Available Online

J. Sci. Res. **15** (3), 869-878 (2023)

JOURNAL OF SCIENTIFIC RESEARCH

www.banglajol.info/index.php/JSR

Hypsometric Analysis of WRC-1 Watershed, Chargarh River Basin, Central India: A Remote Sensing and GIS Approach

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Received 31 January 2023, accepted in final revised form 21 June 2023

Abstract

Hypsometric analysis is a valuable tool for determining the tectonic evolution of a river basin and the erosion susceptibility. It is also important for integrated watershed management, which include selecting suitable locations for groundwater recharge structures and for conservation of soil and water. This type of study can analyze the relationship between horizontal cross sectional area and the altitude of the watershed. It evaluates the hypsometric curve and hypsometric integral, as generated for the WRC-1 watershed, Chargarh river basin through remote sensing and GIS technique. In the present case, hypsometric analysis was carried out using Survey of India topographic maps, Arc map-10.2 software and SRTM-DEM. The hypsometric integral is calculated using mean elevation minus minimum elevation, divided by relief. The hypsometric curve, with a value of 0.69 for the hypsometric integral clearly indicates an inequilibrium stage (youthful stage) of geomorphic development, which is highly susceptible to erosion. These interpretations can further utilize appropriate measures of soil and water conservation for long-term development within the WRC-1 watershed.

Keywords: Geographical information system (GIS); Hypsometric curve; Hypsometric integral; Digital elevation model (DEM); Slope.

doi: http://doi.org/10.3329/jsr.v15i3.64183 J. Sci. Res. **15** (3), 869-878 (2023)

1. Introduction

Groundwater is one of our planet's most precious natural resources and plays a vital role in every facet of human life [1]. Groundwater is stored in the strata below the earth's surface in the critical zone of the asthenosphere [2,3]. A watershed is a region that provides runoff to rivers and their tributaries, and they are considered to be the basic unit of conservation [4]. Assessment of the erosion status of any watershed is an essential prerequisite for integrated watershed management which not only assists in checking out suitable soil and water conservation measures to arrest erosion and conserve water but also helps to devise best management practices to enhance biomass production in watersheds [5]. Hypsometry involves measurement analysis of the relationship between

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altitude and basin area, understanding the degree of dissection and stage of the cycle of erosion [6]. Langbein [7] used hypsometric analysis to describe a drainage basin's slope and shape. The basic purpose of hypsometric integral (HI) analysis is to create a dimensionless relationship between the horizontal cross-sectional area of the watershed and the corresponding Elevation, which allows comparison of watersheds without considering scale [8,9]. The hypsometric curve (HC) and HI values provide vital information regarding the erosional stage of the basin, as well as the tectonic, climatic, and lithological factors that influence it [10-12]. Gautam *et al*. [13] examined the Sai River Basin in Uttar Pradesh and the Dudhnai watershed in Meghalaya-Assam, prone to soil erosion and sedimentation [14]. Several studies have been conducted on sub-watershed prioritization in the outer Himalayan region [15] and identified the tectonic and lithological control over the evolution of its drainage pattern.

The HI is a geomorphological quantity characterized by watershed development through a geologic time span. It is essential in determining the erosion status of the watershed and prioritizing implementing soil and water conservation measures. The 'HI' is a percentage that indicates how much of the volume remains in comparison to the basin's initial volume [16]. The hypsometric curve effectively captures the relief ratio and catchment volume. The hypsometry curve is usually depicted as a distribution of relative height (h/H) against relative area (a/A) [9]. Important indicators of watershed conditions are hypsometric curves and hypsometric integrals [16]. The hypsometric integrals help to describe how the watershed has eroded through time due to river basin and land degradation factors [17]. The hypsometric curves and integrals are significant measures of watershed health [18].

Researchers have recently implemented hypsometric analysis to evaluate the erosional status of many basins across the world utilizing Geographical Information System (GIS) approaches [19,20] as well as for tectonic studies [19]. Considering these findings, a hypsometric analysis of the Chargarh River basin was carried out to determine the stage of basin development.

