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GIS-based hypsometric analysis of the Mand sub-basin of Mahanadi River Basin, Chhattisgarh, India

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Abstract
Assessment of erosion status of the watershed helps in selecting suitable conservation measures to check erosion and water conservative management practices in the watersheds. Hypsometric analysis with the aid of Geographic Information System (GIS) helps to understanding the geological development of basin and for delineation of erosional proneness of watershed. The hypsometric curve and hypsometric integrals are the important indication factors of watershed condition. Hypsometric analysis is the relationship of horizontal cross-sectional drainage basin area to elevation. The graph of hypsometric curve indicates the geological stage of watershed and erosion susceptibility of basin. The present study has been carried out by using SRTM-Digital Elevation Model (DEM) remotely sensed data and GIS in the Mand sub-basin of Mahanadi River basin. The study area is Mand sub-basin of Mahanadi basin which is the part of Chhattisgarh having area of 5332 km^2, lies between 21°42'15.525"N to 23°4'19.746"N latitude and 82°50'54.503"E to 83°36'1.295"E longitude.
The hypsometric analysis of Mand sub-basin is carried out and value of hypsometric integral (HI) is found 0.5 which indicates the watershed is at Equilibrium or Mature stage.

Keywords: SRTM-DEM, hypsometric curve, hypsometric integral, remote sensing and GIS

1. Introduction

Hypsometric analysis was first time introduced by Langbein, (1947) [6] to express the overall slope and the forms of drainage basin. The hypsometric analysis can be used as a morphometric parameter, i.e. hypsometric integral, to deduce its relationship with the area of watersheds. Statistical analysis of these parameters has been carried out by classifying them into different classes based on the natural break's method. This brings out strong relationships for hypsometric integral classes and area classes with the number of watersheds in respective classes and the total area occupied by respective hypsometric and area classes. It has also been found that stronger relationships exist for watersheds The anomalous watershed has been directly attributed to the difference in geologic structure The results are inspiring and very promising as they indicate some statistically strong relationships among the hypsometric integral and area of watersheds that are not apparent in the Hypsometric analysis is the relationship of horizontal cross sectional drainage basin area to elevation. The hypsometric curve has been termed the drainage basin relief graph. Hypsometric curves and hypsometric integrals are important indicators of watershed conditions, (Ritter, 2002) [10]. Differences in the shape of the curve and hypsometric integral values are related to the degree of disequilibria in the balance of erosive and tectonic forces (Weissel, 1994) [19]. The hypsometric curve is related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass (Hurtrez, 1999) [5]. It is a continuous function of non-dimensional distribution of relative basin elevations with the relative area of the drainage basin (Strahler, 1952) [16, 17]. This surface elevation has been extensively used for topographic comparisons because of its revelation of three-dimensional information through two-dimensional approach (Harrison, 1983) [4]; (Rosenblatt and Pinet, 1994) [11]. Comparisons of the shape of the hypsometric curve for different drainage basins under similar hydrologic conditions provides a relative insight into the past soil movement of basins. Thus, the shape of the hypsometric curves explains the temporal changes in the slope of the original basin. Strahler, (1952) [16, 17] interpreted the shape of the hypsometric curves by analysing numerous basins and classified the basins as young (convex upward curves), mature (S-shaped hypsometric curves which is concave upwards at high elevations and convex downward at low elevations) and distorted (concave upward curves).

There is frequent variation in the shape of the hypsometric curve during the early geomorphic stages of development followed by minimal variation after the watershed attains a stabilized or mature stage. Hypsometric analysis is carried out to ascertain the susceptibility of watershed to erosion and prioritize them for treatment. The slope of the hypsometric curve changes with the stage of watershed development, which has a greater bearing on the erosion characteristics of watershed and it is indicative of cycle of erosion. The hypsometric integral (HI) is also an indication of the 'cycle of erosion' (Strahler, 1952) [16, 17]; (Garg, 1983) [2]. The cycle of erosion is the total time required for reduction of land area to the base level i.e. lowest level. This entire period or the cycle of erosion can be divided into the three stages viz. monadnock (old) (HI < 0.3), in which the watershed is fully stabilized; equilibrium or mature stage (HI= 0.3 to 0.6); and in equilibrium or young stage (HI> 0.6), in which the watershed is highly susceptible to erosion (Strahler, 1952) [16, 17]. Hypsometric curves and hypsometric integral is important watershed health indicator. Hypsometric analysis using GIS has been used by several researchers in India dealing with erosional topography (Pandey, 2004) [3]; (Singh, 2008) [12- 15]. Further, there is lack of hypsometric based studies to watershed health, which is attributable to the tedious nature of data acquisition and analysis is involved in estimation of hypsometric analysis. Employing Geographical Information System (GIS) techniques in hypsometric analysis of digitized contour maps helps in improving the accuracy of results and save time. Considering the above facts, this study was undertaken to determine geological stage of development of Mand sub-basin of Mahanadi river basin, Chhattisgarh, India.

