TERRAIN ANALYSIS USING GIS FOR HYDROLOGICAL APPLICATIONS

By

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PROJECT REPORT

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DECLARATION

We hereby declare that this project entitled "**Terrain Analysis Using GIS for Hydrological Applications”** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associate ship, fellowship or other similar title of any other university or society.

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CERTIFICATE

Certified that this project report entitled "**Terrain Analysis Using GIS for Hydrological Applications**" is a record of project work done jointly by **Anjaly C. Sunny** and **Aswathi K.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to them.

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Anjaly C. Sunny

Aswathi K.

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SYMBOLS AND ABREVIATIONS

°	-	Degree
′	-	Minute
″	-	Second
/	-	Per
A	-	Area
ABMZ	-	Aquatic Biodiversity Management Zones
BRB	-	Bharathapuzha river basin
C	-	Crop Factor
CRP	-	Crop Reserve Programme
DBMS	-	Data Base Management System
Dd	-	Drainage density
DEM	-	Digital Elevation Model
Dept.	-	Department
DTM	-	Digital Terrain Model
DSS	-	Decision Support System
ERDAS	-	Earth Resource Data Analysis System
ESRI	-	Environmental System Research Institute
et al	-	and others
etc.	-	Etcetera
EW	-	East West
FCC	-	False colour composite
Ff	-	Form factor
Fs	-	Stream frequency
GIS	-	Geographic Information System
GPS	-	Global Positioning System
H	-	Lowest point elevation on the valley floor of a basin
H	-	Highest point elevation on the valley floor of a basin
Ha	-	Hectare
ILWIS	-	Integrated Land and Water Information System
IRS	-	Indian Remote sensing Satellite
J	-	Journal
J&K	-	Jammu and Kashmir
K	-	Soil Erodibility Factor
Km	-	Kilometer
km^2	-	square kilometer
km^3	-	cubic kilometer
LANDSAT	-	LAND Satellite
LESA	-	land evaluation and site assessment
Lg	-	Length of overland flow
LISEM	-	LImburg Soil erosion Model
LS	-	Land slope factor
Lsm	-	Mean stream length
Lu	-	Stream length
Lu	-	Stream length ratio
Mm	-	Millimeter
NW	-	North West

P - Conservation Practice Factor
R - Relief
Rb - Bifurcation ratio
Rbm - Mean bifurcation ratio
Rr - Relief ratio
RS - Remote Sensing
RUSLE - Revised Universal Soil Loss
SE - South East
SOI - Survey of India
SRTM - Shuttle Radar Topographic Mission
SWAT - Soil and Water Assessment Tool
SWD - Sub-Watershed
T - Drainage texture
TM - Thematic Mapper
U - Stream order
USBC - United States Bureau of Censes
USGS - United States Geological Survey
USLE - Universal Soil Loss Equation
W - Wetness

CHAPTER I

INTRODUCTION

Kerala with her blue mist - capped mountains, undulating hills and valleys of a thousand shades of green, the blue spread of an endless stretch of lagoons and long seacoast is blessed by forty four rivers. Kerala has forty one west flowing rivers and three east-flowing rivers. Bharatapuzha or Nila is the biggest river system among the west flowing rivers and most of its water is impounded in the Parambikulam- Aliyar dam which provide irrigation water to Tamil Nadu and in the Siruvani dam which provide drinking water to Coimbatore city.

The headwaters of the main tributary of Bharathappuzha originates in the Anaimalai Hills in the Western Ghats, and flows westward through Palakkad Gap, across Palakkad, Thrissur and Malappuram districts of Kerala, with many tributaries joining it. With a watershed of 6,186 km^2, the Bharathapuzha basin is the largest among all the river basins in Kerala. A little more than two-thirds of this area (4400 km^2) is within Kerala and the remaining area (1786 km^2) is in Tamil Nadu. Though Bharathapuzha has a large basin, the water flow is relatively less compared to other long rivers in Kerala because a large portion of its basin is located in the comparatively drier regions.

