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Geospatial Technology in Morphological Study of Drought Prone Sakri Basin of Eastern India

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ABSTRACT

A study was carried out to analyze the morphometric parameters including linear, aerial and relief characteristics of the Sakri watershed of Bihar and Jharkhand which is prone to both erosion and sedimentation using remote sensing (RS) and Geographic Information System (GIS). The geomorphological parameters were extracted from SRTM Digital Elevation Model (DEM) using ArcGIS 10.5 and Soil and Water Assessment Tool (SWAT). The Sakri watershed is covered by 1744.85 km^2 with dendritic drainage patterns. Results showed that the stream order varied from 1 to 6. Drainage density and relief of the watershed were 1.18 km^{-1} and 0.622 km, respectively. The results of mean bifurcation ratio (1.86), drainage intensity (1.09 km^{-1}) and constant of channel maintenance (0.85 km) showed that Sakri watershed is an elongated shape with high risk to flooding and soil erosion. However, significantly high values of infiltration number (1.52) and ruggedness number (0.74) obtained are indicative of very low infiltration which may result in high surface runoff and soil erosion. The hypsometric curve of the basin indicated that the watershed was in equilibrium stage. The results are very beneficial for developing and designing conservation structures of soil and water and groundwater recharge on watershed basis.

Keywords: Basin geometry, morphometry, hydrologic behaviour, Sakri river

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INTRODUCTION

Natural disasters like drought, flood and landslide are threatening mankind and causes loss of life and property damage. Such hazards have grown over the years due to population growth, urbanization, industrialization, deforestation, and indiscriminate use of natural resources like land and water (Fernandez *et al*., 2018; Gunjan *et al*., 2020). The study of natural hazards and their effects happened to be one of the most active areas of watershed morphology. Hydrologic design of every hydrological unit is different because the physical factors that affect the hydrologic behaviour vary from location to location. This variation in factors may be based on morphological, climatic, vegetation and land use, and soil related characteristics of each hydrological unit (Deshmukh *et al*., 2010; Fernandez *et al*., 2018). Morphological characteristics of watershed refer to the measurement of the linear, areal and relief features, which are considered as a fundamental geomorphic unit (Desai *et al*., 2016; Pandi *et al*., 2017; Lakshminarayana *et al*., 2022). Morphometric analysis is the measurement and mathematical evaluation of shape, size, and configuration of earth's surface and dimension of landforms (Bhatt *et al*., 2021). In recent years, the morphometric analysis has emerged as a powerful tool to identify and interpret the hydrological behavioural characteristics of the watershed (Deshmukh *et al*., 2010; Rai *et al*., 2018; Kanhaiya *et al*., 2019). Analysis of morphological parameters in Geographic Information System (GIS) environment has proved to be accurate, time saving and efficient technology for spatial representation of topographic situations and for hydrological analysis (Deshmukh *et al*., 2010; Singh *et al*., 2021; Lakshminarayana *et al*., 2022). The quantitative analysis of river basin evaluation, watershed prioritization, soil and water conservation, and natural resources management at micro unit level has been defined using different morphometric parameters (Singh *et al*., 2021). The evaluation of the morphometric features of watershed necessitates the preparation of drainage density, ordering of streams, measurement of the watershed area and perimeter, length of drainage channels, stream frequency, bifurcation ratio, circulatory ratio, and constant channel maintenance etc. (Desai *et al*., 2016; Kanhaiya *et al*., 2019; Bhatt *et al*., 2021). These parameters are useful in various studies of geomorphology and surface water hydrology, such as flood characteristics, sediment yield, and evolution of watershed morphology, characterizing river watershed, and distribution of stream network within the watershed.

