctly coupled with geomorphology and geology. The morphometric analysis provides a quantitative description of the basin geometry to understand initial slope, structural controls, geological and geomorphic history of drainage basin (Strahler, 1964; Kumar et al., 2011). Hence, morphometric analysis of a watershed is an essential first step, toward a basic understanding of watershed dynamics. In the present study, systematic analysis of morphometric parameters through integrated remote sensing and GIS techniques are effectively used in understanding the morphologic and hydrologic characteristics of the Sekmai River basin.

2. Study Area: The River Sekmai is a rain-fed river originates from Langol and Tengnoupal hill ranges, constitute many tributaries important ones are the Khamlang Lok (KL), Tisa Lok (TL), Timit Lok (TM) and Maha River (MR). Geographically, the study area lies in the south-eastern part of Manipur in Tengnoupal district between 24° 28′ 02.33″N to 24° 31′ 24.73″N latitudes and 94° 11′ 34.98″E to 93° 57′ 16.95″E longitudes, covers an area about 380.32 km^2 (Fig.-1). The Sekmai River basin occupies a hilly terrain displaying various types of erosional and depositional landforms while traversing through young Tertiary formation and ultimately enters in the Kharung Pat (Marshy land) near Keirak village.

3. Materials and Methods: The present study area falls under the Survey of India toposheets Nos. 83H/14, 83H/15, 83L/2 and 83L/3 on 1:50,000 scales. These topographical maps were geo-referenced, digitized and enlarged to 1:20,000 scales using the Arc GIS software (version 10.2) so that morphometric analysis of drainage from 1st order to the highest order of the basin can be initiated. The 30m resolution of Digital Elevation Model (DEM) Aster data was downloaded from the USGS Earth Explorer and based on this data the slope map for the watersheds was prepared. Watershed parameter such as area, basin perimeter, basin length, stream length, and stream order are directly-measured from the map and thereafter other parameters like bifurcation ratio, stream length ratio, stream frequency, drainage density, texture ratio, elongation ratio, circulatory ratio, form factor and length of overflow, relief ratio were calculated.

4. Geomorphic Analysis: The analyses of geomorphic parameters which include measurement and calculation of the sub-basins are classified into linear, aerial and relief aspects.

4.1 Linear Aspects: In the present study linear aspects of morphometric analysis of drainage basin comprise the calculation of stream order, stream length, mean stream length, stream length ratio, bifurcation ratio, Rho coefficient using formulae suggested by various authors Table 1.

4.1.1 Stream Order (U): Stream order is the first step to carry out the quantitative morphometric analysis of a watershed (Shrikant and Nikhil, 2015). For stream ordering the Strahler's (1964), the method has been followed in the present study accordingly the smallest headwater tributaries are designated as first-order streams. Where two first-order streams meet, a second-order stream is created and so on. The River Sekmai is a 6th order watershed. The total number of streams in the Sekmai river is 2016, out of which 1561 is the first order, 354-second order, 78 third order, 18 fourth-order, 4 fifth-order and only one is of sixth-order streams (Fig. 2). The number of stream segments progressively decreases as the stream order increases.

4.1.2 Stream Length (Lu): Length of the stream is an indicator of the area contribution to the watershed and steepness of the drainage basin. Steep and well-drained areas generally have numerous small tributaries, whereas in plains, where soils are deep and permeable relatively longer and few tributaries (generally perennial streams) exist. Generally, the total length of the stream segments decreases with increasing stream order. The stream length is calculated after (Horton, 1945). The length of various orders of the watershed has been measured using Arc GIS. The minimum and maximum lengths of 1st, 2nd and 3rd order streams are presented in Table 1. The length of stream segments is higher in the lower order streams and decreases as the stream order increases. The deviation from its general behavior indicates that the terrain is characterized by high relief/moderately steep slopes, underlain by varying lithology and probable upliftment across the drainage basin (Singh and Singh, 1997).

4.1.3 Mean Stream Length (Lsm): The mean stream length of a channel is a dimensional property and it shows the characteristic size of the drainage network components contributing to the drainage basin (Strahler, 1964). It is observed that the mean stream length of any given order is greater than that of the lower but less than that of the next higher order. The mean stream length of the study area varies from 0.24-0.70 for first order, 0.12-1.14 for second-order and 0.08-2.29 for third-order streams respectively (Table 1).