Despite the richness, the river system of River Nila is under threat from human interference. The major threats are sand mining, deforestation, lime stone mining, and urban sewage dumping etc. Studies have shown that the rate of sand mining is way too above the rate of sand generation in Nila. Nila has eleven irrigation dams and several smaller check dams**.** The town of Pattambi which falls under the Palakkad District of the state of Kerala is a major source of urban sewage which pollutes the river extensively, taking over the pollutant cocktail made by the agro-pollutants. Deforestation in its catchment areas like Mangalam, Nelliyampathy, Walayar, Malampuzha, Nellipuzha, Dhoni and Kalladikode is a major threat. Lime stone mining is leading to pollution and siltation in certain areas of the catchment of the river especially Malampuzha, part of the Kalpathipuzha tributary. Apart from triggering an unnatural rise in the silicate content in the water, the dumping of mining debris also damages smaller streams like Seemanthinipuzha in the system.

Studies conducted in 2010 and 2011 discovered that the temperature in the Bharathapuzha basin has been on the rise for a 36 year period from 1969 to 2005. Moreover, rainfall data shows that the Nila watershed gets less rainfall than the state average. The temperature rise is often cited as an impact of climate change phenomenon and the increasing anthropogenic pressure in the river banks of the Nila.

1.1 Geomorphology of the watershed

For a scientific and rational approach to different river problems and proper planning and design of water resources projects, an understanding of the morphology and behaviour of the river is a pre-requisite. Morphology of river is a field of science which deals with the change of river plan form and cross sections due to sedimentation and erosion. In this field, dynamics of flow and sediment transport are the principal elements. The Morphological Studies, therefore, play an important role in planning, designing and maintaining river engineering structures. In recent years, there has been a growing awareness about the need for taking up Morphological study of rivers in the country.

1.2 Digital terrain analysis (DTA)

The process of quantitatively describing the terrain is known as the Digital Terrain Analysis (DTA).The common synonyms are geomorphologic analysis, land form parameterization and land surface analysis. A Digital Terrain Model (DTM) also referred to as Digital Elevation Model is a digital representation of earth’s topography, i.e. an elevation map. DEM can be used to derive topographic attributes, geomorphometric parameters, morphometric variables or terrain information in general. The term DTM may be used to derive set of interpolation or filtering techniques used to derive the topographic surface and the term DTA for a set of techniques used to derive terrain parameters. The terrain analysis or parameterization is the set of techniques used to derive terrain parameters from a DEM. That is, it is a process to quantify the morphology of a terrain. Terrain analysis (DTA) is used as a general term for derivation of terrain parameters and their application.

There are three main groups of digital terrain parameters namely morphometric, hydrologic and climatic parameters. The morphometric parameters describes the morphology of a surface, for example:- slope gradient, aspect and curvatures. The hydrologic parameters or flow accumulation based terrain parameters describe the potential flow of materials that is erosion hazards. And the climatic terrain parameters are climatic variables adjusted to the factors of relief.

In simple terms, geomorphometry aims at extracting land surface parameters (morphometric, hydrological, climatic etc.) and objects (watersheds, stream networks, landforms etc.) using input digital land surface model (DEM) and parameterization software. For DTA, it is more important that, how does the DEM resemble the shapes and flow potential, that is, a good representation of shape is more important than the actual values in the DEM, by adjusting actual value using an additional set of filtering methods. Extracted surface parameters and objects can then be used, for example, to improve mapping and modelling of soils, vegetation, land use, geomorphological and geological features and similar. Using GIS, spatially varying parameters or characteristics can easily be computed, stored, retrieved and analysed and much derivative information can be generated.

The GIS tool (both software and hardware) has made the data handling and analysis much easier with meaningful research outcomes. It has the advantage of handling attribute data in conjunction with spatial features, which was totally impossible with manual cartographic analysis. It stores both spatial and non-spatial data, layer by layer either in raster or vector format. The linking of modelling concepts with the GIS domain is proved useful in development of a Decision Support System (DSS) and expert system based on heuristic logic. This tool makes the data handling job easier and meaningful. It is more versatile for analysing a large data base and large areal extent. GIS facilitates repetitive model application with considerable ease and accuracy.

Since 90’s, DTA has been implemented in in many general GIS packages. DTA software like ILWIS can only run simple filter operations and derive for example the slope, aspect and hill shading maps. The cartographic and data overlaying capability of

GIS coupled with its dynamic linking ability with models plays a vital role in water management decision making process. The model output can be displayed effectively and the information stored in a particular region will be handy for use.

