

# Elicitation of erosional signature of a tropical river basin with high-resolution stereo data

Girish Gopinath · T. V. Swetha · M. K. Ashitha

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**Abstract** The launch of Cartosat-1 turns into a new era for user communities of remote sensing and mapping. Generation of digital elevation model (DEM) of a particular geographic region of interest is the primary goal and advantage of Cartosat-1 mission. To generate the most accurate DEM from Cartosat-1 stereo data, 34 GCP points were used, and 122 tie points are automatically extracted with the aid of LPS-2011. Here, an attempt has been made to study the quantitative hypsometric analysis of six sub-watersheds of the Kuttiyadi River Basin (676 km<sup>2</sup>) with a humid tropical setting, using Cartosat-1 DEM. An extension, CalHypso, an add-on tool to ArcGIS 9.2, was utilized to synthesize hypsometric data from Cartosat-1 DEM which reflects the erosional signature of sub-watersheds based on geological stages of development. From hypsometric analysis, it is found that three sub-watersheds are in old stage, and the remaining three are of mature stage.

**Keywords** Cartosat-1 · DEM · Kuttiyadi River Basin · CalHypso · Erosional signature

## Introduction

Cartosat-1, the first satellite of Indian Space Research Organisation (ISRO) with along-track stereo capability is designed with two payloads PAN-Fore and PAN-Aft, in order to provide images of high quality ([www.nrsc.gov.in](http://www.nrsc.gov.in)). Satellite photogrammetry techniques has been extensively used by the scientific community in deriving high-resolution digital elevation model (DEM), orthoimage, and terrain parameters such as slope, aspect, contours, drainage, etc. (Jayaprasad et al. 2008). Global high-resolution data from Cartosat-1

supports enhanced application in several areas of natural resources management, terrain mapping, infrastructure, and facility planning. The Space Applications Centre, ISRO, India has developed and established a technology to extract DEM from Cartosat-1's high-resolution stereo data based on geometric modeling of long stereo strips using a few ground control points (Amit et al. 2008). Image stereo pairs from Cartosat-1 sensors seem to provide an accurate and cost-affordable source of elevation data. To extract information from the imagery and to perform photogrammetric applications, the software Leica photogrammetric suite (LPS) is the most widely used. An accurate elevation data covering the entire planet surface have important application in terrain analysis. The Earth's land surface exists in a sensitive balance between tectonic forces and erosional forces. Erosion is controlled by climate and by the relief of the landscape.

The hypsometric (area-altitude) analysis is useful in learning how erosion and magnitude influence landscape form under different climates and quantifying these differences. Sivakumar et al. (2011) published an article on hypsometric analysis of Varattaru River Basin, Harur Taluk, Tamil Nadu, using Remote Sensing and Geographic Information System. Their study suggests rainwater harvesting practices and management for the watershed at suitable locations for controlling further erosion and artificial recharge structures at many places to increase groundwater potential and to control soil erosion. Hurtrez and Lucazeau (1999) investigated the sensitivity of hypsometry to DEM of different resolutions and assessed the influence of varying drainage areas on hypsometry in Siwalik Hills of central Nepal. Classically, hypsometric analysis has been used to differentiate between erosional landforms at different stages during their evolution (Strahler 1952; Schumm 1956). The statistical characteristics of hypsometric analysis include hypsometric integral (Ea), hypsometric curve, coordinates of slope inflection points, hypsometric skewness, kurtosis, etc.; density skewness indicates the rate of change in slope, and a positive value is

G. Gopinath (✉) · T. V. Swetha · M. K. Ashitha  
Geomatics Division, CWRDM, Kozhikode, Kerala, India  
e-mail: gg@cwrddm.org

usually associated with typical fluvial landform and a negative one with sapping landform (Luo 2000). Based on the hypsometric integral, a landscape can be genetically classified in terms of the evolution as youthful ( $HI > 0.5$ ), mature or in equilibrium ( $HI = 0.5$ ), or old ( $HI < 0.5$ ) (Strahler 1957). Lower and higher hypsometric toe values indicate minimum and maximum mass accumulation, respectively, at the sub-catchment mouth (Jayappa and Vipin Markose 2011). S-shaped curves indicate the basins in maturity stage, and concave hypsometric curves characterize basins in old stage (Sarp et al. 2011).

The watersheds of the present study area, Kuttiyadi River Basin, are vulnerable to erosion due to high rainfall and deforestation that occurred by the construction of large tunnels running from the reservoirs (Peruvannamuzhi and Kakkayam) in the upstream portion to serve water in Kozhikode District. Due to erosion, reservoir siltation becomes a major future environmental problem. Further, there is a lack of hypsometric based studies to assess the watershed health. Thus, the whole basin is divided into six sub-watersheds, and hypsometric analysis is carried out. The purpose of this work is to bring out erosional signatures of the watersheds of the Kuttiyadi River Basin using high-resolution stereo data. This study can draw attention to the functions of the CalHypso tool for the automated generation of hypsometric curve and data from Cartosat-1 DEM; due to the advent of the GIS technique, the estimation process becomes easy and more accurate.