Earlier, several research have also been done on the watershed management and their characterizations have been entirely based on the analysis of their morphometry (Gunjan *et al*.,

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2020). But in eastern India, particularly in Chota Nagpur Plateau originated river has very limited study and till now no any study on morphometry of Sakri watershed. So, the objective of the present research is to study the morphometric parameters of Sakri watershed and to identify the influence of the underlying geology on the morphometric parameters of the watershed and finally to generate a substantial knowledge base regarding the relationship between surface morphometry and subsurface lithology for integrated water resource management. Sakri watershed is characterized by undulating plateau, hills and mountains, initially high forest cover, which is depleting fast due to mineral and industrial exploitation and encroachment, pockets with chronic drought conditions, uneven and erratic rainfall, low ground water level, high soil erosion, low water retentive capacity of the soil, lack of safe disposal of runoff water during monsoon season and water storage and moisture conservation practices for raising *rabi* crops and drying of tanks and wells, insufficient agricultural and allied activities, lack of soil and water conservation practices leads to agricultural unemployment and acute poverty (Jeyaseelan and Kumar, 2010). Despite good rainfall, the crop productivity in the watershed is very poor, because of the slopy, undulating terrain, non-availability of irrigation infrastructure, and poor soil and water conservation measures (Singh, 2012).

MATERIALS AND METHODS

Description of the study area

The Sakri river watershed is located in drought prone district of south Bihar and Jharkhand in eastern part of India which originates from Tisri village in Giridih district of northern Chhotanagpur plateau, Jharkhand (Jeyaseelan and Kumar, 2010). The Sakri river runs over 158 km before it joins the Panchane river near Nalanda district in Bihar. Sakri river drains a total area of about 1744.85 km^2. It extends between the 85° 29' 34'' E to 86° 8' 59'' E longitude and 24° 26' 2'' N to 25° 14' 35'' N latitude. The climate of the upper reach of Sakri watershed is humid to sub humid tropical monsoon while in lower reach, it is characterised as humid to sub-tropical climate. Elevation of the watershed ranges from 44 to 669 m. It flows in a north-west direction through Jharkhand and enters into Bihar near village Sarkanda of Nawada district. The coverage of state boundary and the district boundary of the Sakri river watershed is shown in Fig. 1.

GIS Analysis

Watershed boundary was delineated on the basis of the Digital Elevation Model (DEM) using ArcGIS 10.5 and Soil and Water Assessment Tool (SWAT) and verified delineated watershed boundary with Google Earth Pro. DEM of