1.3 Geographical Information System (GIS) software - ILWIS

ILWIS is an acronym of the Integrated Land and Water Information System. It is a Geographical Information System (GIS) software with Image Processing capabilities. ILWIS has been developed by the International Institute for Aerospace Survey and Earth Sciences, Enschede, Netherlands and is now ILWIS Open, a Free and Open Source Software (FOSS) developed under 52° North (http://52north.org).

As a GIS and Remote Sensing package, ILWIS allows inputting, managing, analysing and presenting geographical data. From the data one can generate information on the spatial and temporal patterns and processes on the earth surface.

1.4 Objectives of the study

Bharathapuzha river basin within the boundary of Kerala state has been taken for this study with following objectives:

- Terrain analysis of Bharathapuzha watershed using Digital Terrain Analysis.
- Extraction of the geomorphological parameters of the watershed which are important with respect to their hydrological applications.
- Delineation of the watershed in to sub-catchments and delineation of the watersheds of tributaries

CHAPTER II

REVIEW OF LITERATURE

GIS in geomorphological analysis

Turoglu*et al.*(2004) conducted a study with the aim to analyse geomorphological units of Bartın territory (NW Turkey) by using Remote Sensing and Geographical Information System Technologies. LANDSAT 5, Thematic Mapper (TM) scenes of the study area, 1:25,000 scale digitized topographic maps and ERDAS 8.5, ARCVIEW 8x software were used. The basic geomorphological units such as mountainous areas, plateau, lowlands and metric properties of these units, etc. was not only dissected but also calculated and mapped in RS and GIS Technologies. The results of applying RS and GIS for Bartın were tested in field. For instance, geomorphological data produced with unsupervised classifications based on spectral reflectance features and signatures were checked and clearly named using Global Positioning System (GPS) on field.

Finally, Geomorphological features of Bartın and its territory were explained as units and types, quantitative results and digital mapping.

Sarkar*et al.*(2007) initiated a study to determine the capacity of ungauged catchment to produce runoff through geomorphological study as prior investigation to install hydropower. An ungauged catchment of Solani River, a tributary of the Ganges from northern India hilly terrain, has been chosen for investigation. Further, the catchment has been divided in five sub catchments (sub catchments 1 to 5) to study the catchment capacity to produce runoff more precisely. Geographical Information System (GIS) has been used as a tool for geomorphological parameter estimation. The study reveals that the sub catchment 1 is of medium size among all five sub catchments but having maximum drainage density (1.11 km/km^2) and maximum available relief ratio (0.023), which demonstrates better capacity to produce runoff among all. Hence sub catchment 1 can be considered as a site of interest for hydropower installation on Solani River as prior survey basis. The relief value and slope value within the sub catchment 1 measured on main stream were used to explore the hydropower site.

Sreenivasulu *et al.*(2010) made an attempt to evaluate the physical characteristics of a watershed, which are required for hydrological investigations and are the major inputs to various hydrological models. The watershed studied was Devak catchment up to Gura Slathian in Jammu region of Jammu & Kashmir (J&K), India and they used remote sensing and GIS techniques for the study.

Doad *et al.* (2012) conducted a study in Bordi river basin, Maharashtra. The river basin is mainly drained by dendritic drainage which indicates the homogeneity in texture and lack of structural control. The bifurcation ratio (Rb) value is 3.787 indicating that the geological structures are less disturbing the drainage pattern. The basin had medium drainage density (D) of 2.627 km/sq. km indicating moderately permeable subsoil and moderate vegetative cover. The stream frequency (Fs), 3.44 exhibit positive correlation with the drainage density value of the area, indicating the increase in stream population with respect to increase in drainage density. The texture ratio (T) of the basin is moderate 3.43 while elongation ratio (Re) is 0.55 indicating the low relief of the terrain and elongated shape. The circularity ratio (Rc) 0.463 of the basin indicated the elongated shape of the basin, its low discharge of runoff and high permeability of the subsoil. The low form factor (Rf) value of the basin, 0.37 represents a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin. Hence from the study it is clear that morphometric analysis based on GIS technique is a competent tool hydrological studies.