Table-1: Linear Aspects of 3rd Order Watersheds of the Sekmai River

Sl. No.	Parameters	Formulae	Reference	Result	
				Min.	Max.
1.	Stream Order (Nu)	The smallest permanent streams are called "first-order". Two first-order streams join to form a second-order stream; and so on.	Strahler (1964)	1st order	6th order
2.	Stream Length (Lu)	Length of the stream	Horton (1945)	1st order= 1.33	13.57
				2nd order= 0.29	3.57
				3rd order= 0.08	2.89
3.	Mean Stream Length (Lsm)	Lsm=Lu/Nu	Strahler (1964)	1st order= 0.20	0.70
				2nd order= 0.12	1.14
				3rd order= 0.08	2.89
4.	Stream Length Ratio (R_L)	R_L=Lu/Lu-1	Horton (1945)	0.18	2.09
5.	Bifurcation Ratio (Rb)	Rb=Nu/Nu+1	Horton (1945)	2nd order= 2.00	10.50
				3rd order= 2.00	7.00
6	Mean Bifurcation Ratio (Rbm)	Rbm=Average of bifurcation ratio of all orders	Strahler (1964)	2	6.25
7.	Rho Coefficient (Rho)	Rho=R_L/Rb The ratio between the stream length ratio and the bifurcation ratio.	Mesa (2006)	Rho1 = 0.02	0.27
				Rho2 = 0.03	2.03

4.1.4 Stream Length Ratio (RL): It is defined as the ratio of the mean stream length of a given order to the mean stream length of the next lower order and has an important relationship with the surface flow and discharge (Horton, 1945). The change in stream length ratio between orders in the study area differs from one order to another, which indicates late youth to mature stages of geomorphic development (Singh and Singh, 1997). The values of stream length ratio between successive stream orders of the basin vary due to the difference in slope and topographic conditions (Rakesh Kumar et. al., 2000 and Sreedevi et al., 2009). It is an important relationship with the surface water discharge and erosional stage of the basin.

4.1.5 Bifurcation Ratio (Rb): Horton (1945), defined bifurcation ratio is the ratio of the number of streams of a given order to the number of streams of the next higher-order. The irregularity in lithological and geological development of the drainage basin depends on the bifurcation ratio. The higher value of Rb has a circular basin while low Rb values suggest an elongated basin. The Rb value for 3rd order watershed of the study area varies from 2.00-10.50 for second-order streams, 2.00-7.00 for third-order streams (Table 1). The high bifurcation ratio suggests the area is tectonically active. The mean bifurcation ratio (Rbm) value of Sekmai River varies from 2.00-6.25. The sub-basin KL-6, MR-6, and SR-33 has the lowest Rbm values, suggests less structural disturbance and high infiltration rate, and whereas, Rbm values of the highest sub-basin SR-20, indicates that the area has structural distortion and highly dissected drainage basin.

4.1.6 Rho Coefficient (Rho): According to Horton (1945), Rho coefficient is an important parameter that determines the relationship between the drainage density and physiographic development of the basin and allows the evaluation of the storage capacity of the drainage network. In the study area, the value of Rho1 (ratio between 1st and 2nd order) ranges from 0.02 (MR-2, 15, SR-9, 15, 20, 36, TL-2, 8) to 0.27 (KL-6) and Rho2 (ratio between 2nd and 3rd order) varies from 0.03 (SR-34) to 2.03 (MR-12). The average mean Rho coefficient of the study area ranges from 0.04 to 1.03 (Table 1). The lower value of the Rho coefficient is found in SR-5, indicates low water storage during the flood and high erosional effect, whereas a higher Rho value of 2.03 having sub-basin MR-12 suggests high water storage during flood and attenuation effect of erosion during elevated discharge.

4.2. Aerial Aspects: An aerial aspect of a watershed is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment including all tributaries of a lower order. The aerial aspects include basin area, perimeter, basin length, form factor, circularity ratio, elongation ratio, drainage density, texture ratio, length of overland flow, constant of channel maintenance, stream frequency, infiltration number and lemniscate's ratio as shown in Table 2.

