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# Hydrological Inferences from Watershed Analysis for Sustainable Water Management Using Geoinformatics Approach

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## Abstract

*The rapid growth of urbanization, industrialization, an exponential increase in population and change of climate along with uneven distribution of rainfall make proper water management and planning of storage is very challenging. Satellite-based geoinformatics technology has supported to be an efficient tool in the analysis of drainage networks, surface morphological features, and interrelation with groundwater management at the watershed level. Geoinformatics approach such as remote sensing and Geographic information system has used for extraction of watershed analysis using Cartosat Digital Elevation Model (DEM) satellite images for assessment of drainage and extraction of their relative parameters For the Darna watershed in Nashik district, Maharashtra. In the study Hydrological parameters drainage analysis, topographical parameters, and land-use patterns has evaluated and interpreted for sustainable watershed management. The results reveals that Cartosat Data Dem based hydrological evaluation of watershed-scale is applied and accurate compared to available various technique.*

**Keywords:** CARTOSAT-DEM; Geoinformatics; LISSIV; Darna Basin; Watershed

## Introduction

The rapid growth of urbanization, industrialization, an exponential increase in population and change of climate along with uneven distribution of rainfall make proper water management and planning of storage is very challenging. Urban sprawl and growth of population in countries such as India has increased stress of water resource, because of more use for domestic, agriculture and industrial needs [1]. The increased use of water has affected and groundwater supplies and it has resulted in an acute water crisis [2]. Therefore, there is an urgent need for the assessment of water resources because they play a significant role in the sustainability of livelihood and regional economic activity in the whole world. Water is essential for drought conditions as well as plays a principal role in food security at local to global levels. Today's growth of population and urbanization has led to over-utilization of the resources, thus exerting pressure on the limited civic amenities of an urban area, which are on the threshold of breakdown [3,4].

The water resources with proper prioritization for its sustainable development[5].

The morphometric analysis in important to understand the hydrological behavior of the watershed for the development and management of natural resources[6–8]. The morphometric analysis of watersheds can afford information about the hydrological nature of the rocks exposed within a watershed. Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watershed[9].

Basin map of drainage map can be offered a reliable index of permeability of rocks and their relationship between the type of rock, structure, and hydrological status. Watershed characterization and management requires detailed information for topographic features, analysis drainage network, water divide line, channel length, set up of geomorphologic and geological of the area for proper watershed management and implementation plan in water conservation methods[10].

Recently, Remote sensing data, along with increased resolution from satellite platforms, makes these technologies appear poised to make a better impact on land resource management initiatives involved in monitoring Land use and Land cover mapping and change detection at varying spatial ranges in various regions[1,2]. It has understanding severe stresses due to the combined effects of a growing population and climate change[3]. Satellite data provide quick and useful baseline information about the factors controlling the occurrence and movement of groundwater[4,11,12].

Hydrological indications are one of the promising scientific tools for the assessment and management of water resources. Drainage morphometric analysis is a prerequisite for selection of water recharge site, watershed modeling, runoff modeling, delineation of watershed, prospect mapping and groundwater modeling[3,13]. The drainage network analysis has performed to understanding geological variation, information of topographical features and basin structure, and their relationship. Geoinformatics tools based drainage basin evaluation has been carried out by several researchers for different terrains. It has proved to be a very scientific tool for the generation of precise and updated information for characterization of drainage basin parameters[3,14].

The fast-emerging spatial information technology, remote sensing, GIS, and GPS have effective tools to overcome most of the problems of land and water resources planning and management rather than conventional methods of data process[15]. Using the LPS method for sensor geometry modeling the extraction of the corresponding DEM produced good results that are suitable for the operational use in the planning and development of natural watersheds. The DEM accuracy, analyzed both at the point mode and the surface mode, produced good results[16]. Cartosat-1 stereo data can be considered as high accuracy[17]. The images acquired by the satellite can be safely used for the purposes it has been designed for[18], i.e., gathering elevation data with accuracy sufficient for maps with the scale of 1:25,000.

In previous time, topographical map and field survey used for extracting of drainage morphometric parameters. Recently, drainage parameter extractions from the last two decades are more popular from digital topographical information which is called DEM (Digital Elevation Model), which is a very fast, exact, updated, and inexpressive way of watershed analysis.

Digital elevation model(DEM) such as from the Shuttle radar topography mission(SRTM) or the ASTER GDEM product has been used to extracting different geomorphological parameters of drainage basins including drainage networks, catchment divides, slope gradient and aspect and upstream flow contributing areas. GIS-based watershed evaluation using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) and CARTOSAT Data and Shuttle radar Topographic Mission (SRTM) data have given a precise fast and an inexpensive way for analyzing hydrological systems. The drainage delineation shows better accuracy and clear demarcation of catchment ridgeline and more reliable flow path prediction in comparison with ASTER. The results qualify Indian DEM for using it operationally which is equivalent and better than the other publicly available DEMs like SRTM and ASTERDEM[19,20].

Today some researchers have utilized remote sensing data and DEM to extract the catchment hydrological parameters to delineate storage areas. The digital elevation models are a very accurate tool for morphological parameter evaluation and watershed delineation for watershed management[3].

The use of digital elevation model through geographical information system (GIS) is a power full approach in this matter, since automatic methods to analyze topographic features are allowed with both operational and quality advantage while using ASTER GDEM, SRTM, and CARTOSAT Data with GIS techniques is a speed precision, fast and inexpensive way for calculating morphometric analysis. Recently, Numerous studies on morphometric analysis from DEMs have been carried out across the national and international level[10,14,20–53].

Dynamic, low-intensity monsoons create further shortages of surface water supply. As a result, the demand for groundwater resources has increased tremendously from year to year, causing a drastic decline in groundwater levels. Overexploitation of groundwater has led to the drying up of the aquifer zones in several parts of the country. It is, therefore essential to increase the recharge of the basin for the water management program at watershed level[3,15].

The present study comes under the semi-arid region and received maximum recharge through rainfall and the area urgently required integrated watershed-based morphometric analysis to understand the physiographic status of the study area. The hydrological analysis of watershed and their morphometric evaluation of Darna watershed, Nashik district of Maharashtra were carried out for water resource management through the use of CARTOSAT DEM, LISS-IV Image, and GIS analysis. The main objective of present the work is to investigate and identify various drainage parameters to understand the geometry of the watershed for the conservation and management of water resources in a sustainable. The result observed in the present work can be the scientific database for further detailed hydrological investigation and finds out the alternative solutions for water harvesting in the study area through the use of water conservation methods (Nala Banding, Counter trenching, check dam, water storage tank) based on observed calculation. Assessment of the watershed has been useful for resource management, planning and implementation of the development of soil and water conservation erosion control in river catchment.

## Study area

The study area Darna watershed extends between 19° 35' 00" North latitude to 19° 59' 17" North latitude, and 73° 31' 12" E to 73° 58' 58" East longitude, the watershed has 570 m to 1520 m from sea level with an area of about 1304 km$^2$ (Figure 1) in the study area Darna river is the tributaries of Godariv river in Nashik district is located on the northern part of Maharashtra. It originates on the northern slopes of Kulung Hill at elevation 1040 m in Sahyadri ranges about 13 km southeast in Igatpuri Tahsil Nashik district (Gadakh, 2020; Gadakh and Jaybhaye, 2020). On the right bank at Belu village, the river Darna confluences with river Kadva, and on the left bank, it has tributaries namely Vaki, Unduhol, Valdevi, and others such as Bham Nadi. The climate of the study area is characterized by a hot summer and general dryness expect during the southwestern monsoon. The watershed has 1520 m maximum elevation, and the lowest elevation is 570 m with rugged topography. The upper catchment area receives high rainfall (3000–4000 mm), and annual temperature ranges between 18 and 38 °C. It has a long and meandering course, and its bed is wide and sandy.