Ramaiah *et al.* (2012) carried out a morphometric analysis of Sub-basins in and around Malur Taluk, Kolar District, Karnataka. The drainage network of Kanamanahalli and Devaraguttahalli sub-basins were delineated using false colour composite (FCC) of IRS-1C/1D merged satellite data on 1:50,000 scale. Survey of India (SOI) toposheets were used as reference with limited field work. The study area falls in Ponnaiyar river basin covering an area of 686 sq. km comprising two sub-basins namely Kanamanahalli and Devaraguttahalli having an area of 439 sq.km and 247 sq.km respectively. The morphometric analysis of these two sub-basins showed that the terrain exhibits dendritic to sub-dendritic drainage pattern. Stream order ranged from first to sixth order. Drainage density varied between 1.57 and 1.88 km/km^2 and has coarse to fine drainage texture. The relief ratio ranged from 0.0111 to 0.0117. The mean bifurcation ratio varied from 3.51 to 4.86 which fell under the normal basin category. The elongation ratio showed that these sub-basins were associated with high relief and steep ground slopes.

Raj *et al.*(2012) carried out a study in one of the less studied Bharathapuzha river basin (BRB), the second longest river in the state of Kerala, India. The annual discharge of the river is 3.94 km^3. The basin, which receives about 1828 mm of annual rainfall, has been facing dearth of water in recent years. They used GIS and RS tools to study the morphometric characteristics of the basin. The seventh order main river is formed by several lower order streams forming a dendritic flow pattern. They observe that basin geology, slope and rainfall pattern in the basin determine the morphometric characteristics of the basin. Also, the linear aspects of the basin including stream length ratio and bifurcation ratio indicate the role of relief in the basin while the areal ratios indicate the elongate nature of the basin.

Paul *et al.*(2012) carried out a study in Hebbal valley, located in Bangalore district of Karnataka state. In that study, morphometric analysis and prioritization of nine sub-watersheds of this valley was done using Remote Sensing and GIS techniques. The morphometric parameters considered for analysis were stream order, stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio, relief ratio, length of overland flow and basin shape. The watershed has a dendritic drainage pattern. The bifurcation ratio varied from 1.89 to 3.03 and all sub-watersheds fall under normal basin category. The circularity ratio ranged from 0.42 to 0.78 indicating that all the sub-watersheds except one are more or less circular. Elongation ration of all the water sheds except two was above 0.7 indicating that all the sub-watersheds except them are more or less circular. The compound parameter values were calculated and prioritization rating of nine sub-watersheds in Hebbal valley was carried out. The sub-watershed with lowest compound parameter value is given the highest priority. They observed that the sub-watershed named SWD3 was likely to be subjected to maximum soil erosion and it should be provided with immediate soil conservation measures**.**

Magesh *et al.*(2012) developed an automatic extraction tool through the model builder technique in ArcGIS environment to delineate the basin morphometry. The basic requirements to run this tool are SRTM data, and a pour point shape file. The developed model was able to create necessary data required for morphometric analysis after the processing of the input data. The output from that model creates a number of parameters such as, stream network, aspect, slope, DEM, drainage density, hill shade, and basin boundary in meter square. There is an option in the model to select the minimum upstream area to which a stream should be counted, which help the users to select the range of stream delineation. The slope generated will be in degrees and the drainage density is in Sq.km. They observed that this technique is very useful for those who work in the field of terrain analysis, hydrology, and watershed analysis as it is easy to use with a single click for the generation of a reliable database for morphometric analysis.

John *et al*. (2013) conducted a study in the region around Wadakkancheri which has been a site of micro seismic activity since 1989. Studies, subsequent to 1994 M= 4.3 earthquake, had identified a prominent NW–SE structure overprinting the E–W trending lineaments associated with Palghat–Cauvery shear zone. The right angled turn of Bharathapuzha River at Desamangalam and a waterfall near that structure showed the influence of the structure to the drainage system which is identified as a south dipping reverse fault. The hanging wall side of the fault is characterized by abandoned river courses due to the river shift. The network of paleochannels was identified through SRTM data. Distance elevation profiles were drawn from SRTM data to observe the influence of fault on the drainage system of the area. They observed that Near the coast both paleochannels and the river is flowing approximately at the same elevation. The study indicated a marked correlation between channel morphology and the proximity of the fault in the Bharathapuzha river basin.