4.2.1 Basin Area: The area of a basin is defined as the total area projected on a horizontal plane contributing overland flow to the channel segment of the given order and includes all the tributaries of the lower order. The horizontal expansion of the basin depends upon the relief, drainage texture, climate, and geology. The basin size helps to determine the amount of water reaching the river. Larger the catchment area, greater will be the potential of flooding. The area of the basin is delineated from the adjoining one by drainage divided. The drainage divided is a ridge-like feature that can be identified on the basin contour pattern. The basin area of each sub-basin is measured by using Arc GIS software.

4.2.2 Basin Perimeter: The perimeter of a basin is the outer length of the boundary that enclosed its area. It is measured along the divides between basins and may be used as an indicator of basin size and shape. The perimeter of a basin can be directly correlated with the square root of the basin area. The increase or decrease in the basin perimeter depends upon the increase or decrease respectively of the basin.

4.2.3 Basin Length: Length of a basin is expressed as the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). The basin length of the study area for the sub-basin is given in Table 2.

4.2.4 Form Factor (Ff): Form factor may be defined as the ratio of basin area to the square of the basin length and is a quantitative expression of drainage basin (Horton, 1932). The value of the form factor would always be greater than 0.7854 for a near-perfect circular watershed. Smaller the value of a form factor, the more elongated will be the watershed. The circular basin with high form factors has high peak flow of shorter duration whereas elongated basin with low form factors has a lower peak flow of longer duration. The low form factor indicates a long and narrow basin, and high form factor indicates a short and wide basin (H. Chandrasekhar et al. 2005). The Ff value of the study area varies from 0.20-0.96. The lower value of the form factor is found in sub-basin TL-4 suggests that the basin is to be slightly elongated in shape and low peak flows for a longer duration. The sub-basin SR-18 with the higher form factor of 0.96 has a circular basin and high peak flows for a shorter duration. Flood flows of elongated basins are easier to manage than those of the circular basin (Christopher et al., 2010).

Table-2: Aerial Aspects of 3rd Order Watershed of Sekmai River

Sl.No.	Parameters	Formulae	Reference	Result	
				Min.	Max.
1.	Area (A)	Area of the basin in km^2	GIS software	0.31	6.88
2.	Perimeter (P)	Perimeter of the basin in km	GIS software	2.14	12.05
3.	Basin Length (Lb)	Length of the basin in km	GIS software	0.72	4.75
4.	Form Factor (Ff)	$Ff=A/Lb^2$	Horton (1945)	0.20	0.96
5.	Circulatory Ratio (Rc)	$Rc=4\pi A/P^2$	Strahler (1964)	0.44	0.90
6.	Elongation Ratio (Re)	$Re=D/Lb=1.128\sqrt{A}/Lb$	Schumm (1956)	0.50	1.11
7.	Drainage Density (Dd)	$Dd=\sum Lu/A$	Horton (1945)	1.14	7.11
8.	Texture Ratio (Tr)	$Tr=\sum Nu/P$	Smith (1950)	1.32	4.03
9.	Length of Overland flow (Lg)	$Lg=1/2Dd$	Horton (1945)	0.1	0.4
10.	Constant channel maintenance (Cm)	$Cm=1/Dd$	Schumm (1956)	0.14	0.75
11.	Stream Frequency (Fs)	$Fs=\sum Nu/A$	Horton (1945)	2.71	24.32
12.	Infiltration Number (If)	$If=Fs(Dd)$	Faniran (1968)	3.10	142.01
13.	Lemniscate's Ratio (K)	$K=Lb^2\pi/(4A)$	Chorley *et al*. (1957)	0.1	17.4

4.2.5 Circulatory Ratio (Rc): The circulatory ratio is defined as the ratio of the basin area to the area of a circle having the same circumference perimeter as the watershed, which is dimensionless and expresses the degree of circulatory of the basin (Miller, 1953). Greater the value of the circulatory ratio more circular is the basin. The stage of dissection indicates the significant ratio of circulatory ratio in the basin. Its low, medium and high values are correlated with young, mature and old stages of the cycle of the watershed of a region respectively. The Rc value of 0.4 and below indicates the basin is elongated, low discharge of runoff and high permeability of the subsoil condition, and values greater than 0.75 indicate circular basin with high discharge runoff and low permeability. The value of the circulatory ratio varies from 0.44 to 0.90 (Table 2). The Rc lowest value of 0.44, is found in sub-basin TL-4 which indicates that the basin is elongated and highly permeable homogenous geological material may be controlled by structure, while higher Rc having sub-basin MR-2 with 0.90 values suggest circular basin and low relief with the impermeable surface.