2. Location, Climate, and Temperature

WRC-1 watershed is an integral part of Chargarh river basin which is a tributary of Wardha river and ultimately a part of the Godavari river basin of India. The study area covers about 412.51 sq. km of Chandur Bazar and Morshi tahsil of Amravati district, Maharashtra State, India. The area is bounded by the 21°0' to 21° 25' N latitudes and 77° 45' to 78° 05' E longitudes and covered under by the Survey of India toposheets 55G/15, 55G/16, 55K/3 and 55K/4 (Fig. 1). The area experiences sub-tropical monsoon climate, characterized by a hot summer and general dryness throughout the year, except during the south-west monsoon season. There are four seasons, winter from December to February, Summer from March to May, South-West monsoon season from June to September, and the post-monsoon period from October to November. The minimum mean temperature is 15.1°C and the maximum mean temperature is about 42.2 °C [21].

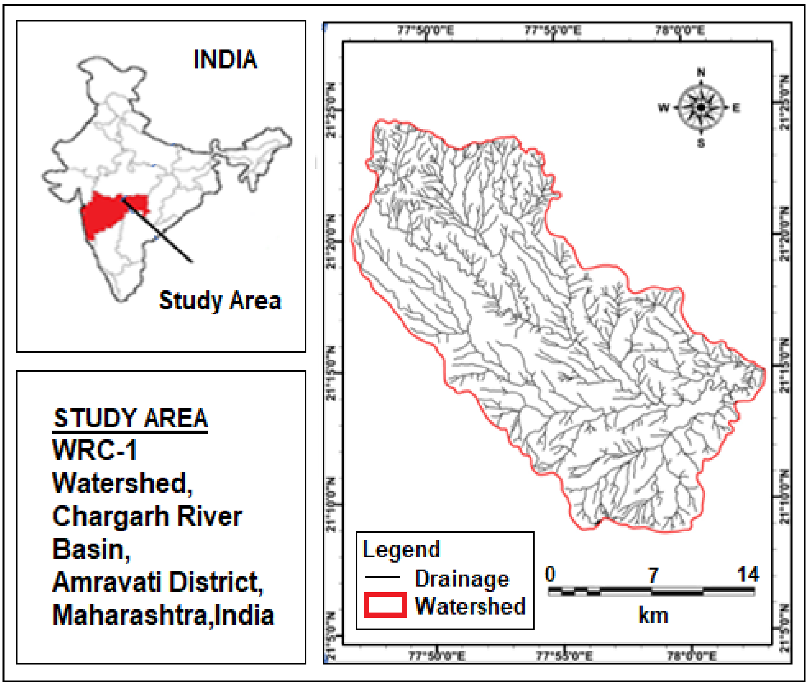

Fig. 1. Location map of the study area.

3. Materials and Methods

The survey of India Toposheets 55G/15, 55G/16, 55K/3, and 55K/4 of 1:50,000 scale utilized as a base map to study the total 412.51 square kilometer area of the Chargarh River basin. The Chargarh River basin, the topographic data, and the drainage network was digitized and geo-referenced with WGS_ 1984_ UTM Zone 43˚N projection system. The study includes data from the GlobalDigital Elevation Model and the Shuttle Radar Topographic Mission. To calculate hypsometric integrals and to create slope maps of the drainage basin. The Digital Elevation Model (DEM) was used. The contours were also digitized in the Arc GIS platform to create a line feature class, representing Elevation with respect to mean sea level. Accordingly, SRTM DEM was created using the Spatial Analyst Module of GIS software. A slope map was created with the help of SRTM DEM to visualize the topography and relief variance fully. The Environmental System Research Institute (ESRI) tools were utilized to calculate the hypsometric curve values based on DEM pixels. The hypsometric curve was calculated, and a graphical representation of the hypsometric curve was created using the hypsometric tools downloaded from the ESRI website. The hypsometric curve was shown graphically using the Arc-Map Geographical Information System (GIS) software. Ritter *et al.* [16] suggested the idea of hypsometric analysis and proposed a model hypsometric curve (Fig. 2). The hypsometric curve for the watershed was developed by adapting Strahler's methods [9]. The HI was projected using the elevation relief ratio method proposed by Pike and Wilson [22]. The digital elevation model was also used for the landscape characterization, adapting methods proposed by Kokkas and Miliaresis [23]. The methodologies of hypsometric analysis were utilized to determine the stages of geomorphic evolution, geomorphic assessment, and stage of river basin development and delineation of the erosional proneness of the study area.