## Database

Morphometric quantitative analysis and drainage pattern provides associated information about the hydrological situations and nature of rock formation exposed within the watershed. Morphometric analysis of a basin indicates permeability, storage scarcity of the rocks and indicates the yield of the basin

In the research work an integrated use of Multispectral satellite data, DEM (digital elevation model) SOI one inch topographical sheets were utilized for the creation of database and extraction of various drainage parameters. The information of the data used is shown in Table 1.

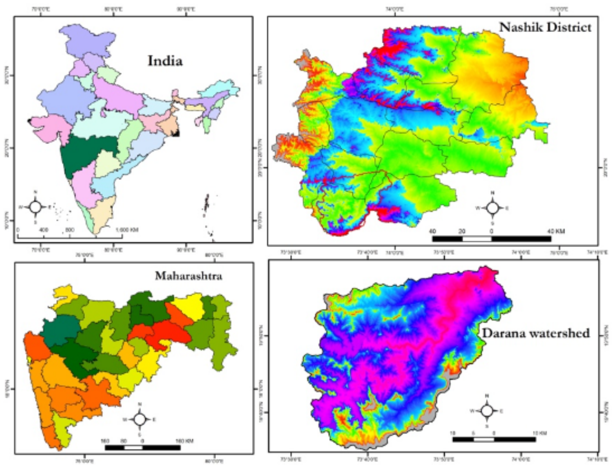


**Fig. 1.** Location map of the Darna Watershed

**Table 1.** Information of data used

| Type of data | Particulars of data | Sources |
|---|---|---|
| Survey of India(SOI) Toposheets, | Toposheets No Scale 1:50000 47 E/9,10 | Survey of India (SOI) India |
| LISS-IV I, Image | Path/Row 95/58 Dated: 27.04.2017 | www.nrac.gov.in |
| CARTOSAT DEM | Carto DEM Ver.3 (30M) | www.bhuvan.nrsc.gov.in |

## Methodology

Following methodology was followed for watershed analysis:

- The survey of India toposheets was geometrically rectified and geo-referenced with the help of GCP (ground control point) points. It has used UTM projection and datum WGS 84. All geocoded toposheets has a mosaic using ERDAS imaging 14.2 image processing software.
- Darna watershed delineated from CARTOSAT DEM and SOI topographical sheets of the study region by using data preparation option in Erdas Imaging software with the help of prepared shapefile of the watershed and the same shapefile has used to mask and subset the Cartosat DEM, SOI toposheets and Satellite image of the study region.
- Resource sat LISS-IV image (27.4.2019) image has utilized to preparation the land use and land cover map and updating of map of watershed.
- DEM (Digital Elevation Model) of the watershed was extracted from CARTOSAT DATA with 30 M resolution (downloaded from the www.bhuvan.nrsc.gov.in website). The CARTOSAT DEM has used to prepare topographic slop, Aspect map, drainage map of the watershed using Spatial Analyst tool of ARC GIS 10.00.

- All the extracted parameters form LISS-IV Images and Cartosat DEM data like the number and lengths of streams of each different order, Drainage area, watershed Parameter, total watershed length, and width has calculated with help of ARC GIS 10.00 Software. Drainage density, drainage frequency, shape form factors, circulatory ratio and elongation ratio etc. The methodologies adopted for the computation of morphometric parameters are given in Table 2.

## Result and Discussion

Assessment of watershed using quantitative morphometric analysis has described basin geometry to understand initial slope or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin[9]. A drainage map of a basin provides a reliable index of permeability of the rock and indicates the yield of the basin.

The digital elevation model has been obtained with a pixel size of 30 M. It has used to calculate slope and aspect map of the watershed. A drainage network of development has depended on geology, rainfall apart from endogenic and exogenic forces of the study region.

CARTOSAT DEM (Digital Elevation Model) data has used for extraction of slope, aspect, and morphometric analysis of the watershed. ARC GIS Software has evaluated linear, areal, and relief aspects of the watershed. Recently, Geospatial technology has well-developed, it impacts the analysis of drainage basin has been more accurate and precise for morphometric parameter evaluation with excellent accuracy. Satellite image and geographical information system tools had utilized to extract data on the spatial deviations in drainage characteristics thus providing an insight into hydrologic situation necessary for developing watershed sustainable management[25].

Hydrogeological observations, intergraded with drainage analysis provide useful clues regarding broad relationships among the geological framework of the watershed. Therefore the results reveal different levels of agreement using morphometric analysis, which were supposed to be different from one region to another. Topography and geology are the main factors controlling groundwater storage are different in space and time, and the majority of these factors depend on the following parameters: (1) Vegetation cover is available in the study to regain[54] (2)Precipitation availability as the source of water; (3) drainage characteristics have a role in the distribution of runoff and indicate an infiltration scheme and it governs the behavior of water flow on terrain surface vertically and horizontally (4) rock type for which the lithologic character governs the flow and storage management (5) slope is another influencing factor and it controls water flow energy, which plays a role in facilitating water flow in the basin[3]. The morphometric analysis has achieved through measurements of linear, areal and relief aspects of watershed.

Quantitative morphometric analysis of Darna watershed has been carried out to assess the drainage characteristics using ARC GIS Software for calculation and topology building of different morphometric parameters. Linear and aerial parameters and their characters have calculated such as basin area, basin length, bifurcation ratio, drainage density, stream frequency circulatory ratio elongation ratio.

- **Linear aspect or Drainage network analysis of Darna watershed**

Linear parameters of the study area have been closely related to the channel patterns of the stream network in which the topographic physiognomies of the stream segments in terms of open relations of the drainage system. The details of various morphometric parameters used in the research work Table 3.

- **Stream order (So)**

Stream ordering is the main process for watershed analysis. In the present study, the stream ordering has been ranked based on a method proposed from the extracting stream from the Cartosat Digital elevation model with using ARC GIS special analyst tools[9,51] . The whole has classified as a seven basin order with a stream length of 3324.954km.and perimeter of 198.05 sq.km. in the present study the stream. It is noticeably seen that the maximum number of stream was found in the first order and as the stream order increases with a decrease in stream number. It is significant factors the number of streams order has been understanding the physiography and structural condition of the study area. Drainage map with stream order of the Darna watershed (Figure 2).

- **Stream number (Nu)**

1$^{st}$ to 7$^{th}$ orders stream has various of the basin. Stream ordering of the Darna watershed was computed using ARC GIS software by applying the law proposed by Horton, 1945[52] says that the numbers of stream sections of each order form an inverse geometric sequence with stream order number. This change in stream orders may indicate flowing of streams from high altitude and lithological variations. The total number of streams in the Darna watershed is 6134 in that 4626 streams are 1$^{st}$ order,956 2nd order,3$^{rd}$ order 305, 4$^{th}$ order 37, 5th order 07, 6$^{th}$ order 02 and 7$^{th}$ order 01. The first order streams account for 4826 of the total stream numbers in the Darna watershed. The maximum numbers of 1$^{st}$ order streams indicated the intensity of permeability and infiltration characteristics of the study area.