4.2.6 Elongation Ratio: Schumm (1956), defined elongation ratio is the ratio between the diameters of a circle of the same area as the basin to the maximum basin length. According to (Singh and Singh, 1997), the circular basin is more efficient in runoff discharge than the elongated basin. Generally, the Re values range between 0.6 and 1.0 over a wide variety of climate and geologic types. The values approaching 1.0 are the characteristics of the region of very low relief, while values in the range of 0.6-0.8 usually occur in the areas of high relief and steep ground slope (Strahler's 1964). These values are further categorized as circular (>0.9), oval (0.8-0.9), less elongated (0.7-0.8) and elongated (<0.7). The elongation ratio values of the study area vary from 0.50 to 1.11 (Table 2). The low Re value of sub-basin TL-4 indicates more elongated basin shape with high relief followed by a steep slope which is susceptible to head wards erosion while the higher Re value is found in sub-basin SR-18 suggests circular basin shape, low infiltration rate, and high runoff, low relief by gentle slopes.

4.2.7 Drainage Density (Dd): Drainage density is defined as the total length of all the streams in a watershed to the area of the watershed. It is an important tool in determining the permeability and porosity of the geological formation and an indicator of landform elements in stream eroded topography. The low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. Generally, low drainage density results in the area of highly resistant or permeable subsoil material, dense vegetation, and low relief, high drainage density is the result of weak or impermeable subsurface material, sparse vegetation, and mountainous relief. The low value of drainage density influences greater infiltration and hence wells in this region will have good water potential leading to a higher specific yield of wells. Thus, drainage density can also indirectly reveal the groundwater potential of the area. In the study area, drainage density ranges from 1.14 to 7.11 (Table 2). The sub-basin MR-19 has a value of 1.14 km/km^2, fells in its low drainage density which indicates the area of highly resistant or permeable subsoil material, dense vegetation and high infiltration with less runoff. The higher Dd having sub-basin SR-17 suggests that the basin is the result of weak or impermeable subsurface material, sparse vegetation, and high relief, less infiltration thereby the large proportion of surface runoff.

4.2.8 Texture Ratio (Tr): According to Horton (1945), has defined drainage texture is the total number of stream segments of all orders in a basin per perimeter of the basin. It is important to geomorphology which means that the relative spacing of drainage lines depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. In the present study, texture ratios are ranging from 1.23 to 4.03(Table 2). The lowest value of texture ratio is recorded in the sub-basin MR-19, while the highest values have been recorded in sub-basin SR-26. The mean texture ratio of the whole sub-basin is about 2.54 indicates that the drainage texture of the basin is coarse leading to low drainage density, permeable sub-soil material and dense vegetation of high infiltration with less run-off.

5.2.9 Length of Overland Flow (Lg): Length of overland flow is the length of water over the surface before it concentrated into the mainstream, which affects hydrologic and physiographic development of the drainage basin (Horton, 1945). When rainfall intensity exceeds soil infiltration capacity, the excess water flows over the land surface as overland flow (Suresh, 2000). The values of Lg factor depends on the rock type, permeability, climatic regime, vegetation cover, slope, relief as well as the duration of erosion (Schumm, 1956). The shorter the length of overland flow, the faster is the surface runoff from the streams (Kumar et. al., 2011). The Lg value of the study area is found to be 0.1 to 0.4 as shown in Table 2. Lg value less than 0.2 means that short flow path with a steep slope and the area has more runoff, and less infiltration. In the study area, Lg values between 0.2 and 0.3 are observed in 12 sub-basins, indicates the presence of moderate ground slopes, where the run-off and infiltration are moderate. Lg values greater than 0.3 is found in sub-basin MR-19 with the value of 0.4 shows the occurrence of long flow-path; and thus, gentle ground slopes, which reflect area has less surface run-off and more infiltration.