Table 1. Formulae for hypsometric analysis [24].

Hypsometric analysis	Formula	Units
Elevation-To-Relief Ratio (E)	E = (Mean Elevation − Minimum elevation /Maximum elevation − Minimum Elevation)	Dimensionless

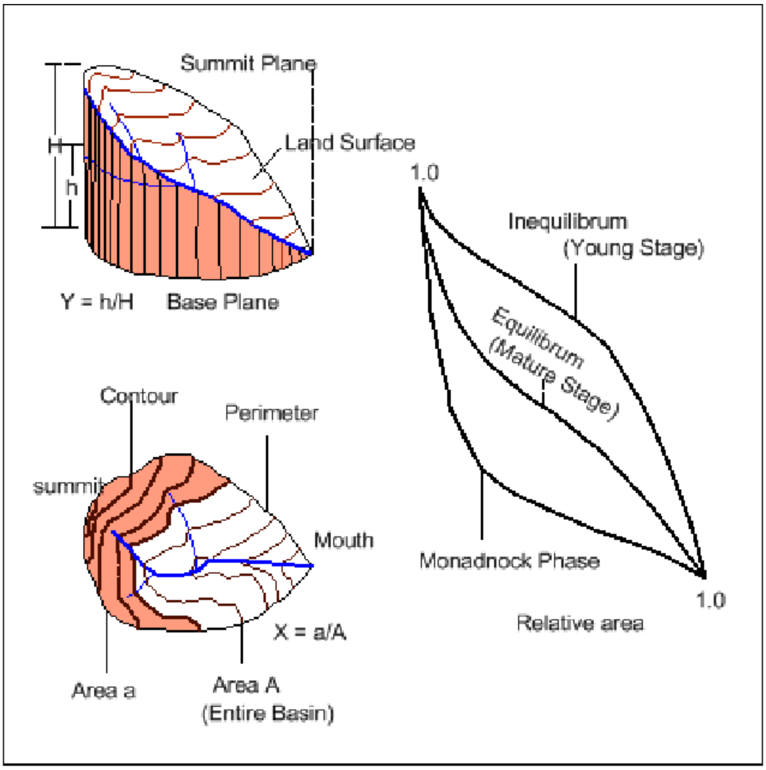

Fig. 2. Hypsometric curve model [16].

3.1. *Geology*

The area of the WRC-1 watershed is covered by the Deccan basalt lava flows and Quaternary alluvium. The basalt lava flows are classified as Chikhli, Karanja, and Ritpur Formations and belong to the Sahyadri Group [25]. The age of the Deccan basalt is Upper Cretaceous to Lower Eocene. The Quaternary alluvium of the Cainozoic age covers the western part of the watershed [25]. The elevated land within the watershed is a part of the Deccan trap, and the plain land portions are covered by the alluvium.

3.2. *Digital elevation model*

The digital elevation model elucidates the topography of the area comprising the highest and lowest elevation as in this case maximum elevation is 596 meters above mean sea level and minimum elevation is 305 meters (Fig. 3a). It depicts a three-dimensional picture of the area. The digital elevation model (DEM) illustrates the direction of groundwater flow, which is from north to South, and the stream finally joins the main Wardha river course near Bhambora village of Morshi Tahsil, Amravati district, part of Central India. Accordingly, this study was carried out, based on the digital elevation model, with the determination of the hypsometric integral which represents early stage watershed development and high susceptibility to erosion.