Magesh *et al.* (2013) carried out a morphometric analysis of Bharathapuzha river basin using geoprocessing techniques in GIS. This technique was found to be relevant for the extraction of river basin and its drainage networks. The Bharathapuzha drainage basin is sprawled over an area of 5,988.56 ^{2}. The extracted drainage network was classified according to Strahler's system of classification and it revealed that the terrain exhibited dendritic to sub-dendritic drainage pattern. The study area was designated as seventh- order basin and lower order streams mostly dominate the basin with the drainage density value of 1.07 km/ ^{2}. The slope of basin varied from 0° to 70° and the slope variation was observed to be chiefly controlled by the local geology and erosion cycles. The elongation ratio of the basin was found to be 0.57 indicating that the study area is elongated with moderate relief and steep slopes. The drainage texture of the basin was found to be 7.78 which indicated an intermediate texture existing over the region. They observed that remote sensing data (SRTM–DEM) coupled with geoprocessing techniques can be a competent tool in morphometric analysis and the data can be used for basin management and other hydrological studies.

GIS in Landuse

Lin *et al.*(1992) conducted study on evaluation of land use in a selected area in south of Guilin by using GIS. The system included four functions: input, storage, analysis and output. The analysis of land potentialities was made by overlaying the map of land use over the map of slope classification.

Dermet *et al.* (1996) formulated a GIS procedure for automatically calculating the USLE LS factor on topography complex landscapes units. They presented a computer algorithm to calculate the USLE and RUSLE LS factor over a two dimensional landscape. The computer procedure had the obvious advantage that it could be easily linked to GIS software. Predicted spill losses could be calculated using a simple overlay procedure, if data on landuse and soils were available.

Richard *et al.* (1997) made studies on comparison of GIS verses manual techniques for land cover analysis in a riparian restoration research project. The cost involve in calculating land cover areas with a GIS were compared with that incurred in calculating it manually with a planimeter and dot grid. While estimates of land cover areas were similar for two methods, GIS cost were much higher than manual technical cost.

Wu *et al.* (1997) studied about evaluating soil properties of CRP land. Remote sensing and GIS Techniques are used to evaluate the present CRP in terms of its main goal and to give recommendations for the future of the program in Finney country, Kansas. With GIS technology, calculation of erosion index was more efficient and value was more accurate that calculated by hand.

Van *et al.* (1998) calculated the total water requirement for a common area with different crops and soils. The table map calculation features of ILWIS were used to combine different map layers and table attributes.

Van *et al.* (1998) conducted a study on methods of combining multiple maps for empirical modelling in a GIS. Several approaches to annualize multiple maps (Boolean logic models. Binary evidence maps, Index overlay with multi class maps and Fussy logic method) were introduced by means of basic exercises.

Hoober *et al.* (2003) conducted a study using the GIS combined with land evaluation and site assessment (LESA) which enhanced land use planning by delivering a versatile and dynamic model to assist state policy and decision makers, country and local officials, landowners and interested citizens in making wasteland management decisions. Objective of this study was to integrate LESA methods and GIS to assess their use for land use planning in East Park Country, Wyoming. Study results were found to be fairly consistent with a park country land use plan, suggesting the combination of LESA and GIS is a rapid, versatile and up to date approach to assist in land management decisions.

Bathgate *et al.* (2003) studied about a GIS based landscape classification model to enhance soil survey. The objective of the research was to develop a quantitative tool to model landscape elements using GIS and digital elevation model for application in soil survey. The model was tested at a case study site in a quarter section of Massac Country, Illinois. Potential productive capabilities of the model were great and should be extended to heterogeneous landscape through further testing the model for communities that contend with landslide risk.

GIS in Watershed management

Hamlet *et al.* (1992) studied about the state-wide GIS based ranking of watersheds for agricultural pollution prevention. GIS combined with a pollutant generation and transport model can be used to identify and rank critical pollutant source areas on a region basis. This model was used to rank the agricultural pollution potential of 104 watersheds in Pennsylvania. The ranking allowed identification of critical non-point source pollutant contributing watersheds in Pennsylvania and was found useful for targeting further investigations and control programs.