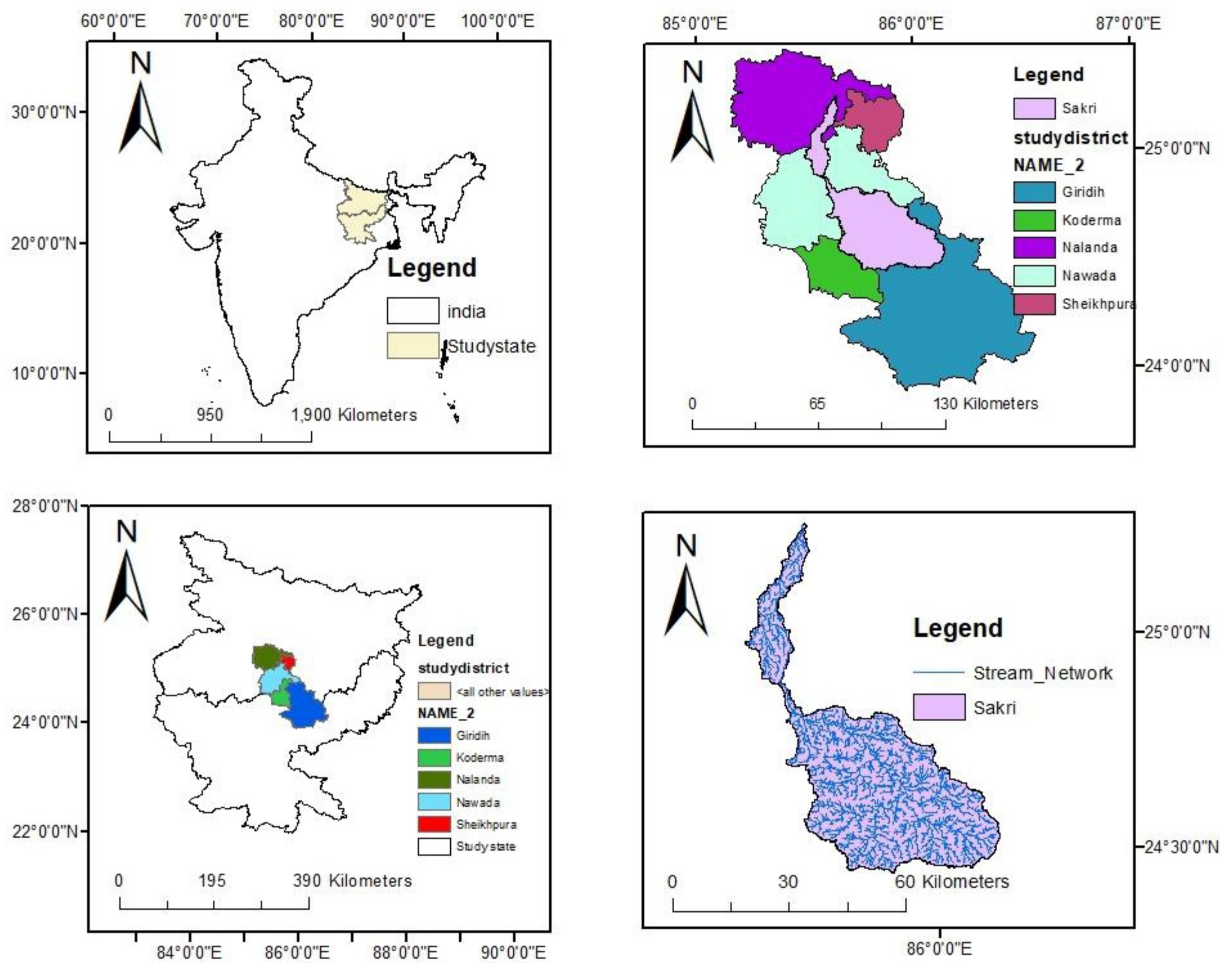

Fig. 1: Study area and drainage network

watershed, drainage network, stream order map (Fig. 3) and slope zonation map (Fig. 2) were digitized in GIS environment (Pande *et al.*, 2021). Various attribute parameters of the digitized layers were derived to compute the morphological characteristics of the Sakri watershed. Various linear, areal and relief morphological parameters were estimated with different geoprocessing ArcTool of GIS and some parameters were obtained using standard mathematical formula (Table 1, 2 & 3). The entire watershed was divided into 5 km X 5 km grid to compute and obtain the value of parameters such as stream length ratio, bifurcation ratio, rho coefficient, drainage density, stream frequency, length of overland flow, texture ratio, drainage texture, lemniscate's, form factor, circularity ratio, elongation ratio, drainage texture, compactness coefficient, constant of channel maintenance, infiltration number, relief, relief ratio, gradient ratio, ruggedness number, asymmetry ratio and hypsometric curve.