**Table 2.** Methodology adopted for computations of morphometric parameters

| Sr.no | Morphometric Parameters | Formulae | |
|---|---|---|---|
| **A. Drainage network** | | | |
| 1. | Stream order (So) | Hierarchical rank | (51) |
| 2. | First order stream (Sof) | Sof=N1 | (51) |
| 3. | Stream number (Nu) | Nu=N1+N2+…Nn | (52) |
| 4. | Stream length (Lu).Km | Lu=L1+L2+….Ln | (9) |
| 5. | Stream length ratio (Lur) | | (9) |
| 6. | Mean stream length ratio(Lurm) | | (52) |
| 7. | Weighted mean stream length ratio (Luwm) | | (52) |
| 8. | Bifurcation ratio (Rb) | | (9) |
| 9. | Mean bifurcation ratio(Rbm) | | (9) |
| 10. | Weighted mean bifurcation ratio(Rbwm) | | (51) |
| 11. | Main channel length (Cl).Km | GIS Software | - |
| 12. | Valley length (Vl),Km | GIS Software | - |
| 13. | Channel index (Ci) | | (53) |
| 14. | Valley index (Vi) | | (52) |
| 15. | Rho coefficient (p) | | (52) |
| **B. Basin geometry** | | | |
| 16. | Basin length (Lb),km | GIS Software | (55) |
| 17. | Mean basin width(Wb) | Wb=A/Lb | (56) |
| 18. | Basin area (sq.km) | GIS Software | (55) |
| 19. | Basin perimeter | GIS software | (55) |
| 20. | Relative perimeter (pr) | Pr=A/P | (55) |
| 21. | Length area relation (Lar) | $Lar=1.4*xA^{0.6}$ | (57) |
| 22. | Lemniscate's(k) | $K=Lb^2/A$ | (58) |
| 23. | Form factor ratio (Ff) | $Ff=A/lb^2$ | (56) |
| 24. | Shape factor ratio(Rs) | $Sf=Lb^2/A$ | |
| 25. | Elongation ratio (Re) | Re=2/Lbx(A/0.5) | (55) |
| 26. | Elipticity index (Le) | $Le=7ixVi^2/4A$ | |
| 27. | Texture index (Rt) | Rt=N1/P | |
| 28. | Circularity ratio (Re) | $Re=12.57x(A/P^2)$ | (53) |
| 29. | Circularity ration (Ren) | Rcn=A/P | (9) |
| 30. | Drainage texture (Dt) | Dt=Nu/p | (52) |
| 31. | Compactness coefficient (Cc) | $Cc=0.2841xP/A^{05}$ | (59) |
| 32. | Fitness ratio (Rf) | Rf=Cl/P | **Melton (1957)** |
| 33. | Wandering ratio (Rw) | Rw=CI/Lb | (60) |
| 34. | Watershed eccentricity (t) | $t=iLcm^2-C^2)^{0.5}/Wcm$ | (61) |
| 35. | Hydraulic sinuosity index(His)% | Hsi=((Ci-Vi)/Ci-1)x100 | |
| 36. | Topographic sinuosity index (Tsi),% | Tsi=((Vi-1)/(Ci-1)x100 | |
| 37. | Standard sinuosity index(Ssi) | Ssi=Ci/Vi | |
| **C. Drainage texture analysis** | | | |
| 38. | Stream frequency (Sf) | Fs =Nu/A | (56) |
| 39. | Drainage density (Dd)Km/Sq.km | Dd=Lu/A | (56) |
| 40. | Constant of channel maintenance (km/Sq.km) | C=1/Dd | (55) |
| 41. | Drainage intensity (Di) | Di=Fs/Dd | (62) |
| 42. | Infiltration number (If) | If=FsxDd | (62) |
| 43. | Drainage pattern (Dp) | | (56) |
| 44. | Length of overland flow(Lg),km | Lg=A/2xLu | (52) |
| **D. Relief characterizes** | | | |
| 45. | Height of basin Mouth (z) m | GIS software &DEM | |
| 46. | Maximum height of the basin(Z)m | GIS software &DEM | |
| 47. | Relief | R=H-h | **Hadley and Schumm (1961)** |
| 48. | Total basin relief (H),m | H=Z-z | (51) |
| 49. | Relief ratio(Rhi) | Rhl=H/Lb | (55) |

*Continued on next page*

*Table 2 continued*

| | | | |
|---|---|---|---|
| 50. | Absolute relief (Ra)m | GIS software &DEM | |
| 51. | Relative relief ratio(Rhp) | Rhp=Hx100/P | **Melton(1957)** |
| 52. | Dissection index (Dis) | Dis=H/Ra | [63] |
| 53. | Gradient ratio (Rg) | Rg=(Z-z)/Lb | [64] |
| 54. | Watershed slope (Sw) | Sw=H/Lb | |
| 55. | Ruggedness number (Rn) | Rn=Ddx(H/1000) | [65] |
| 56. | Melton ruggedness number(MRn) | MRn=H/A0.5 | **Melton(1967)** |
| 57. | Total counter length (Ctl),Km | GIS software &DEM | |
| 58. | Counter interval (Ci),m | GIS software &DEM | |
| 59. | Slope analysis (Sa) | GIS software &DEM | |
| 60. | Average slope (S)% | S=(Zx(ctl/H))/(10xA) | [66] |
| 61. | Mean slope ratio (Sm) | | [66] |
| 62. | Mean slop of overall basin (Os) | Os=(CtlxCin)/A | **Chorley(1969)** |
| 63. | Time of concentration (Tc) | $Tc=0.0078L^{0.77}(L/H)^{0.385}$ | **Kirpich(1940)** |

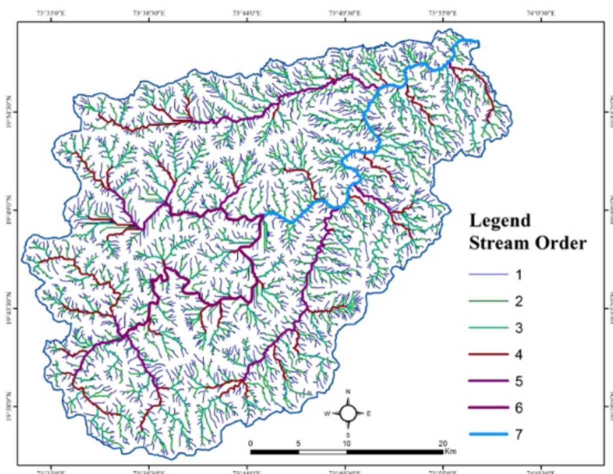


**Fig. 2.** Stream order

- **Stream Length ( Lu)**

Stream length is the most important hydrological parameter of any river watershed as it reveals surface runoff characteristics of comparatively smaller drainage lengths and characteristics of larger gradients area and fine textures. Longer lengths of streams are generally indicative of flatter gradients. The total length of stream segments is high in first-order streams and decreases as the stream order increase. The number of streams of various orders in the basin is counted and their lengths from mouth to divide are measured with the help of ARC GIS Software. There are a total of 3324.95km length of stream networks extracted from CARTOSAT DEM data. Out of which 3324.95 km (4856) is first order, 1707.1, 802.1, 400.0, 177.6, 93.0, 52.2, 92.9 are 2$^{nd}$, 3rd, 4th, 5th, 6th and 7$^{th}$ respectively.

- **Mean stream length (Lum)**

The characteristics and size of a stream segment components and its contributing watershed surface means mean stream length [9] and acquires by dividing the total stream length of an order by total number of stream segments in the subsequent order. The mean stream length of the watershed varies from 0.35 to 92.94. This difference in the values of mean stream length because of variation in slope and topography [9].

- **Stream length ratio**

The stream length ration may be defined as the ratio of the mean length of the one order to the next lower order of the stream segment. The mean of each consecutive orders of a basin tends to evaluate a direct geomantic series with stream increasing towards higher order of stream. Stream length ratio is changed from one order to another order signifying their late youth stage of geomorphic development [3] [50] it is has calculated the stream length ratio differs from 0.35 to 92.94 and understanding the stream length ratio between consecutive stream orders of the basin vary due to differences in gradient and topographical characteristics [13,50,64].

- **Bifurcation ratio and weighted mean bifurcation ratio**

Bifurcation ratio which is related to the branching pattern of the drainage network. The term Bifurcation ratio is the number of the stream units of a given order to the number of streams in the subsequent higher order [67]. Horton [52] has measured the bifurcation ratio as the index of elevation and it has expressed a small range of differences for the diverse area where the influential structural control dominates [68]. Bifurcation ratio values of the Darna river basin ranging between 5.05 and8.24 are considered the characteristics of the basin which have experience minimum structural disturbances [9]. The mean bifurcation ratio of the basin has observed as3.89 this indicated that the drainage pattern of the basin has not been affected by structural disturbances. Bifurcation ratio has observed is not the same from one order to its next order. These irregularities has depend upon Geological and lithological development of the watershed.