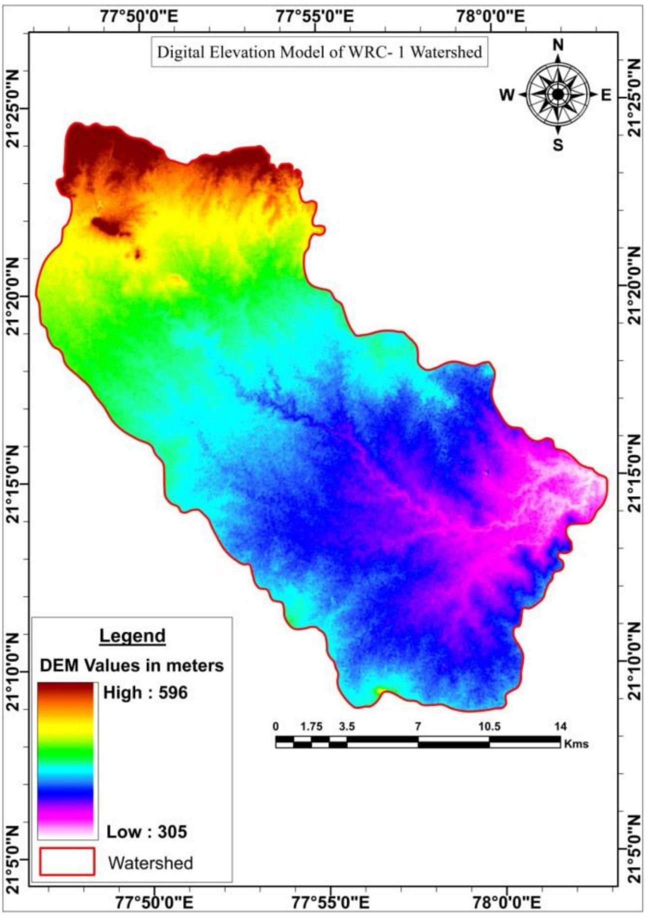

Fig. 3a. Digital elevation model (DEM) of the WRC-1 watershed.

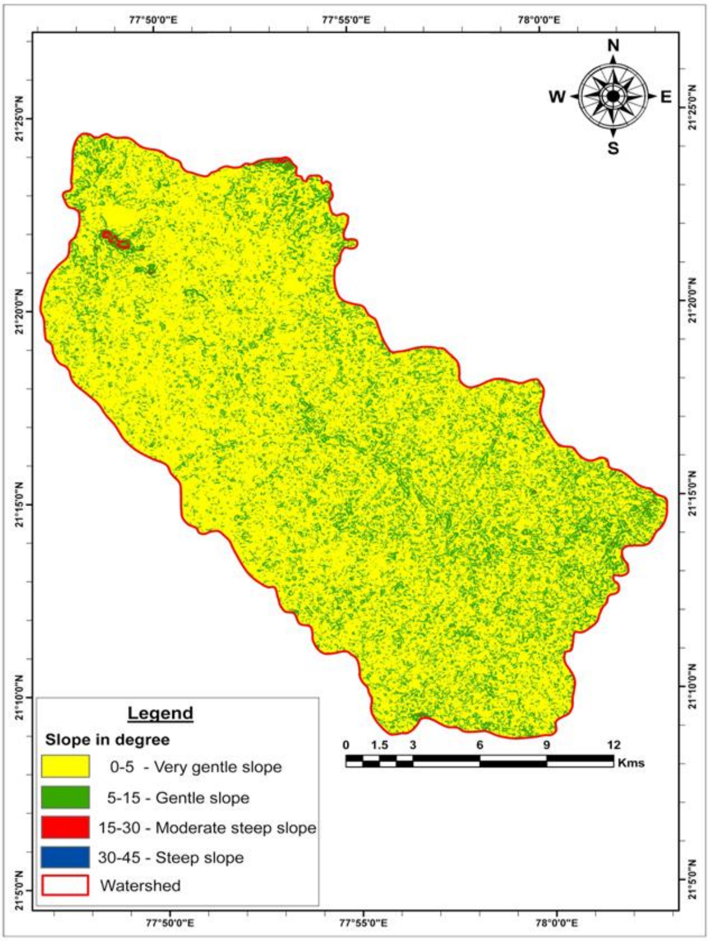

Fig. 3b. Slope map of the WRC-1 watershed.

3.3. *Slope*

The general slope of the ground is towards the South. The digital elevation model of the watershed indicates slope category of 0 to 5^0 (low runoff), an area with slope between 5 to 15^0 (moderate runoff), an area having a slope between $15\text{-}30^0$ (very high runoff) and the area with 30 to 45^0 slope (very high runoff) [Fig. 3b]. However, the overall contribution of runoff in the watershed will be determined by the area covered in each class. The area covered in the higher slope category is comparatively less than that of the lower slope categories. The slope map depicts steep slope hard rock, such as the Deccan basalt. On the other hand, alluvial soft rock formations represent gentle slopes.