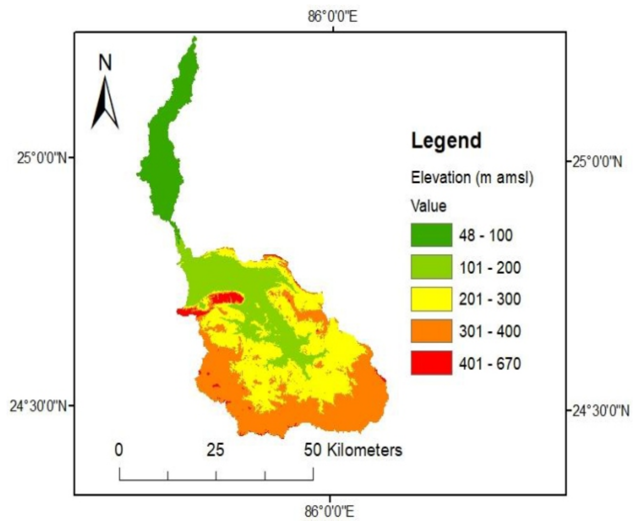

Fig. 2: Elevation map of Sakri watershed

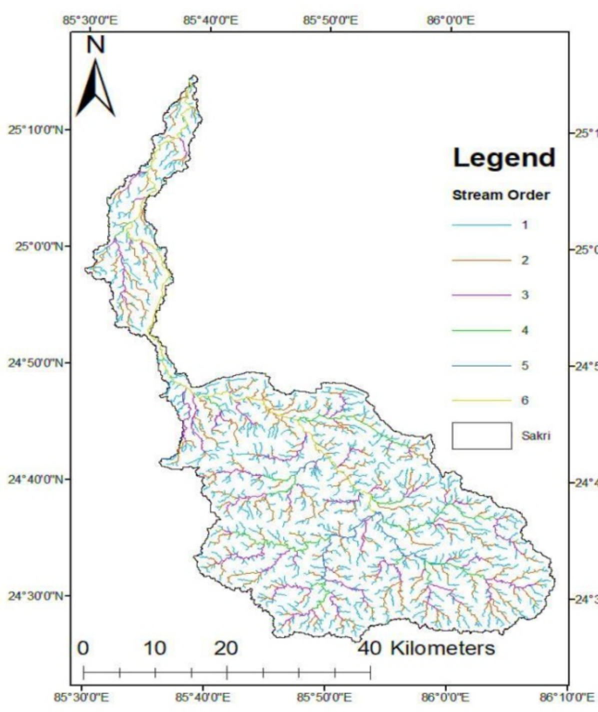

Fig. 3: Stream order of Sakri Watershed

Estimation of morphological characteristics of watershed

In the present study, a total of 48 geomorphological parameters i.e., linear, areal and relief were estimated with the use Software analysis (ArcGIS 10.5) and SWAT model, and some parameters were analysed with the help of standard formula shown in Table 1, 2 and 3. To draw the hypsometric curve, the information about the contour elevation and area above a particular contour was obtained from the ArcGIS toolbox and SWAT model watershed report output. The contour interval of 10 m was considered and graph was plotted between relative area (a/A) and relative height (h/H) to obtain the hypsometric curve of the watershed. The curve was used to represent the stage of development of the drainage network. The elevation information of the watershed, delineated by the ArcSWAT was used for analysis of hypsometric integral.

RESULTS AND DISCUSSION

Linear characteristics

The linear characteristics include stream order, stream number, stream length, stream length ratio, bifurcation ratio, main channel length, rho coefficient, valley length, drainage density, stream frequency, length of overland flow, watershed length and watershed width. These factors directly affect the volume and extent of flow in the watershed.

Table 1 shows that the total number of stream order delineated in the Sakri watershed was 6 (Fig. 3). The maximum stream order frequency was observed in case of 1st order (1129) and 2nd order (536). This result indicates that there is a decrease in stream frequency as the stream order increases. The total length of stream segment is the maximum in the 1st order stream (1005.22 km) and decreases as the stream order increases. The mean stream length was estimated by dividing total stream length of order 'u' and No. of streams of order 'u'. It is varied from 0.80 to 1.09 km. Computed Stream Length Ratio (L_{ur}) value ranges between 0.89-1.35. L_{ur} between successive orders varies mainly because of topographic variation and it has a strong relationship with surface flow of water. Bifurcation ratio (R_b) is defined as the ratio of number of streams of given order (N_u) to the streams number of next higher order (N_{u+1}) (Schumn, 1956). The R_{bm} value of entire watershed is 1.86, which indicates little influence of geological structure on drainage networks. R_b value is less than 3 for those watersheds where the terrain is almost flat and doesn't have any structural influence whereas R_b value varied 3 to 5 indicates the watershed has geological structures with less influence on the drainage pattern (Singh *et al.*, 2020). The analysis showed that the length of the main channel is 87 km. Rho coefficient ( ) is defined as ratio of L_{ur} and R_b (Horton 1945). Its value for Sakri watershed is 0.93. It indicates to the storage capacity of drainage network. Drainage density (D_d) is defined as the ratio of total stream length of all the orders per unit watershed area (Horton 1945). Computed D_d value of watershed is 1.18 km^{-1}, which falls under the very coarse classes of D_d. It indicates to the poorly drained watershed with