2. Location of Study Area

The study area is Mand river catchment which is the part of Chhattisgarh, lies between the North attitudes of 21°42'15.525"N and 23°4'19.746"N and east longitudes of 82°50'54.503"E and 83°36'1.295"E (Figure 1). The Mand river originates from the northern part of the Mainpat plateau village Bargidih of District Sarguja of Chhattisgarh state. It then reaches the Chandrapur which is in the eastern part of Janjgir-Champa and joins the Mahanadi river. Initially it travels north-south then east-west and later on again north-south and south-east. It contributes total area of 5332.07 sq.km thus it contributes only 7.35% towards Mahanadi basin with in Chhattisgarh State. Mand River is a tributary of Mahanadi and joins it in Chandrapur 28 km before Orissa border. The Koirja nalla, Gopal nalla, Chhindai nalla and Kurket river are the principal tributaries. Its flow field is full of forest cover, trees, agricultural land and water bodies. The river rises at an elevation of about 686 m in Surguja district of Chhattisgarh and the total length of the river is 241 km.

It covers parts of Sarguja, Korba, Janjgir-Champa, Jashpur and Raigarh districts in which major part is of Raigarh district. It represents mainly structural plains on Gondwana rocks, structural plains on proterozoic rocks and pediment/pediplains. Soils are mainly red sandy soil , red and yellow soils and red gravelly soils. The geology of the area has Barakar formation, Kamthi formation, Raigarh formation, Deccan trap and Chhotanagpur Gniessic rocks majorly. The region is endowed with sub-tropical monsoon climate with three distinct seasons i.e. summer, monsoon, and winter. The southwest monsoon starts from June and continues till middle of September. Winter season spreads from October to February. Summer season extends from March to middle of June. Rainfall is the major source of ground water recharge in the area and receives maximum (85%) rainfall during the southwest monsoon season. The average annual rainfall (2019) is 1382.12 mm. The normal maximum temperature during the month of May is 42.5 °C and minimum during the month of January is 8.2 °C.

3. Materials and Methods

The SRTM-DEM (Figure 2) was downloaded from United States Geological Survey (USGS) website, www.earthexplorer.usgs.gov. which was in Tagged Information File Format (TIFF) format with 30 m ground resolution. ArcGIS 10.5 software was used for this study. The downloaded DEM tiles are mosaiced in the Arc map Version 10.5 environment. Then mosaiced data is modified by sink and generating the flow direction and flow accumulation by using ArcHydro extension analysis tool. Delineated the Mand sub-basin using pourpoint tool of hydrology tool and also generated the slope map (Figure 3) and Contour map (Figure 4) of the Mand sub-basin using spatial analysis tool.

The thresholds limits have been recommended for deciding the geological stages at the Mand sub- basin as in the study by Strahler (1952) [16, 17].

(i) This watershed is at an equilibrium (youthful) stage if the HI > 0.6
(ii) The watershed is at an equilibrium stage if 0.3 <HI < 0.6.
(iii) The watershed is at a monadnock stage if HI < 0.3.

4. Result and Discussion

4.1 Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) is the raster representation of a continuous surface which usually refers to the earth's surface. The SRTM DEM was then re-projected to co-ordinate Universal Transverse Mercator (UTM) device with Datum WGS 1984 (Zone-44), with a spatial resolution of 30 m. Through the application of various spatial analysis tools in ArcGIS software, the digital elevation model can be used to delineate the watershed and to prepare various thematic maps such as slope chart, contour map, etc. Mand sub-basin.