### Regional settings

The Kuttiyadi River Basin falls in the Kozhikode District, Northern Kerala, which lies between latitudes  $11^{\circ} 30' N$  and  $11^{\circ} 44' N$  and longitudes  $75^{\circ} 34' E$  and  $75^{\circ} 58' E$ , is an important water source of Kannur and Kozhikode Districts of Kerala (Fig. 1). It is a west-flowing river, rising from the Narikota Ranges on the western slopes of the Wayanad Hills, a part of Western Ghats, at an elevation of 1,220 m above mean sea level (amsl) and drains into the Arabian Sea at Kottakal. The river is 74 km long, and along with its tributaries, it drains an area of  $676 \text{ km}^2$  in Kozhikode District of Kerala. The perimeter of the basin is 136 km. The major tributaries are Onipuzha, Thottilpalampuzha, Kadiyangadupuzha, Mannathilpuzha, and Madappalipuzha. The Kuttiyadi basin enjoys typical tropical humid climate. The annual mean rainfall along the highland is 4,522 mm, whereas the lowland receives 3,070 mm. About 60 % of rainfall is received during SW monsoon and 30 % during the NE monsoon. The maximum and minimum temperature of the basin is 34 and  $20^{\circ} C$ .

### Geology and geomorphic setting

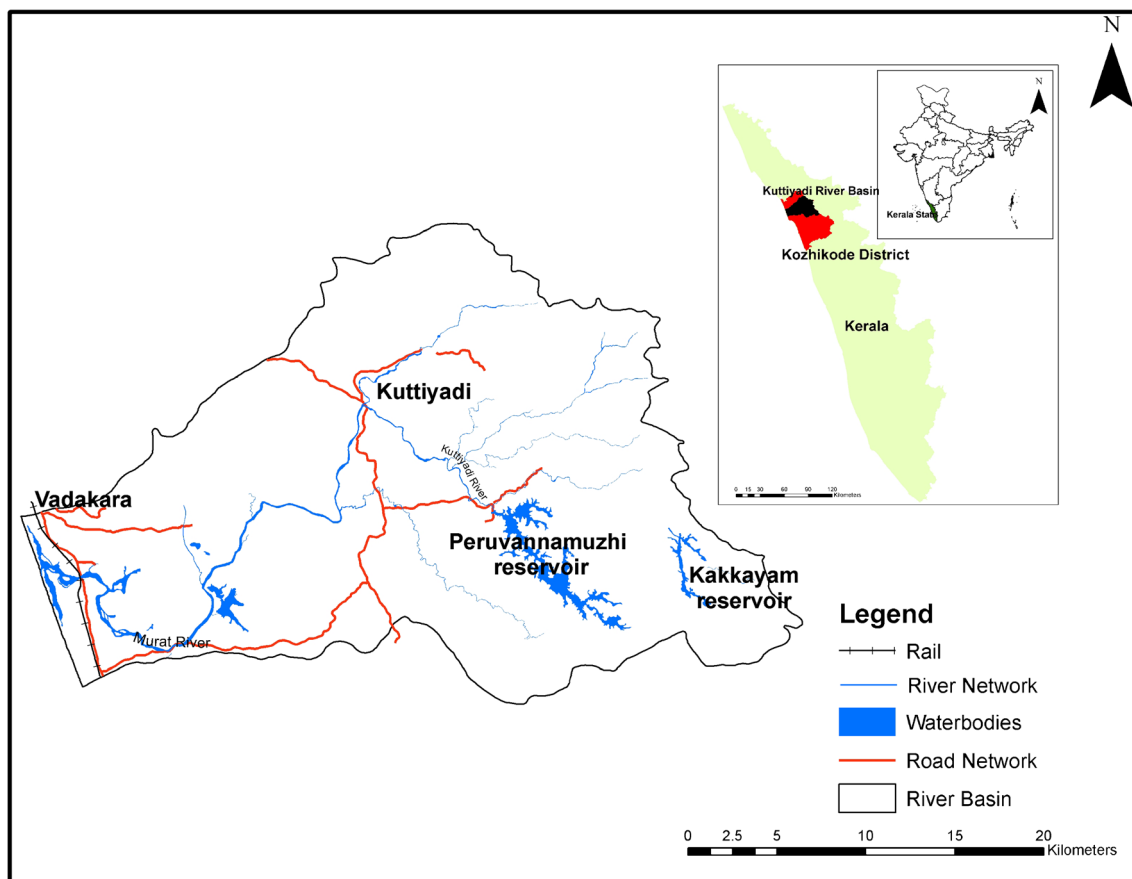
Geologically, the Kuttiyadi River Basin has three distinct formations: (i) crystalline rocks of Archean age, (ii) lateritic

capping over the crystalline and sedimentary rocks, and (iii) recent and sub-recent sediments in low-lying areas. Crystalline rocks chiefly consist of charnockite and gneisses (Fig. 2). The gneisses consist of garnetiferous biotite gneiss and biotite hornblende gneiss (Premachandran 2007). Granite gneiss and charnockite have low permeability and high bearing capacity. Thick laterite layers are porous and slightly permeable, so the layers can function as aquifers. The major distinct geomorphic units in the area are denudational plateaus, denudational hills and valleys, denudational slopes, flood plain, and valley flat (GSI 2002). The geohydrology of the area varies such as the narrow coastal belt, with alluvial deposit. The midland region has a thick laterite cover, foot hills, and high hills in the east, with thin soil cover, and the yield of ground water is poor, but fracture planes are potential zones (CGWB 1983).