Table 1: Linear parameters of Sakri watershed

Morphometric parameter	Unit	Formula	Calculated value
Watershed Length (L_b)	km	Software analysis (ArcGIS 10.5)	156.23
Watershed Width (W_b)	km	Software analysis (ArcGIS 10.5)	113.66
Length Width Ratio	km/km		1.37
Stream order (S_u)	Dimensionless	Based on Hierarchical Rank	1 to 6
Stream Number (N_u)	Dimensionless	$N_u = N_1 + N_2 + N_3 + ….. + N_n$	2243
Stream Length (L_u)	km	$L_u = L1 + L2 + L3 + ….. + Ln$	2062.84
Stream Length Ratio (L_{ur})	Dimensionless	L_{u+1}/ L_u	0.89-1.35
Bifurcation Ratio (R_b)	Dimensionless	$R_b = N_u/ N_{u+1}$	0.47-3
Mean Bifurcation Ratio (R_{bm})	Dimensionless		1.86
Weighted Mean Bifurcation Ratio (R_{bwm})	Dimensionless		1.96
Main Channel Length (Cl)	km		87
Rho Coefficient (?)	Dimensionless	$\varrho = L_{ur}/R_b$	0.93
Valley Length (Vl)	km		135.79
Drainage Density (D_d)	km^{-1}	$D_d = L_u/A$	1.18
Stream Frequency (F_s)	km^{-2}	$F_s = N_u/A$	1.29
Length of Overland Flow (L_g)	km	$L_g = 1/(2*D_d)$	0.42
Sinuosity Index (SI)		SI = Cl/Vl	0.64

a slow hydrologic response and watershed has permeable subsoil material, dense vegetation and low relief (Sukristiyanti *et al.*, 2018). Stream frequency (F_s) is defined as the total number of channel segments of all stream orders per unit area. Its computed value for Sakri watershed is 1.29 km^{-2}. Low value of F_s indicates to the low relief of watershed (Sukristiyanti *et al.*, 2018). Length of Overland Flow (L_g) is related with the Drainage density (D_d) of the watershed. The computed value of L_g is 0.42 km, which indicates to low surface runoff of the watershed (Rawat *et al.*, 2017). Sinuosity Index (SI) as a factor to define a river deviation from the expected straight path (Schumm, 1956). The calculated value of Sakri watershed is 0.64, indicated the nature of river course as sinuous.

Areal characteristics

The areal characteristics include watershed area, watershed perimeter, texture ratio, drainage texture, lemniscate's, form factor, circularity ratio, elongation ratio, drainage texture, compactness coefficient, constant of channel maintenance and infiltration number etc.

Table 2 shows that area of watershed (A) is 1744.62 km^2 and

Table 2: Areal parameters of Sakri watershed

Morphometric parameter	Unit	Formula	Calculated value
Watershed Area (A)	km^2	Software analysis (ArcGIS 10.5)	1744.62
Watershed Perimeter (P)	km	Software analysis (ArcGIS 10.5)	496.28
Relative Perimeter (P_r)	km	$P_r = A/P$	3.52
Longest flow path distance (d)	km	Software analysis (ArcGIS 10.5)	158.37
Texture Ratio (Rt)	km^{-1}	$R_t = N_1 / P$	2.27
Length Area Relation (L_{ar})		$L_{ar} = 1.4*A^{0.6}$	123.35
Lemniscate's (k)	Dimensionless	$k = L_b^2/A$	13.99
Form Factor (F_f)	Dimensionless	$k = A/L_b^2$	0.07
Shape Factor (R_s)	Dimensionless	$k = L_b^2/A$	13.99
Elongation Ratio (R_e)	Dimensionless	$R_e = (2*(A/\pi)^{0.5})/L_b$	0.30
Circulatory factor (R_c)	Dimensionless	$R_c = 4\pi A/P^2$	0.09
Circularity Ration (R_{cn})	km	$R_{cn} = A/P$	3.52
Drainage Texture (D_t)	km^{-1}	$D_t = N_u/P$	4.52
Compactness Coefficient (C_c)	Dimensionless	$C_c = 0.28 * (P/A^{0.5})$	3.33
Fitness Ratio (R_f)	Dimensionless	$R_f = Cl/P$	0.32
Wandering Ratio (R_w)	Dimensionless	$R_w = Cl/L_b$	1.01
Constant of Channel Maintenance (C)	km	$C = 1/ D_d$	0.85
Drainage Intensity (D_i)	km^{-1}	Di = Fs/Dd	1.09
Infiltration Number (If)		If = Fs*Dd	1.52