4.2.10 Constant of Channel Maintenance (Cm): This parameter indicates the number of km^2 of basin surface required to develop and sustain one linear Km of channel. Schumm (1956), defines constant of channel maintenance as the inverse of drainage density having dimension of length as a property. The drainage basins with higher values of constant of channel maintenance are characterized by the lower value of drainage density, whereas, a higher value of constant channel maintenance indicates strong control of lithology with a high surface permeability. The constant of channel maintenance depends not only upon the rock type, permeability, climate regime, vegetation cover, and relief but also on the duration of erosion and climate history. Constant of channel maintenance for the study area vary from 0.14 to 0.87 km (Table 2). The sub-basin SR-17 has a lower value of 0.14, indicates the basin has a more erodible surface runoff, while sub-basin MR-19 has a higher value of 0.87, suggest least erodible due to the underlying hard lithological condition with high permeability and so, relatively high infiltration rate prevails.

4.2.11 Stream Frequency (Fs): The total number of stream segments of all orders per unit area is termed as stream frequency (Horton, 1945). A higher stream frequency points to a condition of larger surface runoff, steeper ground surface, impermeable subsurface, sparse vegetation, and high relief. Low stream frequency indicates high permeable lithology and low relief. The stream frequency of the study area varies from 2.71 to 24.32 as shown in Table-2. The Fs lowest value of having sub-basin MR-19 indicates poor runoff whereas a higher value of sub-basin KL-5 shows more runoff and impermeable subsurface. The stream frequency of the study area shows a positive correlation with the drainage density indicating that the stream number increases with the increase of drainage density.

4.2.12 Infiltration Number (If): The infiltration number is defined as the product of drainage density and stream frequency. The lowest value of infiltration number is found in sub-basin MR-19 value with 3.10 suggest high infiltration and low run-off; while the higher infiltration number of sub-basin KL-5 has lower infiltration and hence, higher will be run-off

(Table 2). The present study leads to the development of higher drainage density and it gives an idea about the infiltration characteristics of the basin reveals impermeable lithology and higher relief.

4.2.13 Lemniscate's Ratio (K): Chorley (1957), express the lemniscate's value to determine the slope of the basin. The lemniscate value for the study area ranges between 0.8 and 4.0 (Table-2). The sub-basin TL-4 is considered the highest value that recorded the sub-basin has occupied the maximum area in its region of inception with a large number of streams of a higher order. The low value of 0.8 is found in sub-basin SR-17 and 18; represent basins nearly rounded and prevailing vertical and lateral erosions, which refer to the geomorphic stage of development of a basin (Ashour and Torab, 1991).

4.3. Relief Aspects: Relief aspects in an important factor in understanding the extent of the denudation process that has undergone in the watershed and also an indicator of the flow direction of the water. It includes watershed relief, relief ratio, relative relief, and ruggedness number. Figure 4 shows the DEM of 3rd order watersheds of the Sekmai River.

4.3.1 Basin Relief (R): Basin relief refers to the difference in elevation between the highest and lowest point in a drainage basin (Strahler, 1964). Basin relief is an important factor in understanding the denudation characteristics of the basin. The highest relief in the watershed is found to be 1629m and the lowest relief is 772m above the mean sea level. The overall relief calculated for the 3rd order watershed ranges between 125m (MR-11) to 654m (SR-8) Table 3. The sub-basin having MR-11 has the lowest basin relief indicates that the area is peneplain and valley, whereas the highest basin relief is found in sub-basin index SR-8 suggests the basin is in the hilly region of a steep slope and high runoff.

Table-3: Relief Aspects of 3rd Order watershed of Sekmai River.

Sl. No.	Parameters	Formulae	Reference	Result	
				Min.	Max.
1.	Relief (R)	R=H(max.)–h(min.)	Hadley and Schumm (1961)	125	654
2.	Relief Ratio (Rf)	$Rf = R/L_b$	Schumm (1963)	0.06	0.42
3.	Channel gradient (Sg)	$Sg = H\text{-}h/Lb^2$	Schumm (1963)	0.01	0.48
4.	Ruggedness number (Rn)	Rn = Dd (R /1000)	Strahler (1964)	0.31	2.76

4.3.2 Relief Ratio (Rf): The relief ratio is the ratio of maximum relief to the horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm, 1956). Relief ratio is a dimensionless number that provides a measure of the average drop in elevation per unit length of the basin (Fryirs and Brierley, 2013). It measures the overall steepness of a watershed and is an indicator of the intensity of the erosional process operating on the slope of the watershed. The relief ratio of the study area ranges between 0.06(KL-4, MR-11, SR-37, TL-10) to 0.42(SR-17) Table 3. The great similarity concluded due to the homogeneity of climatic conditions, surface relief, rock formations, and geologic structure. The increase in relief ratio is due to increasing shape means to decrease the time required for the concentration of runoff. So the highest value of the sub-basin SR-17 reveals high hill slopes and high stream gradient.