- **Length of the main channel**

The basin upper extent to the boundary of the basin has channel longest. GIS software analysis has measured the main channel length is103.27k.m

- **Rho coefficient**

It is a notable parameter relates drainage density of physiographic growth of a basin which facilitates an assessment of storage ability of stream network hence a reason for eventual degree of drainage development in the watershed [52]. This parameter has changed the climatic, geological, biological, geomorphological, and human activities. The Rho coefficient value of the basin is 0.58, it has lower hydrologic storage capacity in the floods period.

## Areal aspect of the Darna watershed

Analysis of the areal aspect of the Darna watershed in Table 4

• **Length of the basin**: According to Schumm [55] the basin length is parallel to the principal drainage line. The total length of the Darna basin is 1304.51K.M

• **Basin, perimeter , and width:** The perimeter of a drainage basin is defined as the horizontal projection of its water divide. The interrelationship between the total watershed and the total stream lengths [55] . Total areal extension of the Darna basin is 1304.51 km2 while its perimeter198.05and width is 23.94 km.

**Table 3.** The details of various morphometric parameter used in the research work

| Stream order | Stream number | Stream length | Mean stream length | Stream length ratio | Bifurcation ratio | Weighted mean bifurcation ratio: | Length of the main channel | Rho coefficient |
|---|---|---|---|---|---|---|---|---|
| 1 | 4826 | 1707.12 | 0.35 | 0 | 0 | | | |
| 2 | 956 | 802.15 | 0.84 | 2.37 | 5.05 | | | |
| 3 | 305 | 399.99 | 1.31 | 1.56 | 3.13 | | | |
| 4 | 37 | 177.59 | 4.80 | 3.66 | 8.24 | 4.87 | 103.27 | 0.58 |
| 5 | 7 | 92.96 | 13.28 | 2.77 | 5.29 | | | |
| 6 | 2 | 52.19 | 26.10 | 1.97 | 3.50 | | | |
| 7 | 1 | 92.95 | 92.95 | 3.56 | 2.00 | | | |
| **Total** | **6134** | **3324.95** | **139.63** | **0.54** | **27.21** | **4.87** | **103.27** | **0.58** |

**Table 4. Areal aspect of the Darna watershed**

| Basin Area (km2) | Perimeter | Width | Length area relation | Lemniscate | Form factor | Elongation ratio | Texture ratio | Circularity ratio | Compactness coefficient | Fitness ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| 1304.51 | 198.05 | 23.94 | 103.61 | 2.28 | 0.43 | 0.74 | 24.36 | 0.41 | 0.11 | 0.73 |

- **Length area relation:** A large number of basins, the stream length and basin area is associated by a simple power function the following length area relation= 1.4xA 0.6 .the length area relation of the basin is 103.61

- **Lemniscate's :** Its value has used to measure the gradient of the basin [58] 2.28 is the Lemniscate value of the Darna basin which it resulted in the basin covers the maximum area in its regions of beginning with a large sum of streams of lower order.

- **Form factor :** The form factor may define the ratio of the basin area to the square of the basin length and used to predict the intensity of a basin [10,52] in the form factor 0.43 value of the basin is small then the basin will be more elongated and experience lower peak flow of longer duration while the basin with high form factor experience higher peak flows of smaller period.

- **Elongation ratio :** according to the Schumm [55] has demarcated as the ratio of the diameter of a circle of the same area as the basin to the maximum basin length. 0.6 to 1.0 over a wide variety of climatic and geologic condition of variety Elongation ratio has divided the variable slopes of the basin such as circular (0.9-0.10), Oval (0.8-0.9), less elongated (0.7-0.8) elongated (0.5-0.7) and more elongated (<0.5) the basin value of elongation ratio is 0.74 which represents the basin is less elongated. This suggests that the basin belongs to the less elongated shape and high relief.

- **Texture ratio**: Lithology, infiltration ability and relief aspect of the topography in depends on texture ration [55]. Iration means between the first order streams and basin perimeter. The texture ratio value of the watershed is 24.36.

- **Circularity ratio**: Circularity ratio means the ratio of basin area of the area of a circle having the same perimeter as the basin [53] . Ratio is influenced by the length and frequency of streams, geological structures, land use/land cover, climate relief, and slope of the watershed. According to Miller, the circularity Ratio ranges from 0.4 to 0.7 indicate sturdily elongated and extremely permeable homogenous geologic materials. A circularity ratio of the basin is 0.4180 which indicates an elongated shape. The Observed circularity ratio of the basin indicates that the basin is less elongated in shape.

- **Compactness coefficient:** The ratio of the perimeter of the basin to the circumference of the circular area which equals the basin area [50,59]. The compactness coefficient is independent of the size of the watershed and dependent only on the slop. The compactness of the basin is 0.11.

- **Fitness ratio:** the ratio of the main channel length to the basin perimeter which is a measure of topographic fitness is fitness ratio (Melton 1957; Ra et al.2018). The fitness ratio for Darana watershed is 0.73 (Table 4)

**C. Drainage texture analysis of Darna watershed**

Analysis of the Drainage texture analysis of Darna Watershed in Table 5

- **Stream frequency:** The number of the stream segments per unit area means stream frequency [52,56]. The stream frequency of the watershed is 4.70.which is stream frequency of the Moderate category. It is controlled by the lithology of the watershed and specifies the texture of the stream network.

- **Drainage density :**

The drainage density defines as the stream length per unit area in the watershed area [51,52,56,68,69]. Which is expressed in terms of km/km$^2$. The drainage density is an element of drainage analysis that has expressed the study of landform, through climate, lithology, and structure and relief history of the area. Drainage density increase with decreasing infiltration capacity of the underlying rocks and decreasing transmissivity of the soil. The drainage density for the whole

**Table 5.** Drainage texture analysis of Darna watershed

| Stream frequency (Sf) | Drainage density (Dd)Km/Sq.km | Constant of channel maintenance (km/Sq.km | Drainage intensity (Di) | Infiltration number (If) | Drainage pattern (Dp) | Length of overland flow(Lg),km |
|---|---|---|---|---|---|---|
| 4.70 | 2.60 | 0.38 | 1.80 | 12.22 | | 2212205 |

watershed is 2.60 km/km$^2$.

• **Drainage texture**: **Smith (1956)** has classified into five classes such as the drainage density less than 2 indicates very coarse. 2and 4 is too coarse, 4 to 6 moderate, 6 to 8 is fine, and greater than 8 is very fine. Drainage texture depends on climate, rainfall, vegetation, rock, type of soil, the capacity of infiltration, and relief of the watershed. It has observed that the drainage texture is 24.36 it indicates the presence of highly resistant permeable material with high relief. The soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture. Sparse vegetation of climate causes finer textures. The texture of a rock is dependent upon vegetation type and climate.

• **Constant of channel maintenance:** it used the inverse of drainage density as a property termed as "Constant of channel maintenance"[(55)]. Rock type, permeability, climatic region, vegetation cover, relief, and duration of erosion it depends. Higher value has suggested more area is required to produce surface flow, which implies that part of water lay lost by evaporation, percolation, etc. Lower value indicates less chance of preculation and more surface runoff.

• **Drainage intensity :** it is the ratio of the stream frequency to the drainage density of the basin[(62)]. The study shows a low drainage density of 1.80 for Darna watershed.

The lower value has inferred the land surface by agents of denudation and higher value indicated susceptible to flood, gully erosion, and landslides.