### Materials and method

Cartosat-1, the ISRO's first satellite with along-track stereo capability, was launched in May 2005 providing high-resolution stereo imagery of the Earth's surface for cartographic applications. The satellite was launched into circular (altitude is 618 km) near-polar sun-synchronous orbit on May 5, 2005 from the Satish Dhawan Space Centre, Sriharikota, India. Cartosat-1 is equipped with two panchromatic cameras capable of simultaneously acquiring images of 2.5-m spatial resolution. One camera is looking at  $+26^{\circ}$  forward, while another looks at  $-5^{\circ}$  backward to acquire stereoscopic imagery with base to height ratio of 0.62. The time difference between acquiring the stereo pair images is approximately 52 s. Stereo Orthokit is one of the important products released for Cartosat-1. The cameras are across-track-steerable to enhance the system productivity. On-board solid-state recorder's capacity is 120 gigabits. The radiometric resolution is 10 bits; stereoscopic swath width is about 26 km, while wide-field (using both cameras) mono swath is 55 km (Lutes 2006; Navalgund 2005; [www.nrsc.gov.in](http://www.nrsc.gov.in)). Orthokit products (mono/stereo) are geometrically raw, but radiometrically corrected. Cartosat-1 data is one of the ideal sources for topographic map updating, and it is important to provide enough geometric accuracy with a minimum number of ground control points (GCP). In order to maintain these accuracies, geometric orientation better than these values should be achieved. The imagery is supplied with rational polynomial coefficients (RPC) and intended for photogrammetric processing ([www.nrsc.gov.in](http://www.nrsc.gov.in)).

Cartosat-1 Orthokit imagery data contains one tif file, one meta data file, and RPC files for Band A and also for Band F. In working with LPS to carry out triangulation, generate automatic DEM, and generate orthoimages, the stereo data Band A and Band F will be used. The high-resolution stereo data beamed from twin cameras (Fore and Aft) in Cartosat-1 mission



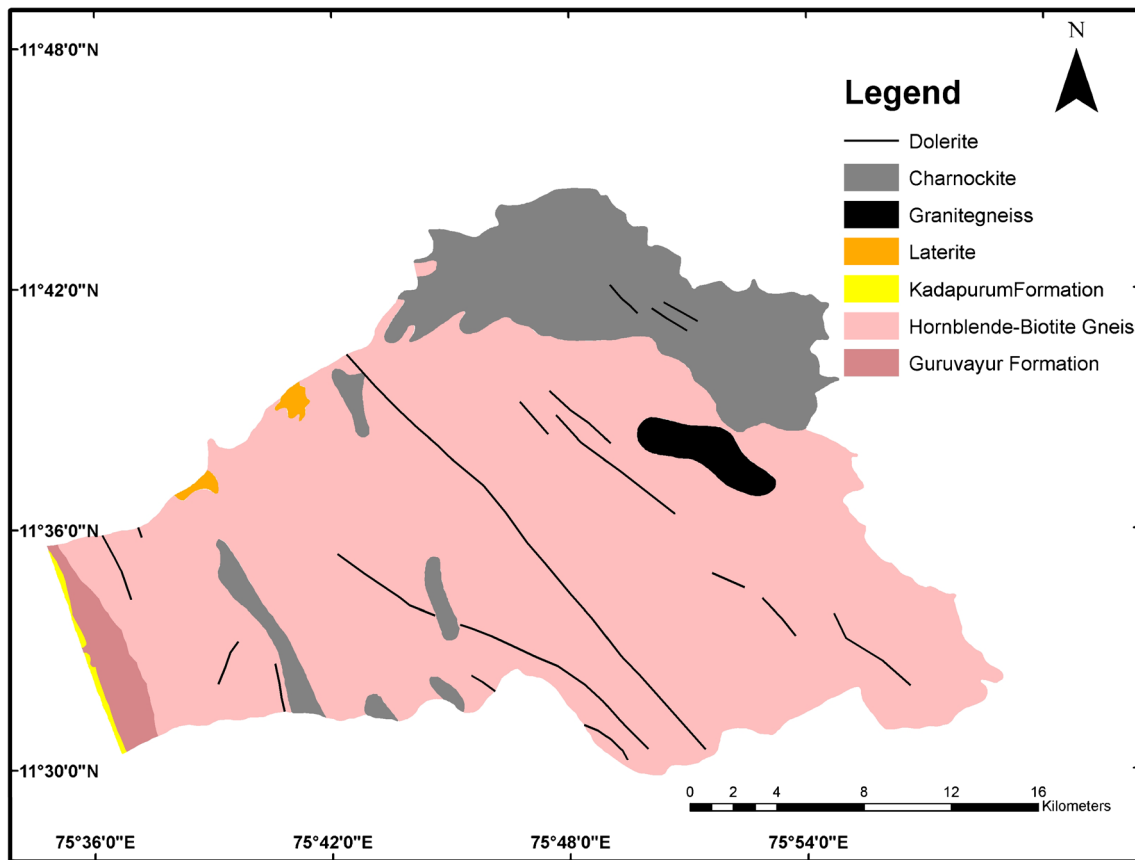
**Fig. 1** Location map of the Kuttiyadi River Basin