4.2 Contour Map

A contour map is a map represented with contour lines, which shows both valleys and hills along with their steepness. Contour map (contour interval 50 m) of the Mand sub-basin is presented in Fig. 4. which was prepared through spatial analyst tool of ArcGIS using DEM. Details regarding contour length and area under each contour interval is tabulated in Table 1.

4.3 Slope Map

The slope map was generated using DEM of the study area in ArcGIS 10.5 and is presented in Fig. 3. The elevation in the Mand catchment varies from 187 to 1147 m above MSL. The catchment has general slope towards north-east direction with average elevation of 667 m above MSL. The slope was classified in different classes namely “level”(0 percent), “nearly level (0-2 percent)”, “very gently sloping (2-4 percent)”, “gently sloping (4-6 percent)”, “slightly moderate sloping (6-8 percent)”, “moderately sloping (8-10 percent)”, “strongly sloping (10-12 per cent & 12-14 percent)”, “steep sloping (14-16 percent)”, and “very steep sloping (16-100 percent)”. The slope map of the Mand catchment depicts the complex terrain with undulation and irregular slopes. Most of the area of the catchment has nearly level to very gently sloping field which can be considered as very good sites for groundwater recharge as the surface water gets more time to get infiltrate.

4.4 Relative Area

The relative area of Mand sub-basin shows the distribution of area with respect to relative elevation. Total elevation of watershed was divided into 20 equal parts and the DEM of watershed was reclassified corresponding to these values. Table 2 is showing values of relative area and relative elevations.

4.5 Plotting Of Hypsometric Curves

The percentage hypsometric method has been used for the present study. There are two ratios involved in this method and plotted against each other on a graph. The ordinate represents the ratio of relative elevation (h/H) and the abscissa represents the ratio of relative area (a/A). The relative elevation is computed as the ratio of the height of a given contour (h) from the base plane to the maximum basin elevation (H). The relative area is obtained as a ratio of the area above a particular contour (a) to the total area of the basin above the outlet (A). The value of relative area (a/A) is in a range from one to zero. One at the lowest point in the drainage basin (h/H = 0) and zero at the highest point in the basin (h/H = 1). The hypsometric curve of the Mand sub-basin (Figure.5) represents curve indicating an equilibrium mature stage of landscape development. The shapes of the hypsometric curve in the study area might be due to the lithological variations, incision of bed rock, down slope movement of eroded materials and removal of the sediments from the basin.

4.6 Estimation of Hypsometric Integral

The hypsometric curve can be represented by an equation x=f(y) also known as hypsometric function. When the hypsometric function is integrated between the limits of x=0 to x=1, a measure of landmass volume with respect to total landmass volume above the horizontal plane passing through outlet is obtained. This integral is designated as hypsometric integral and denotes the area under the hypsometric curve. Hypsometric integral (HI) which is equivalent to elevation relief-ratio (E) as proposed by Pike and Wilson (1971) [9] is computed by the relationship:

E = HI = Elevation (mean) – Elevation (min) / Elevation (max) – Elevation (min)

Elevation (max) and Elevation (min) are the maximum and minimum elevation within the watershed and Elevation (mean) is the mean elevation of the watershed. The Elevation (max) and Elevation (min) were found out from the DEM of the watershed and Elevation (mean) was obtained by the formula:

Elevation (mean) = (ΣNiEi) / (ΣNi)

Ni is the number of the pixel corresponding to elevation Ei in digital elevation model of a watershed which was obtained from the attribute table of respective DEM.

Hypsometric Integral=[(Xi*Yi+1)- (Xi+1*Yi)]/2

Where Xi is the Cumulative Area and Yi Cumulative Altitude
The hypsometric integral (HI) values obtained for the Mand sub-basin is presented in Table.3. The HI value of the Mand sub-basin is computed to be 0.5, which represents the watershed is at equilibrium or mature stage. Curve pattern indicating a mature stage of landscape development with moderately eroded regions. The hypsometric integral value of Mand sub-basin is 0.5 indicates that the basin has just entered into middle maturity stage from the early maturity stage and 50% of rock masses still exist in the basin. Thus, the potential energy of the river basin is more due to high runoff with faster rate of erosion.