• **Infiltration number:** the infiltration number of a basin is the product of the drainage density and stream frequency and describes about the infiltration physiognomies of the watershed. It is inversely proportional to the infiltration capacity of the basin, if higher value than lower infiltration and high runoff. The value of the study area is 12.22 which specifies that the low infiltration capability because more water flows in a small period during the monsoon season.

• **Drainage pattern:** The drainage pattern has reflected the impact of slope, lithology, and structure and understanding the stage of the cycle of erosion. Drainage pattern has presented the characteristics of the river basin through drainage texture. Drainage pattern has information that the geology of the watershed, the existence of faults, the strike and depositional rock, existence of faults, and geological structure. The time formation of the basin is long then the more easily the dendritic pattern is developed.

• **Length of overland flow**: the length of the overland flow is the length of the flow path, projected to the horizontal, on-channel flow from a point on the stream divide to appoint on the neighboring stream channel[(52)] in the study the length of overland flow value of the basin is 2213205 km. which shows high surface runoff in the area.

## Relief Parameters

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 landforms wherein different morphometric methods are used to analyze terrain characteristics which are the result of basin process. The assessment of the relief parameters in details Table 6.

• **Relief ratio:** The termed as relief ratio of maximum relief to the horizontal distance along the longest dimension of the basin parallel to the principal drainage line[(55)]. Basin relief is a key indicator of a drainage system shown by the elevation. It measured the overall steep slope of the drainage basin and it is an indicator of the intensity of the erosion processes operation on the slope of the basin. The relief ratio value of the basin is 18.22 which shows that the major portion of the basin in having a gentle slope.

• **Relative relief**: The maximum basin relief has calculated from the highest point on the basin perimeter to the mouth of the stream. Relative relief was computed as proposed by[(55)] the Relative value of the study area is 501.38.

• **Ruggedness number and Melton ruggedness number**: the ruggedness number is the product of the basin relief and the drainage intensity[(69)] and combines slope steepness with its length and his implications on the structural complexity and erosion potential of the landforms. The ruggedness number value of the study area is 2.58 the ruggedness of the basin suggests that the area is rugged with high relief and high stream density. The Melton ruggedness of the basin is 0.76 which indicates the basin is debris flood basin, where the bed load component dominates sediment under transport.

• **Dissection index :** The dissection index is a factor inferring the degree of vertical erosion and explains the phases of landform development in any region[(63)]. Generally dissection index is o to 1.which it indicates the absence of vertical erosion and one id indicated vertical escarpment of the hill slope. The value of the basin is 0.64 which indicates the area is a moderately dissected.

**Table 6.** Relief Parameters

| Height of basin Mouth (z) m | Maximum height of the basin(Z)m | Relief | Total basin relief (H),m | Relief ratio(Rhl) | Absolute relief (Ra)m | Relative relief ratio(Rhp) | Dissection index (Dis) | Gradient ratio (Rg) | Watershed slope (Sw) | Ruggedness number (Rn) | Melton ruggedness number (MRn) | Total counter length (Ctl),Km | Counter interval (Ci),m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 538M | 153M | 1069M | 993M | 18.22 | 1531M | 501.38 | 0.64 | 18.22 | 18.22 | 2.58 | 076 | 8844225.40 | 20 |

• **Gradient ratio:** Gradient in the steepness of a slope and explained as a proportion between its vertical intervals reduced to unity. It used to estimate the tangent of the angle of the slope of the basin. Gradient ratio is a parameter of channel slope that facilities calculation of the runoff volume [50,64]. The gradient ratio value of the study area is 18.22 which revels the mountainous nature of the terrain.

• **Slope map:** Slope analysis is a significant parameter in geomorphic studies**.** Slope is the measure of the change in surface value over distance and it has expressed in degrees and as a percentage. The slope elements are controlled by climatomorphogenic processes in the study area. Slope distribution is essential to provide data for planning, human settlement, agriculture practices or activates, deforestation, planning engineering structures, morph conservation practices [50,64]. The maximum rate of change in value from each cell to its neighbors using the methodology to identify the slope grid [70].

In a raster format, the digital elevation model is a grid where each cell is a value referenced to a common datum.in the study topographical elevation map for the study area has developed by DEM (Digital elevation model) extracted from CARTOSAT Data. The DEM was subjected to two-directional gradient filters. The resultant maps were used to extract a slope map of the study area using Spatial Analyst tools in ArcGIS.

• **Aspect map:** Aspect map has refers to the direction to which a mountain slope faces. The aspect map is a very significant parameter to understand the impact of the sun on the local climate of the study area. Generally, west-facing slope showing the hottest time of the day in the afternoon, and in most cases, a west-facing slope will warmer than sheltered an east-facing slope [3]. The distribution of vegetation type in aspect map. The aspect map has derived from CARTO SAT DEM represents the compass direction of the aspect 0 is north and 90 is east. The Darna watershed shows east-facing slopes and therefore these slopes have higher moisture content and higher vegetation.

• **Land use and land cover mapping :**

Land use and land cover pattern changes are the most important factors for understanding the groundwater conditions of the study area. A water resource has severed pressure because of land use practice and climate change. Land use pattern changes and their estimation describe the utiliza-

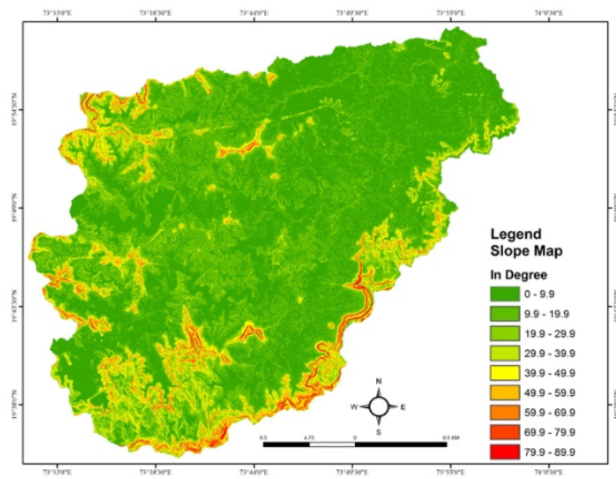


**Fig. 3.** Slope

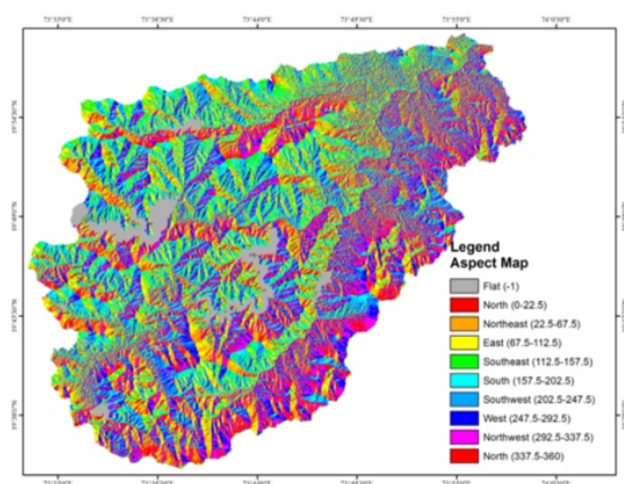


**Fig. 4.** Aspect

tion of land resource by human activities mainly agriculture and human settlement [3].

Hydrological interfaces from the land-use and land cover pattern are helpful to understand the changing scenario of water demand form different activates such as requirements of agricultural practice, domestic needs, industrialization and it can also use to understand the infiltration recharge and runoff rate of the watershed. Land use pattern changes become an important component in hydrological monitoring and natural resources management.

Analysis of the land-use changes for hydrologic processes are major needs for the future, which includes changes in water demands from changing land-use practices such as irrigation and urbanization, changes in water supply from altered hydrological processes of infiltration, groundwater recharge and runoff. Land use maps and their role is a very important parameter to understand the hydrological conditions of the watershed and their management.

In this paper supervised classification scheme was performed to assess the land use pattern and their spatial variation form recent available satellite data of LISS-IV data which have 23.7 m spatial resolution.