facilitates topographic mapping of up to 1:25,000 scale with planimetric accuracy requirement of approximately 5 m and vertical accuracy of approximately 3 m. A yardstick methodology has been adopted for the generation of DEM as shown in Fig. 3. Data from Cartosat-1 will be used for large-scale mapping, urban and rural development, land and water resource management, disaster management, relief planning and management, environmental impact assessment, and various other geospatial and mapping applications. Cartosat-1 provides RPC with the raw imagery, and it is possible to improve the RPCs by a direct and indirect approach. RPCs have been successfully used for the terrain extraction, orthorectification and feature extraction tasks (Grodecki and Dial 2003). Triangulation was performed using photogrammetric techniques by using RPCs available with the Cartosat-1 stereo data in LPS software. Thereafter, the DEM and orthoimage were generated in LPS. The DEM generated from Cartosat-1 stereo data, through automatic mode, is accurate to better than 2 to 2.5 pixels depending on the topography, and it can be useful for topographic analysis (Ashutosh 2013). Ortho-rectification can be performed using RPCs provided along with data, without any ground control points. However, it will cause a lack in the accuracy part, and to get accurate data, 34 GCP points and 122 automatically extracted tie points were used for this study. LPS 2011 was used for photogrammetric analysis. Block file and orthoimage with SW-

V are given in Fig. 3a, b, which are used to highlight the importance of GCP points.

The block project has assigned the horizontal and vertical coordinates with UTM projection and WGS 84 datum. The stereo pair images Band A and Band F were added to the frame. The interior and exterior orientations corresponding to the RPC files were carried out in frame editor. Interior orientation defines the internal geometry of a sensor, as it existed at the time of image capture, and exterior orientation is the position and angular orientation of the sensor that captured the image. The software extracts sensor information from RPC file and carries out the interior and exterior orientations. The pyramid layers were computed and updated.

The generation of DEM from stereo data needs geometric model and GCPs. The classical point measurement tool was used to add the GCPs and to generate tie points. Ground points are added to the images. Tie points are generated both manually and automatically for their even distribution. The triangulation was run after adding GCPs and tie points, and it is in order to improve the accuracy and refinement of GCPs and tie points. A DEM prepared using GCPs is known as absolute DEM and that, without using GCPs, is known as relative DEM. In the absolute DEM, the horizontal and vertical reference systems are tied to geodetic coordinates whereas a relative DEM is a DEM with relative differences in position,



**Fig. 2** Geology map of the Kuttiyadi River Basin

scale, and rotation from the geodetic coordinates on the ground (horizontal reference system) and the mean sea level (vertical reference system). According to Pandey and Venkataraman (2012), the relative DEM overestimates the absolute DEM in terms of its vertical accuracy for their study in Chotta Shigri Glacier, Himalaya. The Cartosat-1 data scenes were processed for satellite triangulation using ground control points, and GPS data was post-processed using the Leica photogrammetric suite to achieve high accuracy.

In order to perform the hypsometric analysis, the Kuttiyadi watershed was extracted from Cartosat-1 DEM data covering the whole catchment. A survey of India topographical maps on a 1:50,000 scale of study area was georeferenced; after georeferencing, an onscreen digitization process was carried out using ArcGIS 9.2 to extract stream network and sub-watersheds. The six sub-watersheds of the Kuttiyadi River Basin extracted from Cartosat-1 DEM (Fig. 4), hypsometric curves, and data were automatically derived for each of the subareas by inputting DEM data to the CalHypso tool. It employs a new and easy methodology to extract the hypsometric curve by using the integer data-model properties of ArcGIS and summation algorithms. This provides an optimal integration within the program environment, allowing the representation and comparison of curves directly within the GIS main program (Perez-Pena et al. 2009). Hypsometric attributes such as hypsometric integral,

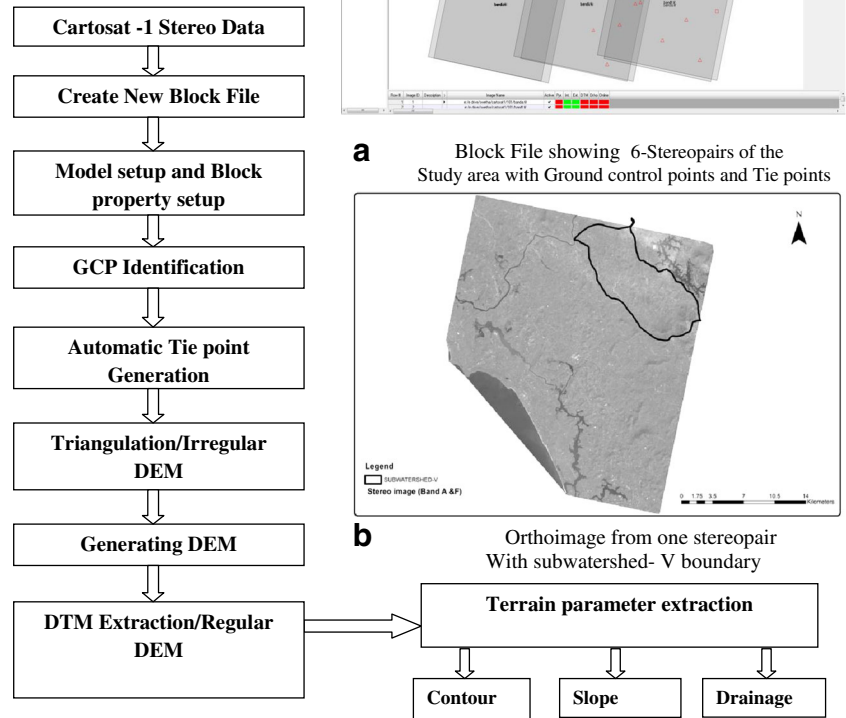
skewness, kurtosis, density kurtosis, and density skewness that depict different characteristics of a basin were automatically derived and used for the further interpretation.