overall perimeter of Sakri watershed (P) is 496.28 km. Texture ratio (R_t) is defined as the ratio of total number of stream segments of all order in a river basin and the perimeter of the basin (Sukristiyanti *et al.*, 2018). The R_t value of Sakri watershed is 2.27 km^{-1}. It indicates the pattern of texture of Sakri watershed is coarse drainage texture (Rawat *et al.*, 2017). Form factor is defined as the ratio of watershed area to the square of the length of the watershed (Horton, 1932). The value of form factor of Sakri watershed is 0.07 indicating the lower value of F_f which represents to an elongated shape of Sakri watershed. Elongation ratio (R_e) is the ratio of the diameter of a circle of the same area as the basin to the maximum basin length (Schumn, 1956). The value of R_e of Sakri watershed is 0.30, indicates to elongated shape of Sakri watershed. Circulatory Ratio (R_c) is defined as the ratio of the area of a watershed to the area of the circle having the same circumference as the perimeter of the watershed (Miller, 1953). Low, medium and high R_c is indicative of shape of the basin (Desai *et al.*, 2016). The value of R_c of 0.09 indicated elongated shape of the Sakri watershed. Compactness coefficient (C_c) of a watershed is defined as the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. The C_c is independent of size of watershed and dependent only on the slope (Rai *et al.*, 2018). The computed value of C_c of Sakri watershed is 3.33. Fitness Ratio (R_f) is defined as the ratio of main channel length to the length of the watershed perimeter, which is a measure of topographic fitness. The fitness ratio for Sakri watershed is 0.32. Wandering ratio (R_w) is defined as the ratio of the mainstream length to the valley length. In the present study, the wandering ratio of the watershed is 1.01. Constant channel maintenance (C) is inversely related with drainage density. Channel maintenance of the watershed is 0.85. The higher the infiltration number, the lower will be the infiltration and higher will be a run-off (Bhatt *et al.*, 2021). The higher infiltration number 1.52 computed for Sakri watershed is indicative of lower infiltration and higher runoff.

Table 3: Relief parameters of Sakri watershed

Morphometric parameter	Unit	Formula	Calculated value
Height of Watershed Outlet (z)	km	Software analysis (ArcGIS 10.5)	0.048
Maximum Height of the Watershed (Z)	km	Software analysis (ArcGIS 10.5)	0.670
Total Watershed Relief (H)	km	H = Z - z	0.622
Relief Ratio (R_h)	km/km	$R_{hl} = H / L_b$	0.004
Relative Relief (R_p)	Dimensionless	$R_{hp} = H / P$	0.0013
Gradient Ratio (R_g)	km/km	$R_{hl} = H / L_b$	0.004
Ruggedness Number (R_n)	Dimensionless	$R_n = H*D_d$	0.74
Melton Ruggedness Number (MR_n)	Dimensionless	$MR_n = H / A^{0.5}$	0.015
Mean slope of the basin	km		0.358
Watershed slope (S_w)	Dimensionless	$S_w = H/L_b$	0.004
Asymmetry Factor (AF)	Percentage	$AF = A_r / A$	58.79
Hypsometric Integral (HI)	Percentage	$HI = (H_{mean} – H_{min}) / (H_{max} – H_{min})$	

Relief characteristics

Relief characteristics deals with three-dimensional parameters like relief, relief ratio, gradient ratio, ruggedness number, watershed slope, asymmetry ratio and hypsometric curve.