A standard approach was applied for classification of the satellite image using Erdas imagine 14 software starting from defining of the training sites, extraction of signatures from the image and then classification was performed finally maximum likelihood classification methods were applied. A field survey was also performed to finalize the land use and land cover map of the watershed by using GCP Points. Land use categories were identified regarding their water requirements such as Agricultural /Vegetation land, Settlement, Fallow land, Scrubland, and water bodies (Figure 5). Assessment of land use pattern of the watershed revels that most of the area comes under agricultural and fallow land which indirectly supports the future for sustainable development and management of watersheds in the Darna watershed. The analysis of the land use and land cover in Table 7.

**• Hydrological interference from morphometric analysis**

Morphometric analysis of watershed-based on Geoinformatics techniques and satellite images derived Digital Elevation Model is the most important data for the proper hydrological investigation of any terrain which directly support the hydrological status of the watershed. The quantitative analysis of morphometric parameters id found to be of immense utility in watershed delineation, soil and water conservation, and their management. The morphometric analysis carried out in the Darna watershed shows that the basin has —-relief and elongated slope. Artificial recharge and runoff harvesting in the area for groundwater development management are selected based on small scale topographic maps. Drainage analysis makes a positive contribution through the advantage of Geoinformatics tools in selecting artificial recharge sites. These analyzed drainage parameters provide comparative indices of the permeability of the rock surface in various parts if a drainage basin. If this information is integrated with the other hydrological characteristics of the drainage basin, the strategy of sitting recharge and water harvesting measures provides better groundwater development and management plan.

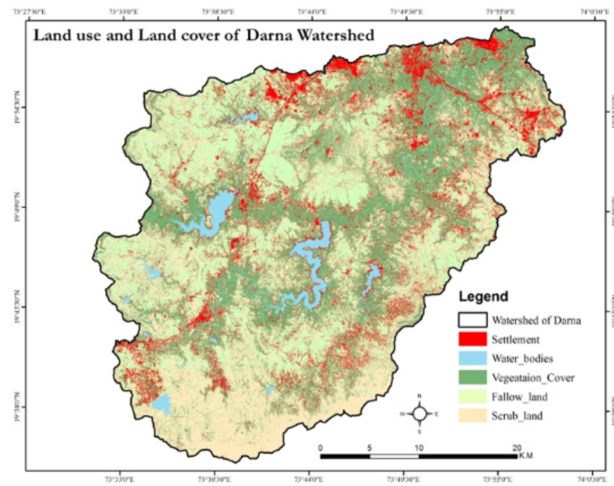


**Fig. 5.** Land use and landcover

The drainage pattern in the present watershed is dendritic. This may be due to more or less homogeneous lithology and structural controls. In the study area, high drainage density is observed over the hilly terrain with impermeable hard rock substratum and low drainage density over the highly permeable subsoils and low relief areas. Low drainage density areas are favorable for the identification of groundwater potential zones. Slope plays a very significant role in determining infiltration and runoff relation. Infiltration is inversely related to slope gentler is the slope higher is infiltration and less is runoff.

## Conclusion

The result achieved in this study proposes that morphometric attributes defining basin geometry as well as shape, length of stream, stream network topology and topography dissection can be well retrieved from CARTOSAT data and accomplished to generate data on stream number and basin relief. Various parameters of morphometric like linear, areal, and relief were enumerated and deliberated concerning the hydrological process.

The hydrological analysis carried out for Darna watershed confirms that the watershed is having low relief and elongated shape. The drainage network of the basin reveals mainly dendritic types which indicate the homogeneity in texture

**Table 7.** Land use /Land cover of the Darna Watershed

| Sr.No | Land use class | Area (Sq.Km) | Percentage (%) |
|---|---|---|---|
| 1. | Settlement | 152.93 | 11.72 |
| 2. | Vegetation Cover | 391.57 | 30.02 |
| 3. | Water Bodies | 34.22 | 2.62 |
| 4. | Fallow land | 352.70 | 27.04 |
| 5. | Scrub Land | 373.07 | 28.60 |
| **Total** | | **1304.49** | **100.00** |

and lack of structural control. Lower drainage density and stream frequency indicate a high permeability rate of the subsurface formation. The observed parameters revel recharge related measures and areas where surface water augmentation measures can be undertaken for water resource management and soil conservation structures. Large scale watershed analysis using Geoinformatics tools and Digital elevation model (DEM) has efficient tools for understanding any terrain parameters such has nature of bedrock, infiltration capacity, surface runoff, etc. which help in better understanding the status of landform and their processes, drainage management and evaluation of groundwater potential for watershed planning and management. Natural resource management at the micro-level of any terrain for sustainable development by planners and decision-makers for sustainable watershed development Programme has used this research work.

The results observed in the present work can be used for site suitability analysis of soil and water conservation structures in the area. Land use and land cover, landforms, geology, water level, and soil in the geoinformatics tools to decide on a suitable site for soil and water conservation methods have integrated with other hydrological information in the area for groundwater development and management. The research study recommended that the watershed needs a hydrological and geophysical investigation in the future for proper water management and selection of artificial groundwater recharge structures within the study area.

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## References

1) Singh P, Thakur JK, Kumar S, Singh UC. Assessment of Land Use/Land Cover Using Geospatial Techniques in a Semi-arid Region of Madhya Pradesh, India. In: Geospatial Techniques for Managing Environmental Resources. Springer Netherlands. 2011;p. 152–163. Available from: https://doi.org/10.1007/978-94-007-1858-6_10.
2) Thakur JK, Thakur RK, Ramanathan AL, Kumar M, Singh SK. Arsenic Contamination of Groundwater in Nepal—An Overview. *Water*. 2011;3(1):1–20. Available from: https://doi.org/10.3390/w3010001.
3) Singh P, Gupta A, Singh M. Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques. *The Egyptian Journal of Remote Sensing and Space Science*. 2014;17(2):111–121. Available from: https://doi.org/10.1016/j.ejrs.2014.09.003.
4) Jha MK, Chowdhury A, Chowdary VM, Peiffer S. Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. *Water Resources Management*. 2007;21(2):427–467. Available from: https://doi.org/10.1007/s11269-006-9024-4.
5) Panhalkar SS, Mali SP, Pawar CT. Morphometric analysis and watershed development prioritization of Hiranyakeshi Basin in Maharashtra. *International Journal of Environmental Science*. 2012;3(1):525–534. Available from: https://vidyaprabodhinicollege.edu.in/wp-content/uploads/2022/08/2.EIJES31052.pdf.
6) Kumar A, Darmora A, Sharma S. Comparative Assessment of Hydrologic Behaviour of Two Mountainous Watersheds Using Morphometric Analysis. *Hydrology Journal*. 2012;35(3and4):14–14. Available from: https://doi.org/10.5958/j.0975-6914.35.3X.008.
7) Aher PD, Adinarayana J, Gorantiwar SD. Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: A remote sensing and GIS approach. *Journal of Hydrology*. 2014;511:850–860. Available from: https://doi.org/10.1016/j.jhydrol.2014.02.028.
8) Malik A, Kumar A, Kandpal H. Morphometric analysis and prioritization of sub-watersheds in a hilly watershed using weighted sum approach. *Arabian Journal of Geosciences*. 2019;12(4):118–118. Available from: https://doi.org/10.1007/s12517-019-4310-7.
9) Strahler AN. Quantitative geomorphology of drainage basins and channel networks. New York. McGraw Hill Book Company. 1964;p. 4–11.
10) Sreedevi PD, Sreekanth PD, Khan HH, Ahmed S. Drainage morphometry and its influence on hydrology in an semi arid region: using SRTM data and GIS. *Environmental Earth Sciences*. 2013;70(2):839–848. Available from: https://doi.org/10.1007/s12665-012-2172-3.
11) Bobba AG, Bukata RP, Jerome JH. Digitally processed satellite data as a tool in detecting potential groundwater flow systems. *Journal of Hydrology*. 1992;131(1-4):25–62. Available from: https://doi.org/10.1016/0022-1694(92)90212-E.
12) Meijerink A. Groundwater. In: GA S, ET E, editors. Remote Sensing in Hydrology and Water Management. Springer Berlin Heidelberg. 2000;p. 305–325.
13) Magesh NS, Jitheshlal KV, Chandrasekar N, Jini KV. Geographical information system-based morphometric analysis of Bharathapuzha river basin, Kerala, India. *Applied Water Science*. 2013;3(2):467–477. Available from: https://doi.org/10.1007/s13201-013-0095-0.
14) Grohmann CH, Riccomini C, Alves FM. SRTM-based morphotectonic analysis of the Poços de Caldas Alkaline Massif, southeastern Brazil. *Comput Geosci*. 2007;33:10–19. Available from: https://doi.org/10.1016/j.cageo.2006.05.002.