In hypsometric curve, two ratios are involved and plotted against each other on a diagram: the abscissa represents the ratio of area between a given contour and the basal plane (cumulative area), and the ordinate represents the ratio of the height of a given contour above the basal plane to the total height of the area. Based on the hypothetical curve (Fig. 5) of maximum concavity (Sinha 2002), coordinates of slope inflection point ( $I$ ) given by  $a^*$  and  $h^*$  are calculated. The shape of hypsometric curves and value of hypsometric parameters were considered to bring out geomorphic stages of the sub-watersheds of the study area and to predict the erosion status.

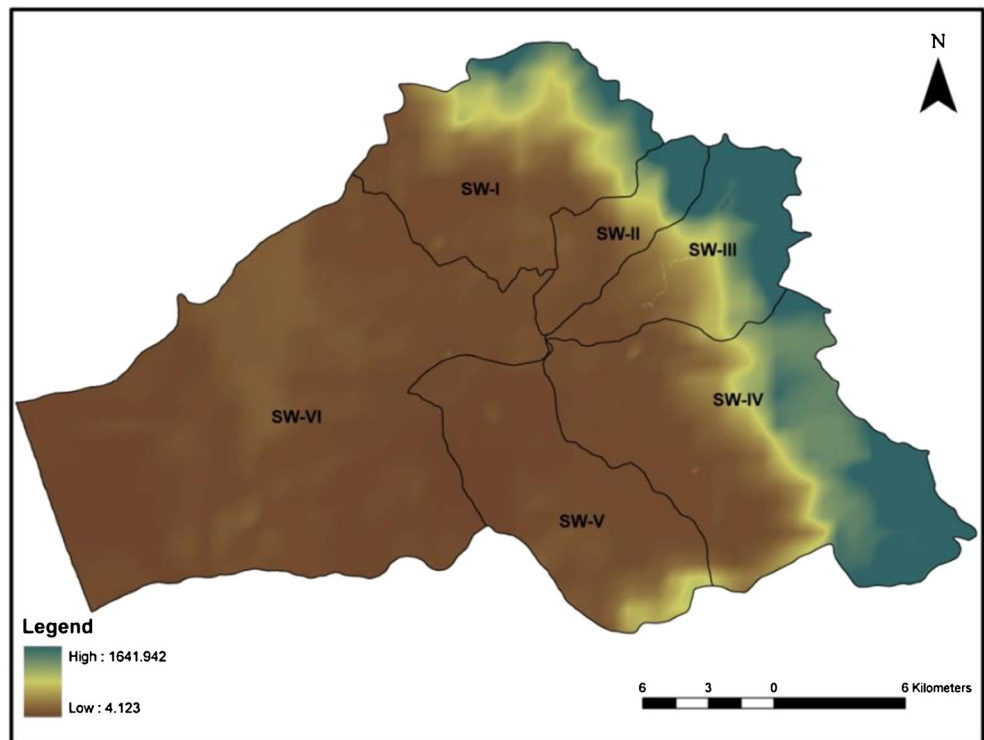
## Results and discussions

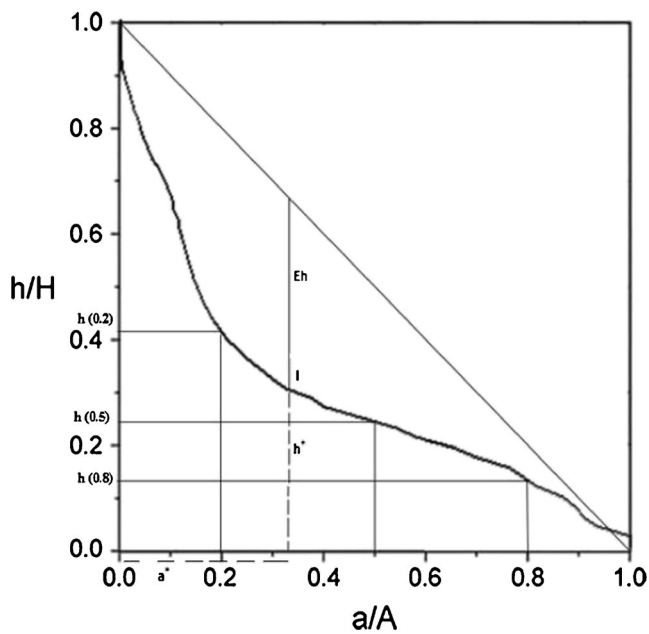
To validate the accuracy, the check points measured by GPS surveying methods were used, and accuracy assessment was done by using these check points. It reveals that for a plain terrain, the root mean square error should be less than a pixel value; for an urban and relatively plain area RMSE should be less than 2 pixel value. In a highly hilly area, the RMSE is above 3 pixels and less than 4 pixels. Accuracy of DEM and