4.4.1 Channel gradient (Sg): The channel gradient is the total drop in elevation from the source to the mouth of the trunk channel in each drainage basin. In the present study area sub-basin having index KL-4 and SR-37 has the lowest 0.01 km and the sub-basin SR-17 has the highest gradient of 0.48 Table 3.

4.4.2 Ruggedness number (Rn): Strahler (1968), defines ruggedness number as the product of the basin relief and the drainage density and also it combines the steepness of the slopes with its length. The ruggedness numbers were worked out for each sq.km and spatial distribution of ruggedness condition in the basin is generated. The ruggedness number of the study area ranges from 0.31-2.27 in Table 3. The low ruggedness value of sub-basin MR-19 implies that the area is less prone to soil erosion and have intrinsic structural complexity is associated with relief and drainage density (Patton and Baker, 1976). The highest value of 2.76 is observed in sub-basin TL-5 and is considered as extremely high values of ruggedness number. They occur both variables (basin relief and drainage density) are large and when the slopes are not only steep but long as well.

4.4 Slope: Slope is defined as the angular inclination of terrain between hilltops (crest) and valley bottoms, resulting from the combination of many causative factors like geological structure, climate, vegetation cover, drainage and drainage texture (Singh, 1998). The Slope is one of the major controlling factors in the development and formation of different landforms. In geomorphic studies slope analysis is an important element, in turn, are controlled by the climatic and morphogenic processes in the area underlying the rocks of varying resistance. An understanding of slope distribution is essential as a slope map provides data for planning, settlement, mechanization of agriculture, deforestation, planning of engineering structures, morpho-conservation practices, etc. (Sreedevi et.al 2005). The slope map of the study area is shown in Fig-5. The slope map is classified into six classes as given in Table 3. It is observed from the table that 26% area has a slope less than 5^o and ≈32% of the area has a slope >20^o. The alluvial plains show a comparatively low slope (<5^o), gentle in nature. It is clearly observed that the piedmont area, alluvial fan, and terraces have a moderate slope (5^o-10^o). Interestingly <1% of the total area has a slope of >45^o. An area of 31% of the total area has occupied a slope of 10^o-20^o (moderate slope), which is the dominant slope in the area.

Table-4: Slope Classes and their area coverage.

Slope Angle	Area (Km^2)	Area%
<5^o	102.34	26.91
5^o-10^o	36.60	9.62
10^o-20^o	120.06	31.57
20^o-30^o	97.30	25.58
30^o-45^o	22.56	5.93
>45^o	1.44	0.39

5. CONCLUSION: In the present study linear, aerial and relief aspects of morphometric parameters are analyzed using GIS techniques. Based on the length of overland flow the majority of watershed indicates short flow paths, with steep ground slope, reflecting that the area is associated with more runoff and less infiltration. The remaining watersheds indicate moderate ground slopes, where the run-off and infiltration are moderate and long flow paths and gentle ground slopes, which reflect the area of fewer surface runoffs and more infiltration. The bifurcation ratio indicates the absence of any significant structural control on the development of the drainage. The drainage density of Sekmai River 3rd order watersheds reveals that the subsurface strata are impermeable as the majority number of sub-basin show fine drainage density. The stream is mostly dominated by the lower order. The elongated shape of the basin is mainly due to the guiding effect of the thrusting and faulting. The erosional processes of fluvial origin are predominantly influenced by subsurface lithology of the basin. Relief ratio indicates that the discharge capabilities of some of the watershed are high and in others, infiltration is more with good groundwater potential. The results of this study provide information on drainage morphometry that can help in better understanding the watershed characteristic and serve as a basin for improving the planning of watershed management, and decision making to ensure sustainable use of the watershed resources.