4. Result and Discussion

4.1. *Hypsometric analysis (hs)*

The relief aspects of the drainage basins are related to the study of three-dimensional features of the basin, involving area, volume and altitude of the vertical dimension of the landform. Hypsometry refers to the proportions of an area at varying heights within a geographic area. Stream erosion, weathering processes and sediment movement by surface runoff all contribute to land degradation and topographical changes within watersheds [15]. According to Strahler [9], a concave hypsometric curve is representative of the youth stage of the basin, but the S-shaped curve is characteristic of the mature stage of the basin. The curve concave upward at higher elevations and concave downwards at lower elevations characterize the mature stage of the basin. The hypsometric curve of the peneplain watershed is concave. The hypsometric curve of the watershed was produced using the method proposed by [9]. The hypsometric integral was projected using the elevation relief ratio approach proposed by Pike and Wilson [22]. During this study, Strahler's methodology was used to create a hypsometric curve of the watershed elevation relief ratio approach by Pike and Wilson's [22] to project the hypsometric integral.

$$E \approx H_{Si} = (\text{Elev. mean- Elev. min.}) / (\text{Elev. max. - Elev. min.}) \quad (1)$$

Where, E is the elevation-relief ratio that corresponds to the hypsometric integral (HI); mean elevation is the weighted mean elevation of the basin, calculated from the recognizable contours, and the minimum and maximum elevations in the basin are denoted as elevation minimum and elevation maximum, respectively. It uses percentage units to express the hypsometric integral. The 'HI' values greater than 0.60 indicate a young stage (convex curve), 0.30 to 0.60 indicate a mature stage (sigmoidal curve) and 'HI' less than 0.30 indicates an old stage (concave curve).

The phenomena of denudation are complex and long-term in nature and have been operating with varying degrees of intensity, making topographical variations difficult to interpret [26]. The Hypsometric curve represents the early stage if the curve is convex upward, matured stage if the curve is concave upwards at high altitude, and convex downwards at low altitude The 'S' shaped hypsometric curves indicate peneplain, if the curve is concave upward [9].

The hypsometric integral values and hypsometric curve indicates geological stage of basin development and accordingly, if HI< 0.35, the basin represents an old stage of development; if HI value is between $0.35 \leq HI < 0.6$, the basin is at equilibrium (mature) stage and if $HI \geq 0.6$ indicates that the basin is an inequilibrium (youth) stage [9, 27]. In strongly eroded areas, the 'HI' value is nearly zero, while in moderately eroded areas, the 'HI' value is close to one.

Table 2. Hypsometric integral for the Chargarh River basin.

Watershed basin	Area of the Watershed (Sq.Km.)	Maximum Elevation (m)	Minimum Elevation (m)	Mean Elevation (m)	Hypsometric Integral	Stage of river developments	Watershed basin
▪WRC-1	412.51	596	305	146	0.69 (>0.60)	Young Stage	WRC-1

If the calculated value of the hypsometric integral (HI) is >0.60 (Table 1), it indicates that the watershed is in the early stage and highly susceptible to erosion. As a result, they are prone to erosion, mass mobilization, and erosion of incised channels. Variations in lithology and rejuvenation processes are responsible for significant variations in mass removal from the watershed. The Hypsometric analysis of the WRC-1 watershed, Chargarh River basin, indicates an HI value of 0.69, indicating that the basin is in the youth stage and more prone to erosion decline in an inequilibrium stage (Table 3 and 3b, Fig. 4).

Table 3. Hypsometric analysis of the WRC-1 watershed, Chargarh River basin, central India.