**Fig. 3** Flow chart methodology showing the procedure for DEM generation from Cartosat-1 stereo pair using LPS-2011. **a** Block file showing six stereo pairs of the study area with ground control points and tie points. **b** Orthoimage from one stereo pair with sub-watershed V boundary



**Fig. 4** Cartosat-1 DEM of the Kuttiyadi River Basin with six sub-watersheds





**Fig. 5** A hypsometric curve defining the parameters which are extracted for the present study

orthoimage was improved by triangulation option with less RMSE. Figure 6a, b is showing the difference in DEM generated for the sub-watershed (SW-V) from the orthoimage. For the relative DEM, the elevation ranges from  $-73$  to  $521$  m, and for the absolute DEM, the elevation is ranging from  $9$  to  $464$  m.

Hypsometric attributes suggestive of processes

Skewness indicates the amount of headward erosion in the upper reach of basin in the Kuttiyadi River Basin, and it

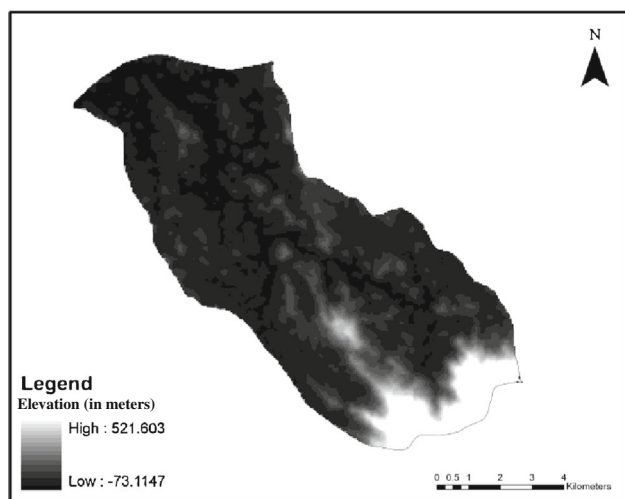
ranges between  $1.230$  and  $-1.725$  (Table 1). Density kurtosis gives idea about midbasin slope (Luo 2002). Kurtosis values show erosion on both upper and lower reaches of basin. Density skewness indicates the rate of change in slope, and a positive value is usually associated with typical fluvial landform, i.e., the valley network was carved by high-energy process.

#### Hypsometric curve

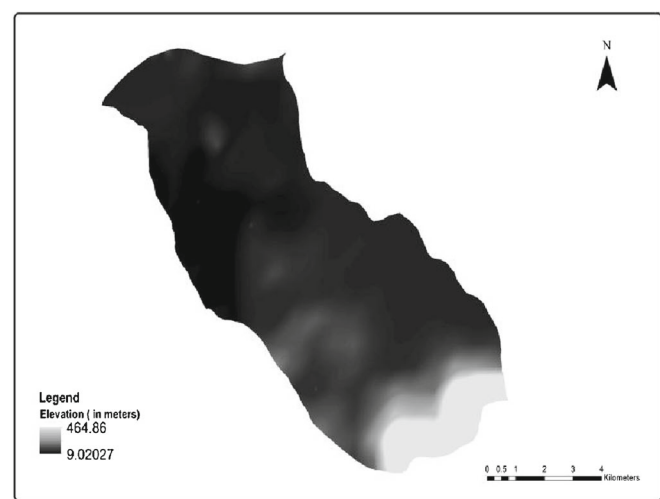
Hypsometric curves of SW-I, SW-II, SW-V, and SW-VI with upward concavity and hypsometric integral (Ea) values  $<0.25$  indicate old or monadnock stage, and the SW-III and SW-IV with downward concavity and Ea value  $0.34$  and  $0.28$  indicate mature stage. From the hypsometric curves, hypsometric attributes like skewness, kurtosis, density skewness and density kurtosis are given in Table 1 and hypsometric parameters such as hypsometric integral (HI), point of maximum concavity (Eh), coordinates of point of inflection ( $h^*$ ,  $a^*$ ), and height of hypsometric curve at different points have been determined and is tabulated in Table 2. Figure 7 shows hypsometric curves of six sub-watersheds and the Kuttiyadi River Basin.

The longitudinal profile of Kuttiyadi River Basin is shown in Fig. 8. A sudden change in elevation is found between  $55$  and  $60$  km from the river mouth.