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Figures

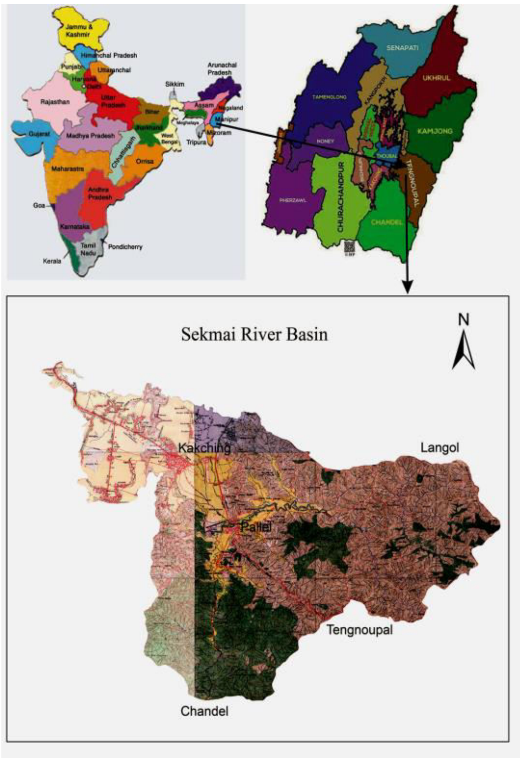

Fig. 1: Location map of study area.

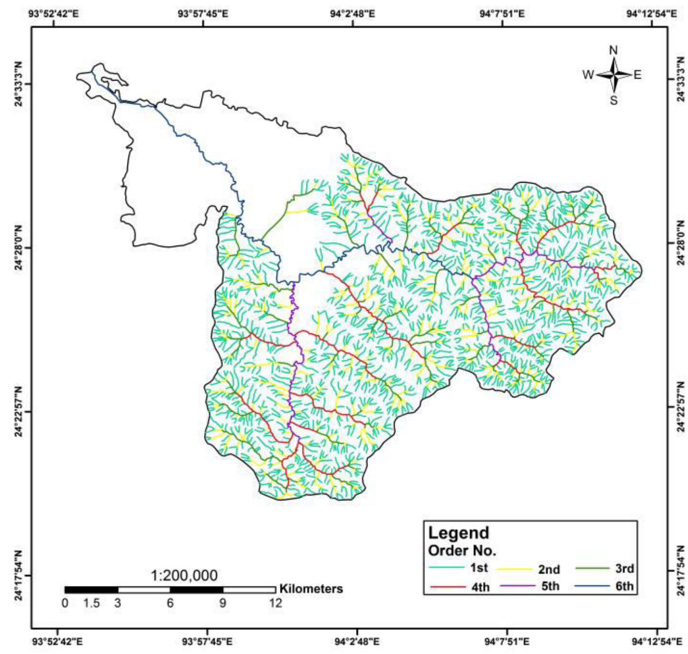

Fig. 2: Drainage Map of Sekmai River.

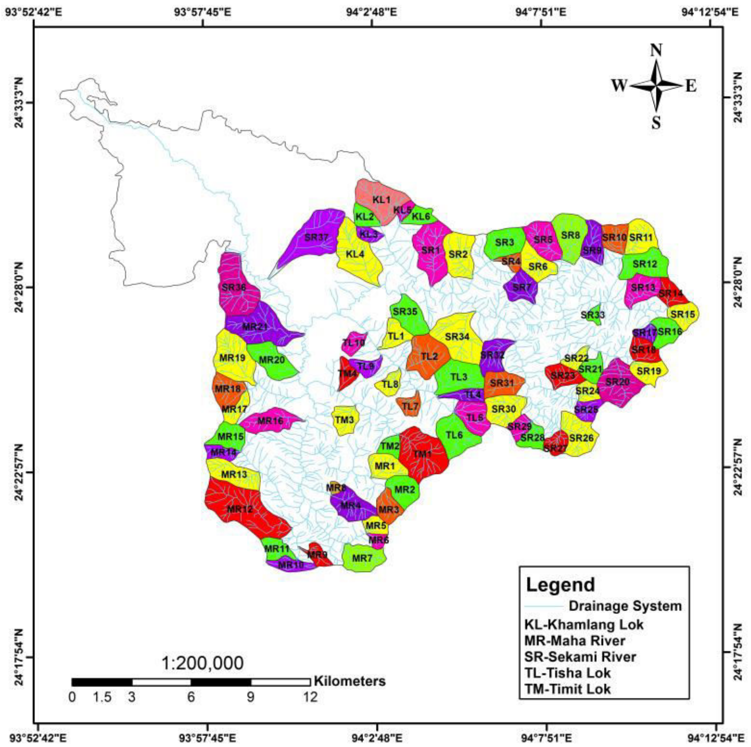

Fig. 3: 3rd Order Watershed of Sekmai River.