Table 3 shows that, height of watershed outlet (z) and maximum height of the watershed (Z) is 0.048 km and 0.670 km, respectively. Watershed relief (H) is defined as the difference in elevation between the highest and the lowest points on the valley floor of a basin. In the study, H is obtained as 0.622 km. The relief ratio (R_h) may be defined as the ratio between the total relief of a watershed and the longest dimension of the watershed parallel to the main drainage line (Schumm 1956). R_h for Sakri watershed has calculated as 0.004. Low R_h indicates that the gradient in Sakri watershed is moderately steeper and less prone to erosion. The ruggedness number (R_n) is defined as the product of the basin relief and drainage density (Strahler, 1952). The R_n value calculated for the Sakri watershed is 0.74, indicates to low relief of the watershed. Sakri watershed has an MR_n of 0.015. The low value of MR_n suggests little variation in the relief ruggedness within the watershed. Asymmetry factor (AF) is used to measure the drainage watershed asymmetry. AF is greater than 50% replies the main channel has shifted towards the downstream left side of the drainage basin and AF is less than 50% replies to the channel has shifted

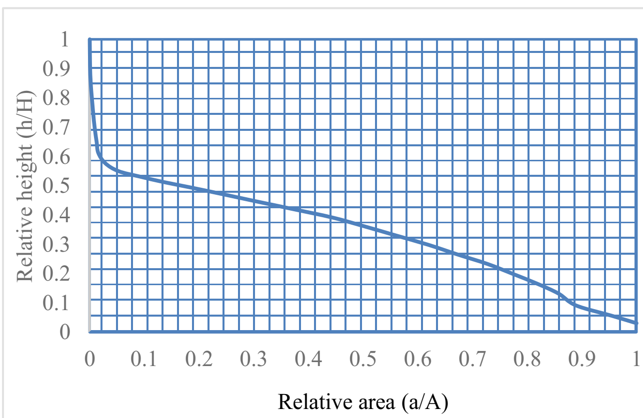

Fig. 4: Hypsometric curve of Sakri river watershed

towards the downstream right side of the drainage basin (Bhat *et al.*, 2013). The calculated value AF of Sakri watershed is 58.79%.

Hypsometric Analysis

Hypsometric analysis is done to establish relationship between horizontal cross-sectional area of watershed and its elevation. It is obtained by plotting relative area (a/A) along abscissa (X-axis) and relative elevation (h/H) along ordinate (Y-axis). Hypsometric integral provides information on the geologic stages of development and erosion proneness of the watersheds. According to Strahler (1952), if the value of the hypsometric integral (HI) is more than 60%, the watershed is in an inequilibrium stage, i.e. it is easily susceptible to erosion. If HI value lies between 35 to 60%, the watershed is in an equilibrium stage, i.e., it is at a mature stage and less susceptible to erosion. If HI value is smaller than 35% then the watershed is in monadnock phase, i.e., it is the most stable or least susceptible to erosion. The hypsometric curve of the watershed (Fig. 4) indicated that the Sakri watershed is in equilibrium stage.

CONCLUSION

Application of GIS and SWAT along with remote sensing data proved to be efficient tools for extracting morphometric parameters. The estimated morphological characteristics of Sakri watershed revealed that this watershed is dominated by lower order streams with the total length of stream segments maximum in first order streams. The stream order varied from 1 to 6. The slope map indicated presence of low degree of slope gradient in Sakri river watershed. The variation of stream length ratio between different order streams was due to differences in slope and topographic conditions. Bifurcation ratio of the study area indicated that its values were not same for all the stream orders. Low values of drainage density and drainage texture revealed very coarse drainage texture in the Sakri watershed. The form factor, circulatory factor and elongation ratio revealed that basin was elongated with low relief and medium slope. The hypsometric curve indicated that the watershed is in the equilibrium stage and value of the hypsometric integral showed that most of them were in monadnock and equilibrium stage. The estimated morphological parameters may be useful to simulate hydrological response of the watershed as they are the major inputs parameters to various hydrological models.

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