15) Rao NK, Swarna LP, Kumar AP, Krishna HM. Morphometric analysis of Gostani River Basin in Andhra Pradesh State, Indian using spatial information technology. *Int J Geomatics Geosci*. 2010;1(2):179–187. Available from: https://www.researchgate.net/publication/348760409_Morphometric_analysis_of_Gostani_River_Basin_in_Andhra_Pradesh_State_India_using_spatial_information_technology_International_Journal_of_Geomatics_and_Geosciences.
16) Murthy, Yvn S, Rao S, Rao P, Jayaraman DS, V. The International Archives of the photogrammetry, remote sensing and spatial information sciences. vol. 37. Beijing. 2008;p. 1343–1348.
17) Dabrowski R, Fedorowicz-Jackowski W, Kedzierski M, Walczykowski P, Zych J. The international archives of the photogrammetry, remote sensing and spatial information sciences. 2008;37:1309–1313.
18) Srivastava PK, Srinivasan TP, Gupta A, Singh S, Nain JS, Amitabh, et al. Recent Advances In Cartosat-1 data processing, proceedings of ISPRS international symposium "high-resolution earth imaging for geospatial information. Hannover, Germany. 2007. Available from: https://www.isprs.org/proceedings/xxxvi/1-w51/paper/Srivastava_etal.pdf.
19) Muralikrishnan S, Pillai A, Narender B, Reddy S, Venkataraman VR, Dadhwal VK. Validation of Indian National DEM from Cartosat-1 Data. *Journal of the Indian Society of Remote Sensing*. 2013;41(1):1–13. Available from: https://doi.org/10.1007/s12524-012-0212-9.
20) Dikpal RL, Prasad TJR, Satish K. Evaluation of morphometric parameters derived from Cartosat-1 DEM using remote sensing and GIS techniques for Budigere Amanikere watershed, Dakshina Pinakini Basin, Karnataka, India. *Applied Water Science*. 2017;7(8):4399–4414. Available from: https://doi.org/10.1007/s13201-017-0585-6.
21) Sarangi A, Madramootoo CA, Enright P. Development of user Interface in ArcGIS for estimation of watershed geomorphology. 2003.
22) Reddy GPO, Maji AK, Gajbhiye KS. Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India – a remote sensing and GIS approach. *International Journal of Applied Earth Observation and Geoinformation*. 2004;6(1):1–16.
23) Valeriano MM, Kuplich TM, Storino M, Amaral BD, Mendes JN, Lima DJ. Modeling small watersheds in Brazilian Amazonia with shuttle radar topographic mission-90m data. *Computers & Geosciences*. 2006;32(8):1169–1181. Available from: https://doi.org/10.1016/j.cageo.2005.10.019.
24) Ozdemir H, Bird D. Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point of floods. *Environmental Geology*. 2009;56(7):1405–1415. Available from: https://doi.org/10.1007/s00254-008-1235-y.
25) Das S, Patel PP, Sengupta S. Evaluation of different digital elevation models for analyzing drainage morphometric parameters in a mountainous terrain: a case study of the Supin–Upper Tons Basin, Indian Himalayas. *SpringerPlus*. 2016;5(1):1544–1544.
26) Mondal B, Mistri B. Analysis of hydrological inferences through morphometric analysis: a remote sensing-GIS based study of Gandheswari river basin in Bankura district, West Bengal. *Int J Hum Soc Sci Stud*. 2016;2(4):68–80. Available from: https://www.ijhsss.com/files/09.-Biswajit-Mandal.pdf.
27) Savita R, Satishkumar U, Mittal H, Singh P, Yadav K. Analysis Of Hydrological Inferences Through Morphometric Analysis: A Remote Sensing-Gis Based Study Of Kanakanala Reservoir Subwatershed. . Available from: https://journals.indexcopernicus.com/api/file/viewByFileId/191676.pdf.
28) Pareta K, Pareta U. Quantitative morphometric analysis of a watershed of Yamuna basin, India using ASTER (DEM) data and GIS. *International Journal of Geomatics and Geosciences*. 2011;2(1):248–269. Available from: https://www.researchgate.net/publication/260319314_Quantitative_morphometric_analysis_of_a_watershed_of_Yamuna_basin_India_using_ASTER_DEM_data_and_GIS.
29) Pal B, Samanta S, Pal DK. Morphometric and hydrological analysis and mapping for Watut watershed using remote sensing and GIS techniques. *International Journal of Advances in Engineering & Technology*. 2012;2(1):357–357. Available from: https://www.researchgate.net/publication/260437533_Morphometric_and_hydrological_analysis_and_mapping_for_Watut_watershed_using_remote_sensing_and_GIS_techniques.
30) Nag SK, Lahiri A. Morphometric analysis of Dwarakeswar watershed, Bankura district, West Bengal, India, using spatial information technology. *International Journal of Water Resources and Environmental Engineering*. 2011;3(10):212–219. Available from: https://academicjournals.org/journal/IJWREE/article-full-text-pdf/64FC87E54617.pdf.
31) Mahadevaswamy G, Nagaraju D, Siddalingamurthy S, Nagesh PC, Rao K. Morphometric analysis of Nanjangud taluk Mysore District, Karnataka, India, using GIS Techniques. *International Journal of Geomatics and Geosciences*. 2011;1(4):721–734. Available from: https://www.indianjournals.com/ijor.Aspx?target=ijor:ijggs&volume=1&issue=4&article=005&type=pdf#:~:text=Nanjangud%20taluk%20lies%20on%20Southwestern,of%202400%20feet%20above%20MSL.
32) Zolekar RB. Integrative approach of RS and GIS in characterization of land suitability for agriculture: a case study of Darna catchment. *Arabian Journal of Geosciences*. 2018;11(24):780–780. Available from: https://doi.org/10.1007/s12517-018-4148-4.
33) Nag SK. Morphometric analysis using remote sensing techniques in the chaka sub-basin, purulia district, West Bengal. *Journal of the Indian Society of Remote Sensing*. 1998;26(1-2):69–76. Available from: https://doi.org/10.1007/BF03007341.
34) Lindsay JB, Creed IF, Beall FD. Drainage basin morphometrics for depressional landscapes. *Water Resources Research*. 2004;40(9):9307–9307. Available from: https://doi.org/10.1029/2004WR003322.
35) Mesa LM. Morphometric analysis of a subtropical Andean basin (Tucumán, Argentina). *Environmental Geology*. 2006;50(8):1235–1242. Available from: https://doi.org/10.1007/s00254-006-0297-y.
36) Deng Y. New trends in digital terrain analysis: landform definition, representation, and classification. *Progress in Physical Geography: Earth and Environment*. 2007;31(4):405–419. Available from: https://doi.org/10.1177/030913330708129.
37) Wilson JP, Aggett G, Yongxin D, Lam CS. Water in the Landscape: A Review of Contemporary Flow Routing Algorithms. In: Q Z, B L, G T, editors. Lecture Notes in Geoinformation and Cartography;vol. 3. Springer Berlin Heidelberg. 2008;p. 213–236. Available from: https://doi.org/10.1007/978-3-540-77800-4_12.
38) Wang D, Laffan SW, Liu Y, Wu L. Morphometric characterisation of landform from DEMs. *International Journal of Geographical Information Science*. 2010;24(2):305–326. Available from: https://doi.org/10.1080/13658810802467969.
39) Jacques PD, Salvador ED, Machado R, Grohmann CH, Nummer AR. Application of morphometry in neotectonic studies at the eastern edge of the Paraná Basin, Santa Catarina State, Brazil. *Geomorphology*. 2014;213:13–23. Available from: https://doi.org/10.1016/j.geomorph.2013.12.037.
40) Chopra R, Dhiman RD, Sharma PK. Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing*. 2005;33(4):531–539. Available from: https://doi.org/10.1007/BF02990738.
41) Kale VS, Shejwalkar N. Western Ghat escarpment evolution in the Deccan Basalt Province: geomorphic observations based on DEM analysis. *JGeol Soc India*. 2007;70:459–473. Available from: https://www.researchgate.net/publication/285650782_Western_Ghat_escarpment_evolution_in_the_Deccan_Basalt_Province_Geomorphic_observations_based_on_DEM_analysis.
42) Patel PP, Sarkar A. Application of SRTM data in evaluating the morphometric attributes: a case study of the Dulong River Basin. *Pract*. 2009;13(2):249–265. Available from: https://www.researchgate.net/publication/323772587_Application_of_SRTM_Data_in_Evaluating_the_Morphometric_Attributes_A_Case_Study_of_The_Dulung_River_Basin.
43) Dar RA, Chandra R, Romshoo SA. Morphotectonic and lithostratigraphic analysis of intermontane Karewa Basin of Kashmir Himalayas, India. *Journal of Mountain Science*. 2013;10(1):1–15. Available from: https://doi.org/10.1007/s11629-013-2494-y.