Gridcode	Elevation (m)	Area (sq. km)	Altitude	Area	Area %	Cumulative area %	Elevation difference (h)	Elevation relief (h/H)	Cumulative area (Sq. Km) (a)	a/A
	305	0.000	305	0	0	0	291	1.000	0.000	0.000
1	305-320	5.373	320	5.373	1.30	100	276	0.948	5.373	0.013
2	320-340	35.203	340	35.203	8.53	98.70	256	0.880	40.576	0.098
3	340-360	112.480	360	112.480	27.27	90.16	236	0.811	153.056	0.371
4	360-380	101.262	380	101.262	24.55	62.89	216	0.742	254.318	0.617
5	380-400	58.791	400	58.791	14.25	38.34	196	0.674	313.109	0.759
6	400-420	40.698	420	40.698	9.87	24.09	176	0.605	353.807	0.858
7	420-440	24.113	440	24.113	5.85	14.22	156	0.536	377.920	0.916
8	440-460	17.556	460	17.556	4.26	8.38	136	0.467	395.476	0.959
9	460-480	12.450	480	12.450	3.02	4.12	116	0.399	407.926	0.989
10	480-500	3.449	500	3.449	0.84	1.10	96	0.330	411.375	0.997
11	500-520	0.870	520	0.870	0.21	0.27	76	0.261	412.245	0.999
12	520-540	0.143	540	0.143	0.03	0.06	56	0.192	412.388	1.000
13	540-560	0.054	560	0.054	0.01	0.02	36	0.124	412.442	1.000
14	560-580	0.026	580	0.026	0.01	0.01	16	0.055	412.468	1.000
15	580-596	0.011	596	0.011	0.00	0.00	0	0.000	412.479	1.000
		412.479		412.479	100.00	0.00				11.576

Table 3b. Hypsometric values for the WRC-1 watershed, Chargarh River basin.

Contour Interval	Maximum Elevation (Z)	Minimum elevation (z)	H= Z-z	Basin Area (A)	h/H	a/A	Stage of river development =(h/H)/(a/A)
20 meter	596	305	291	412.479	8.0241	11.576	0.6931

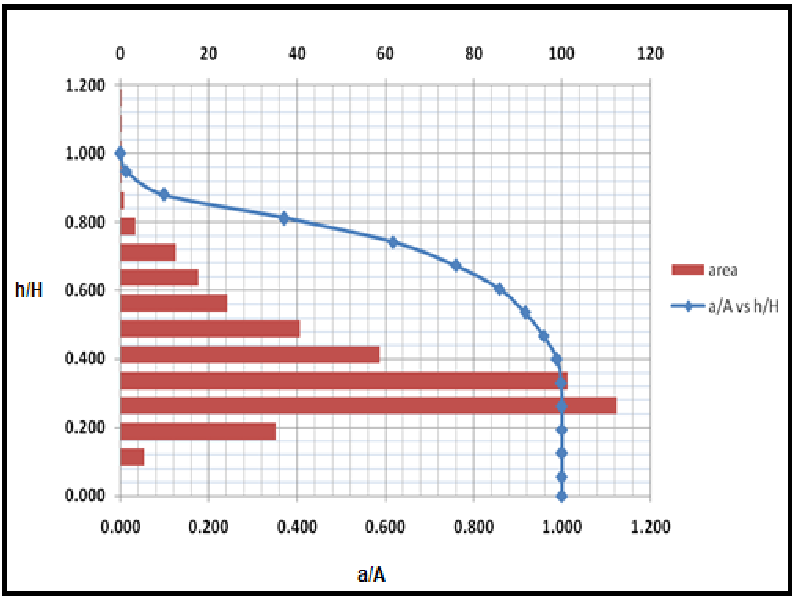

Fig. 4. Hypsometric curve for the study area.

5. Conclusion

Hypsometry involves measurement and analysis of the relationship between altitude and area of the basin. It has immense importance in determining the erosion status of the watershed and prioritizing sites for soil and water conservation measures. Lithological variations within the basin also affect the hypsometric parameters, as in the present case (WRC-1 watershed) which is covered partially by the Deccan Trap basalt and partially by alluvial soft rock formations. The calculated value of the hypsometric integral (HI) for WRC-1 watershed is 0.69 (which is >0.60), indicating an early stage of basin development and the basin is highly susceptible to erosion. As a result, they are susceptible to mass mobilization and erosion of incised channels. The result is further supported strongly by the convex hypsometric curve which represents the youth stage of the basin. The greater rate of erosion is mainly due to soft rock formation (alluvium) and weathered basalt, and this can be a probable area for the surface water management and groundwater recharge, along with the soil conservation.

Acknowledgment

The authors are thankful to the Authorities of R. T. M. Nagpur University, Nagpur, for providing logistic support to carry out laboratory analysis.

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