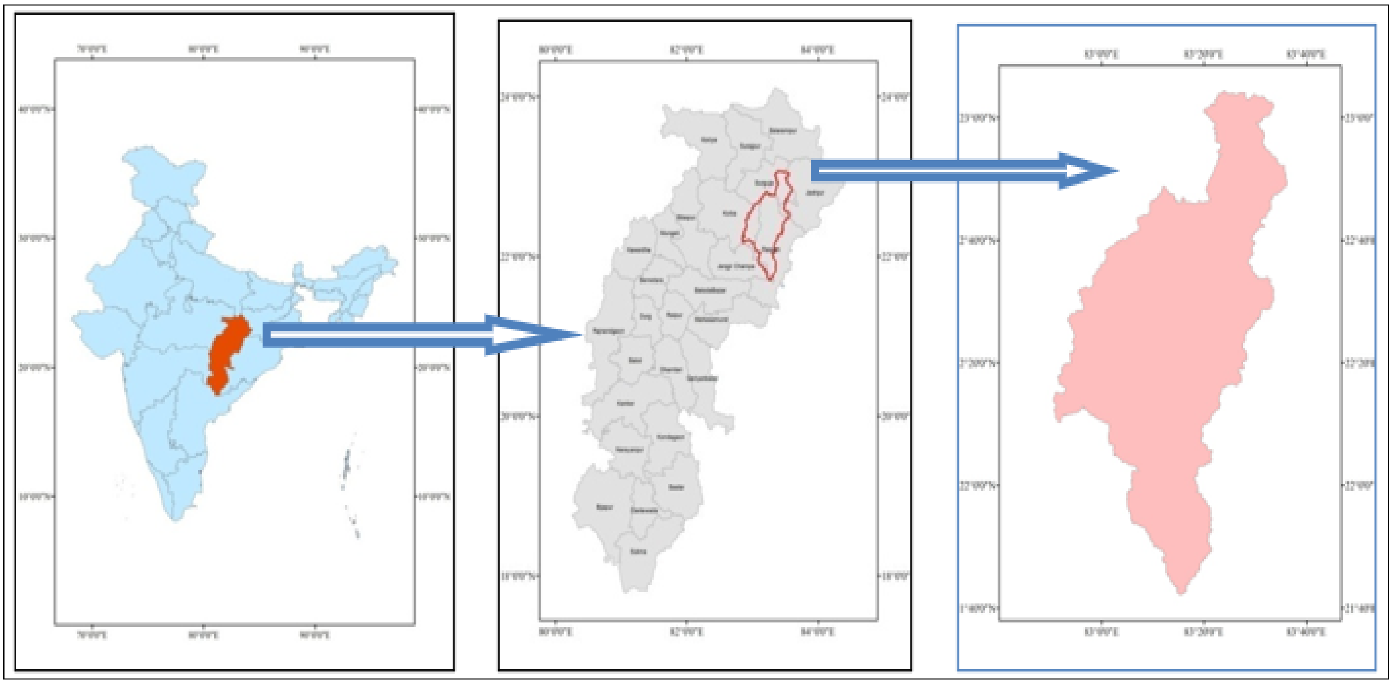

Fig 1: Location of the study area (Mand river Basin)