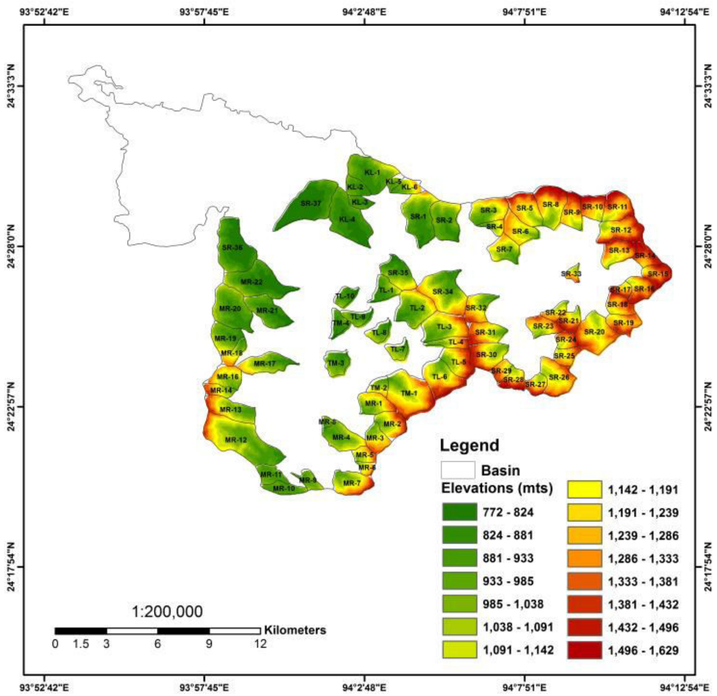

Fig.4: Digital Elevation Model of 3rd Order Watersheds of Sekmai River.

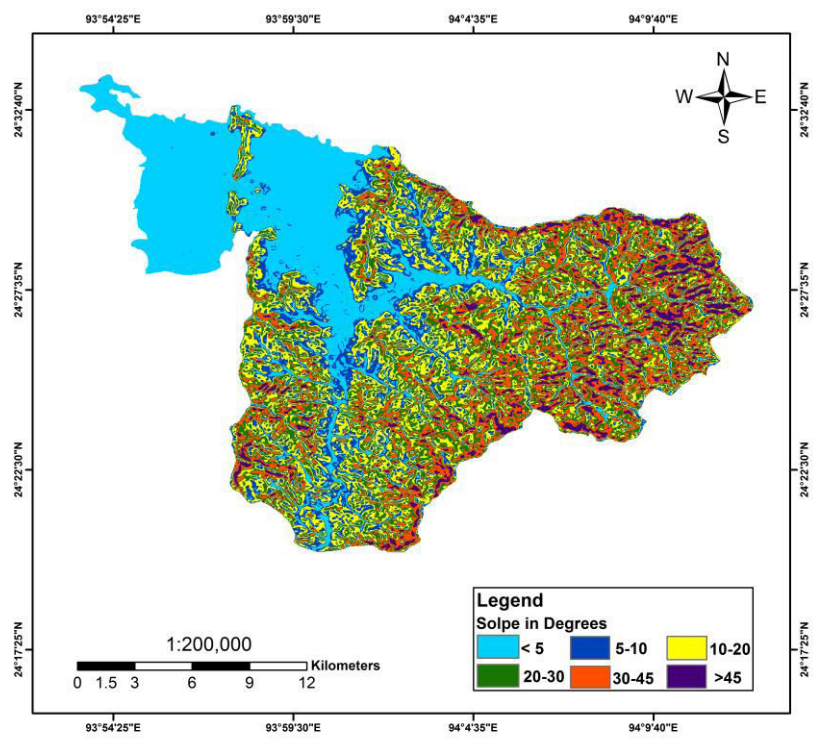

Fig. 5: Slope Map of Sekmai River.