The hypsometric curve shape can also control hypsometric integral; concave up with low integrals typify old and deeply dissected landscapes. In the present study, sub-watersheds are classified into old (SW-I, II, V) and mature (SW-III, IV, VI) stages based on hypsometric integral. The percentage of Ea value can give idea about the area already eroded and the



**a** DEM generated for a SW-5 using ortho image without GCPs



**b** DEM generated for a SW-5 using ortho image with GCPs

**Fig. 6** a DEM generated for a SW-V using orthoimage without GCPs. b DEM generated for a SW-V using orthoimage with GCPs

**Table 1** Hypsometric attributes automatically calculated

Sub-watersheds	Skewness	Kurtosis	Density kurtosis	Density skewness
SW-I	1.2304	3.8384	4.4439	1.4646
SW-II	0.5392	1.4458	2.6556	0.4058
SW-III	0.6797	2.4798	2.0569	0.4630
SW-IV	-1.7259	-12.5962	1.3980	0.0744
SW-V	-0.0669	0.9221	6.1397	2.4863
SW-VI	0.7347	2.3576	2.4729	1.0076
Basin	0.4332	1.5613	1.8526	4.3214

remaining area with respect to elevation. Here, SW-III with  $E_a$  0.34 suggests that 66 % of upland is eroded, and remaining 34 % is now in its mature stage. Sub-watersheds in mature stages are still in inequilibrium, so they are more susceptible to get eroded.

**Hypsometric head and toe**

On the basis of hypsometric head ( $h$  at 0.2), it has been observed that out of six sub-watersheds, four sub-watersheds (SW-I, II, V, VI) are showing hypsometric head value  $<0.50$ , signifying less diffusive process at their upper reaches. Sub-watersheds III and IV have moderate hypsometric head (0.61 and 0.59), indicating moderate diffusive processes at the upper reaches of these sub-watersheds. The toe values are considered to know about mass accumulation, and hypsometric toe values  $<0.2$  signify less mass accumulation at the sub-watershed mouth. The position of maximum concavity ( $E_h$ ) values of six sub-watersheds are positive, indicating more eroded upland areas and also points to old and late mature stages of development.

While considering the slope inflection points, SW-I, SW-II, SW-V, and SW-VI show a lower value ( $<0.3$ ); SW-III shows a moderate value (0.46); and SW-IV shows a higher value (0.61). The value of other inflection point  $h^*$  is less ( $<0.3$ ) for SW-IV and SW-V (0.08 and 0.11), whereas SW-I, II, III, and VI show a moderate value of  $h^*$  (0.34, 0.35, and 0.39, respectively). The lower the value of  $a^*$ , the greater is the

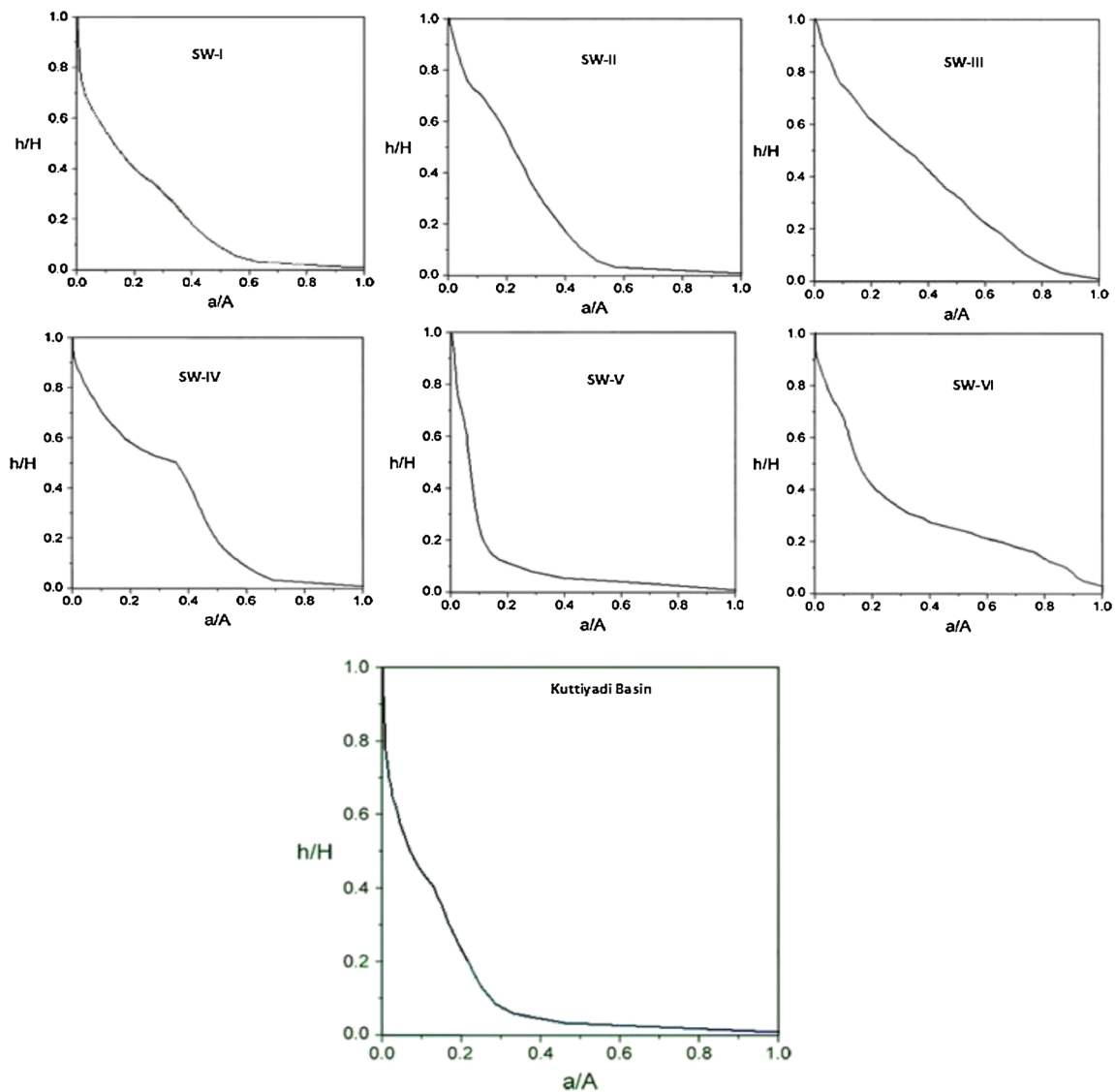
extent of subducted topography, approaching Davision style of peneplain, and the lower the value of  $h^*$ , the higher the degree of peneplanation (Sinha 2002). The hypsometric analysis of the Kuttiyadi River Basin showed that the basin is characterized by old geomorphic stage with low hypsometric integral, head and toe, and point of inflection. Hypsometric parameters point to sub-watersheds with low erosion indicating the old stage of the basin. Sub-watersheds III, IV, and VI showed a deviation from this. Lithology is an important factor related to erosion; areas with hard rock terrain can stabilize further erosion, and watersheds in old stage have hornblende biotite gneiss rock type.