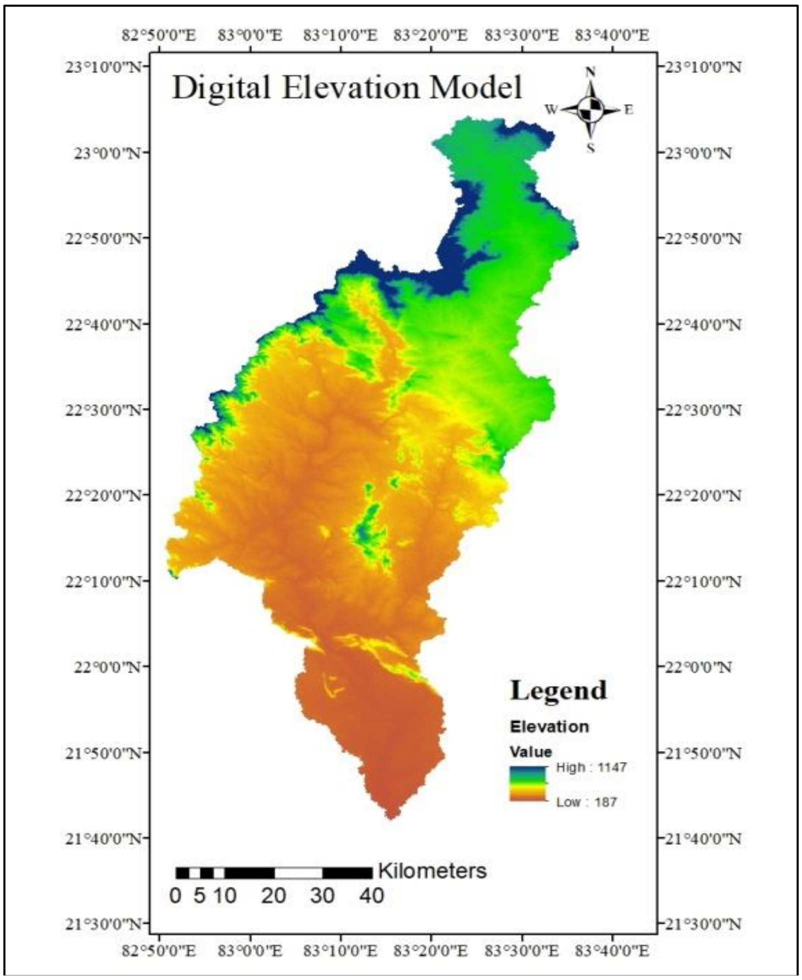

Fig 2: DEM Map

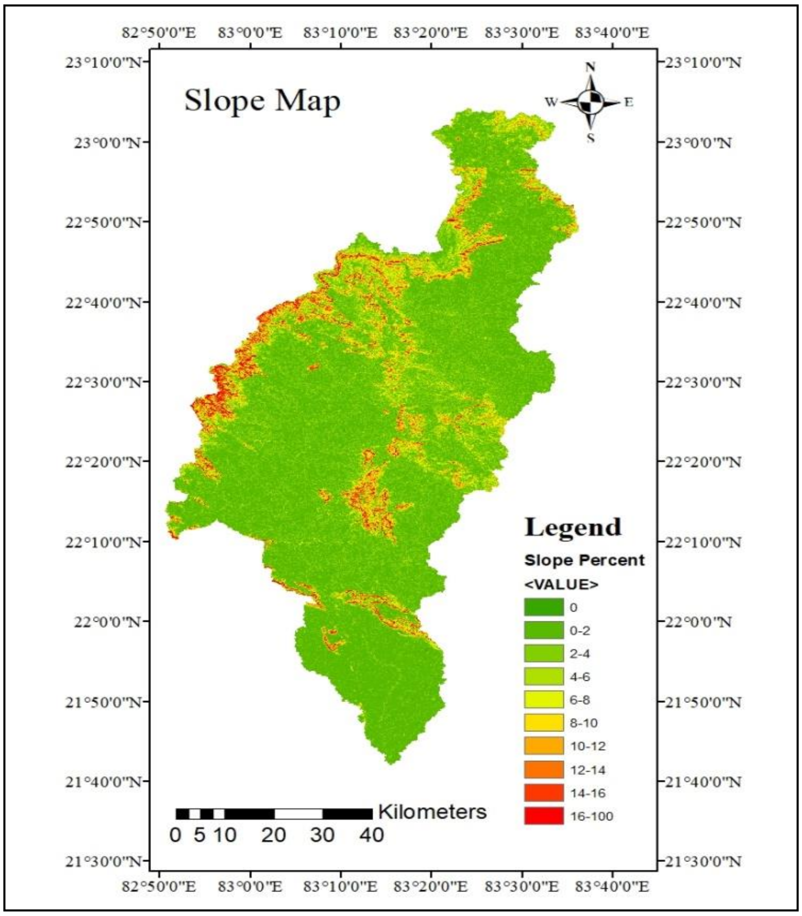

Fig 3: Slope Map

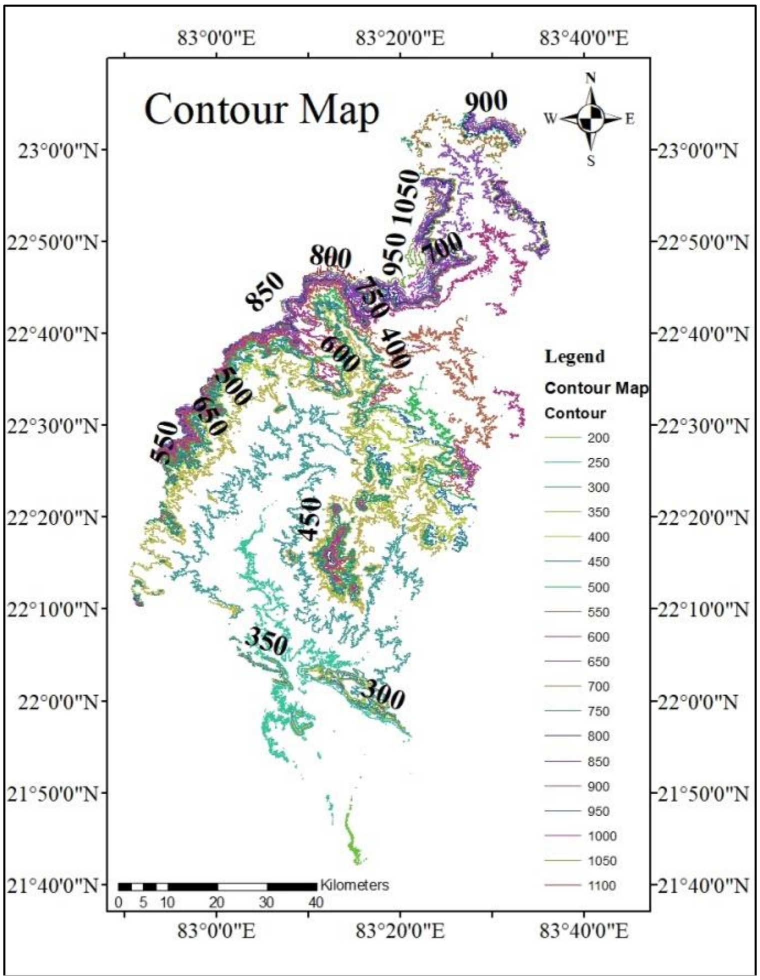

Fig 4: Contour Map

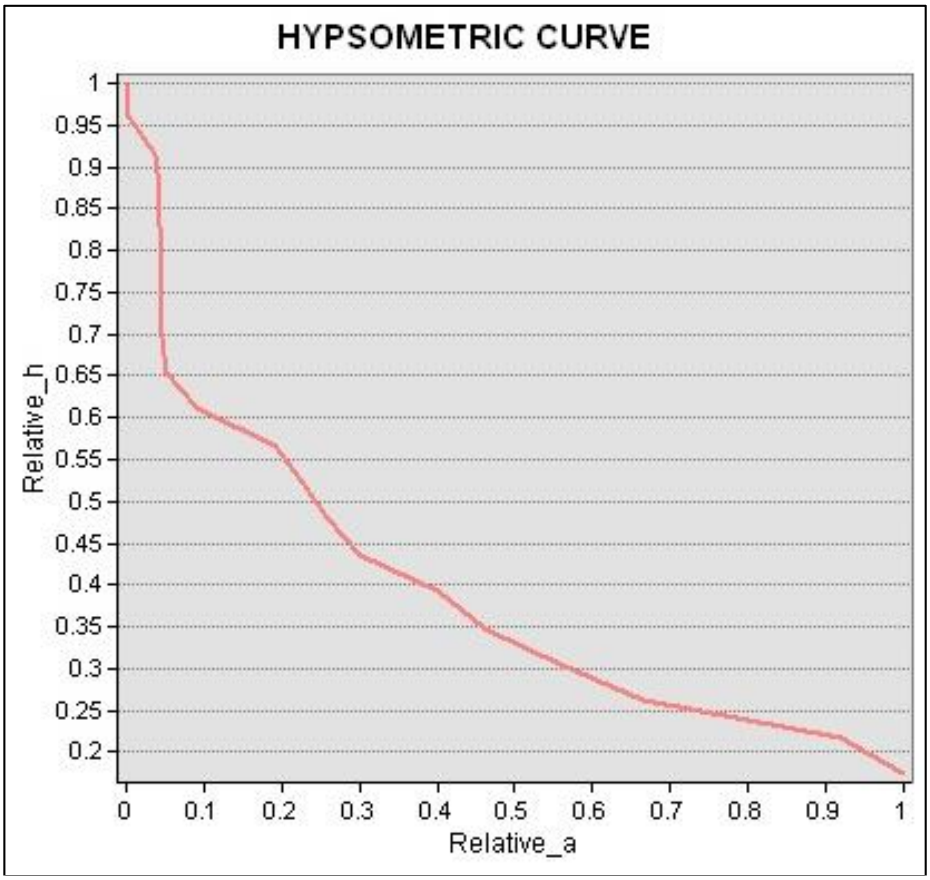

Fig 5: Hypsometric Curve

Table 1: Area and contour length under each contour interval

S. No.	Contour interval (m)	Contour length (km)	Area distribution (sq.km.)
1.	200	64.21	3.37
2.	250	849.66	657.60
3.	300	1612.98	907.52
4.	350	1312.75	987.29
5.	400	1149.84	255.30
6.	450	935.15	455.32
7.	500	891.13	190.16
8.	550	1096.08	396.60
9.	600	851.99	550.68
10.	650	680.59	295.85
11.	700	521.84	44.52
12.	750	367.18	49.67
13.	800	319.34	42.91
14.	850	263.52	36.28
15.	900	226.10	46.20
16.	950	195.37	42.30
17.	1000	136.90	44.84
18.	1050	111.81	90.90
19.	1100	44.02	224.22
20.	1150	31.81	10.54

Table 2: Relative Area and Relative Elevation of the Mand Sub-basin

S. No.	Contour interval	Contour length	Area distribution	a/A	h/H	Area percent	Mean elevation