44) Prabu P, Baskaran R. Drainage morphometry of upper Vaigai river sub-basin, Western Ghats, South India using remote sensing and GIS. *Journal of the Geological Society of India*. 2013;82(5):519–528. Available from: https://doi.org/10.1007/s12594-013-0183-7.

45) Ambili V, Narayana AC. Tectonic effects on the longitudinal profiles of the Chaliyar River and its tributaries, southwest India. *Geomorphology*. 2014;217:37–47.

46) Suwandana E, Kawamura K, Sakuno Y, Kustiyanto E, Raharjo B. Evaluation of ASTER GDEM2 in Comparison with GDEM1, SRTM DEM and Topographic-Map-Derived DEM Using Inundation Area Analysis and RTK-dGPS Data. *Remote Sensing*. 2012;4(8):2419–2431. Available from: https://doi.org/10.3390/rs4082419.

47) Pande CB, Moharir K. GIS based quantitative morphometric analysis and its consequences: a case study from Shanur River Basin, Maharashtra India. *Applied Water Science*. 2017;7(2):861–871. Available from: https://doi.org/10.1007/s13201-015-0298-7.

48) Elabanavi S, Lamani S. Hypsometric Analysis of the Malaprabha Sub Basin of Krishna River, Karnataka, India. *International Journal for Research in Applied Science and Engineering Technology*;7(7):846–850. Available from: https://doi.org/10.22214/ijraset.2019.7136.

49) Bhatt S, Ahmed SA. Morphometric analysis to determine floods in the Upper Krishna basin using Cartosat DEM. *Geocarto International*. 2014;29(8):878–894. Available from: https://doi.org/10.1080/10106049.2013.868042.

50) Rai PK, Chandel RS, Mishra VN, Singh P. Hydrological inferences through morphometric analysis of lower Kosi river basin of India for water resource management based on remote sensing data. *Applied Water Science*. 2018;8(1):15–15. Available from: https://doi.org/10.1007/s13201-018-0660-7.

51) Strahler AN. Hypsometric (area-altitude) analysis of erosional topography. *Geological Society of America Bulletin*. 1952;63(11):1117–1117.

52) Horton RE. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*. 1945;56(3):275–275.

53) Miller VC. A quantitative geomorphic study of drainage basin characteristics on the Clinch Mountain area, Virginia and Tennessee. New York. 1953.

54) Zomlot Z, Verbeiren B, Huysmans M, Batelaan O. Spatial distribution of groundwater recharge and base flow: Assessment of controlling factors. *Journal of Hydrology: Regional Studies*. 2015;4:349–368. Available from: https://doi.org/10.1016/j.ejrh.2015.07.005.

55) Schumm SA. The evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological Society of America Bulletin*. 1956;67(5):597–597.

56) Horton RE. Drainage-basin characteristics. *Trans Am Geophys Union*. 1932;13:350–361.

57) Hack J. Studies of longitudinal stream profiles in Virginia and Maryland. US Geological Survey. 1957;p. 294–294. Available from: https://pubs.usgs.gov/pp/0294b/report.pdf.

58) Chorley RJ, Malm DEG, Pogorzelski HA. A new standard for estimating drainage basin shape. *American Journal of Science*. 1957;255(2):138–141. Available from: https://doi.org/10.2475/ajs.255.2.138.

59) Gravelius H, Flusskunde. Goschen Verlagshan dlung Berlin In: Zavoianu I (ed) Morphometry of drainage basins. 1914.

60) Smart JS, Surkan AJ. The relation between mainstream length and area in drainage basins. *Water Resources Research*. 1967;3(4):963–974. Available from: https://doi.org/10.1029/WR003i004p00963.

61) Black PE. Hydrograph responses to geomorphic model watershed characteristics and precipitation variables. *Journal of Hydrology*. 1972;17(4):309–329. Available from: https://doi.org/10.1016/0022-1694(72)90090-X.

62) Faniran A. The index of drainage intensity-a provisional new drainage factor. *Aust J Sci*. 1968;31:328–330.

63) Singh S, Dubey A. Geoenvironmental planning of watershed in India. Allahabad. Chugh Publications. 1994;p. 28–69. Available from: https://search.worldcat.org/title/geoenvironmental-planning-of-watersheds-in-india/oclc/60108652.

64) Sreedevi PD, Subrahmanyam K, Ahmed S. Integrated approach for delineating potential zones to explore for groundwater in the Pageru River basin, Cuddapah District, Andhra Pradesh, India. *Hydrogeology Journal*. 2005;13(3):534–543. Available from: https://doi.org/10.1007/s10040-004-0375-8.

65) Paton PC, Baker VR. Morphometry and foods in small drainage basins subject to diverse hydrogeomorphic controls. *Water Resour Res*. 1976;12:941–952. Available from: https://www.edwardsaquifer.org/wp-content/uploads/2019/02/1976_PattonBaker_SmallDrainageBasins.pdf.

66) Wentworth CK. A simplified method of determining the average slope of land surfaces. *American Journal of Science*. 1930;s5-20(117):184–194. Available from: http://ui.adsabs.harvard.edu/abs/1930AmJS...20..184W/abstract.

67) Strahler AN. Quantitative geomorphology of drainage basins and channel networks. In: Chow VT, editor. Handbook of Applied Hydrology. McGraw Hill Book Company. 1964.

68) Strahler AN. Quantitative analysis of watershed geomorphology. *Trans Am Geophys Union*. 1957;38:913–920.

69) Strahler AN. DIMENSIONAL ANALYSIS APPLIED TO FLUVIALLY ERODED LANDFORMS. *Geological Society of America Bulletin*. 1958;69(3):279–279.

70) Burrough PA. Principles of geographical information systems for land resources assessment. *Geocarto International*. 1986;1(3):54–54. Available from: https://doi.org/10.1080/10106048609354060.