**Conclusion**

The present study reveals the effectiveness of remote sensing and GIS techniques for hypsometric analysis of sub-watersheds of the Kuttiyadi River Basin, Kozhikode. Cartosat-1 stereo images have proved to be an excellent source of data for the production of DEM with a ground resolution of 5 m, and it is found that GCPs are the inevitable components for generating an accurate DEM and orthoimages. It is found that DEM generated from Cartosat-1 stereo data through automatic mode was very smooth, and no manual editing is required, which is then used to carry out hypsometric analysis for the six sub-watersheds of the Kuttiyadi River Basin. The

**Table 2** Hypsometric parameters of six sub-watersheds of the Kuttiyadi River Basin

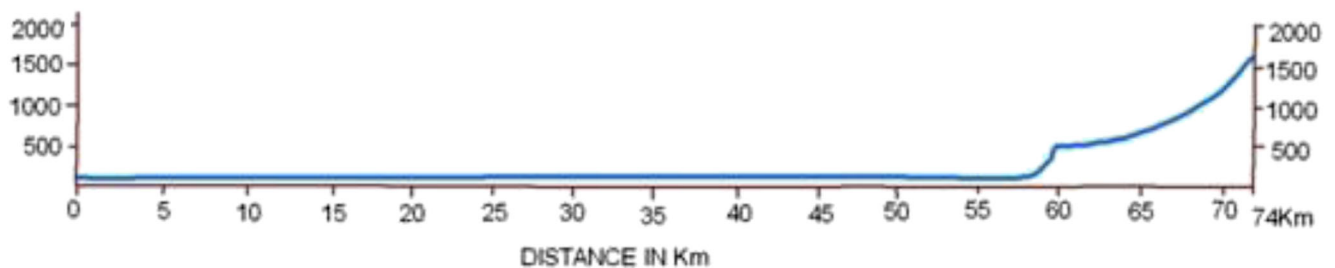
Sub-watershed	Area (km <sup>2</sup> )	Hypsometric integral ( $E_a$ )	Maximum concavity ( $E_h$ )	$a^*$	$h^*$	$h$ (0.2)	$h$ (0.5)	$h$ (0.8)	Geological stage
SW-I	93	0.20	0.41	0.26	0.34	0.40	0.09	0.04	Old
SW-II	29	0.22	0.44	0.26	0.34	0.40	0.09	0.04	Old
SW-III	54	0.34	0.19	0.46	0.35	0.61	0.32	0.06	Mature
SW-IV	148	0.28	0.31	0.61	0.08	0.59	0.19	0.02	Mature
SW-V	84	0.11	0.71	0.16	0.11	0.12	0.06	0.03	Old
SW-VI	268	0.28	0.39	0.22	0.39	0.41	0.23	0.12	Mature
Basin	676	0.19	0.67	0.29	0.09	0.23	0.04	0.03	Old



**Fig. 7** Hypsometric curves of sub-watersheds and the Kuttiyadi River Basin

results of the analysis show that out of the six sub-watersheds, three are in mature geomorphic stage (SW-III, IV, VI), whereas the remaining are in old stage. When considering the geology, these sub-watersheds are overlain by hornblende biotite gneiss. These mature-stage sub-watersheds are susceptible to runoff and erosion when

compared to others. Therefore, immediate attention towards soil conservation measures is required towards the sub-watersheds to preserve the land from further erosion and for proper management of the Kuttiyadi River Basin at suitable locations for reducing the runoff and increasing the ground water potential.



**Fig. 8** Longitudinal profile of the Kuttiyadi River Basin



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