1	200	64.21	3.37	0.003	0.17	0.06	667
2	250	849.66	657.60	0.67	0.22	12.33	
3	300	1612.98	907.52	0.92	0.26	17.02	
4	350	1312.75	987.29	0.19	0.31	18.52	
5	400	1149.84	255.30	0.26	0.35	4.79	
6	450	935.15	455.32	0.46	0.39	8.54	
7	500	891.13	190.16	0.19	0.44	3.57	
8	550	1096.08	396.60	0.40	0.48	7.44	
9	600	852.00	550.68	0.56	0.52	10.33	
10	650	680.59	295.85	0.30	0.57	5.55	
11	700	521.84	44.52	0.05	0.61	0.84	
12	750	367.18	49.67	0.05	0.65	0.93	
13	800	319.34	42.91	0.04	0.70	0.81	
14	850	263.52	36.28	0.04	0.74	0.68	
15	900	226.10	46.20	0.05	0.79	0.87	
16	950	195.37	42.30	0.04	0.83	0.80	
17	1000	136.90	44.84	0.05	0.87	0.84	
18	1050	111.81	90.90	0.09	0.92	1.71	
19	1100	44.02	224.22	0.23	0.96	4.21	
20	1147	31.81	10.54	0.20	1	0.20	

Table 3: Estimation of hypsometric integral of Mand sub-basin

Sub-basin Name	Area (in sq. km.)	Minimum elevation (E min) m	Maximum elevation (E max) m	Mean elevation (E mean) m	Hypsometric integral (HI)	Geological Stage
Mand Sub-basin	5332.07	187	1147	667	0.5	Equilibrium or Mature stage

5. Conclusion

The Hypsometric analysis of a basin has several applications both hydrological and topography. The Hypsometric analysis of watershed is prerequisites the development of geological stages and it is also useful to undertaking soil and water conservation measures. Mand sub-basin is elongated having relief indicating enough slope for runoff to occur. Further the hypsometric integral value 0.5 (equilibrium or mature Stage) indicates the geological stage of the watershed which helps to quantifying the erosion susceptibility of the watershed. Soil erosion measures and land utilization can be done from the hypsometric analysis. However, this method was observed to be less cumbersome and faster than the other methods in practice.

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