Kwong *et al.* (1992) conducted a study on erosion assessment of large watershed in Taiwan. The objective of that study was to integrate the agricultural Non-point source pollution model and technology of GIS to quantify erosion problems at Bajun river basin and Tswengwen reservoir watershed in Taiwan. They found that the annual sedimentation depth for the Tswengwen reservoir is approximately 5.9 mm, which is not significantly different from the observed rate.

Sidhu *et al.* (1998) prioritized the upper Machukund watershed covering an area of 16111 ha by Remote Sensing and GIS Techniques. Based on secondary and tertiary drainage pattern, watershed areas were subdivided into 8 sub watersheds. By using GIS, land use, land cover and slope maps were combined to generate erosion intensity and composite maps. Watershed was prioritized by following sediment delivery index approach.

Roo *et al.* (1998) conducted a study on modelling runoff and sediment transport in catchments using GIS. They observed that existing erosion models can be loosely coupled to a GIS, such as the ANSWERS model and more models can be fully integrated by embedded coupling, such as the LISEM model.

Tripathi *et al.* (2001) conducted a study using a calibrated Soil and Water Assessment Tool (SWAT). The model was verified for a small watershed (Nagvan) and used for identification and prioritization of critical sub-watersheds to develop an effective management plan. The study revealed that the SWAT model could successfully be used for identifying and prioritizing critical sub-watershed for management purposes.

Fernandez *et al.* (2003) studied about estimating water erosion and sediment yield with GIS and RUSLE. The method was applied to a typical agricultural watershed in the state of Idaho, which is subjected to increasing soil erosion and flooding problems. The spatial pattern of annual soil erosion and sediment yield was obtained by integrating RUSLE and raster GIS. Required GIS data layers included precipitation, soil characteristics, elevation and landuse. Thus it provides a useful and efficient tool for predicting long term erosion impacts of various cropping systems and conservation support practices.

GIS Applications

Noveline *et al.* (1992) conducted a study on wasteland development using GIS techniques. Soil pH, soil texture, soil drainage and permeability conditions, rainfall, altitude , slope, water availability, water quality forms the layers which were analysed for land suitability. Favourable sites for conducting percolation ponds have been selected by adopting GIS techniques to augment the ground water potential. The same methodology can be extended to develop the cultivable wastelands elsewhere.

Joseph *et al.*(1992) conducted a study on the highway route production line using a GIS-based approach for economic road construction and maintenance costs. The generalized, probabilistic analysis methods were based on GIS concepts and they were applied to a test area in Nigeria. GIS concepts allowed the creation of predictive cost models that can support road way planning. This numerical model defined road way cost factors by accessing database from Remote Sensing Image Interpretation.

Srivastava *et al.* (1992) conducted a study on RS and GIS for natural resource study. The effectiveness of this technique increased manifolds when it is integrated with other kinds of data sets. They observed that GIS permits integration of different sets of spatially referenced data of interrelated parameters or periodic data sets about a resource type for its better utilization and management.

Cheryl *et al.*(1996) conducted a study about GIS as a tool for siting farm ponds. GIS technique was developed for identifying potential sites for a farm pond to serve as a permanent livestock watering system amenable to rotational grazing and independent of ephemeral streams. Using water balance calculations for 10 years of simulated climate data, the potential amount of water harvested at each site was determined using water harvesting potential. Using location and negative impacts of a pond at a specific site as criteria, nine sites were ranked as most desirable.

Pascal *et al.*(1997) made a GIS based distributed hydrology model for prediction of forest harvest effects on peak stream flow in the Pacific Northwest. The model, known as Distributed Hydrology Soil Vegetation Model provided a dynamic representation of the spatial distribution of soil moisture, snow cover, and evapotranspiration and runoff prediction, at the scale of digital topographic data.

Zaitchik *et al.* (2003) studied about applying a GIS slope stability model to site specific landslide prevention in Honduras. This model was applied to an agricultural region of Honduras that suffered extensive landslide damage during Hurricane Milth. Zones of predicted instability were subsequently categorized according to local slope gradient and relative wetness (w) based on steady hydrology for Hurricane conditions. They observed that knowledge about, ‘w’ in potentially unstable zones allow for informed stability, management practices, improving the utility of hazard.

CHAPTER III

MATERIALS AND METHODS

3.1 Study area

The Bharathapuzha river basin lies between 10°26’30.16”to 11°12’32.78”North latitudes and 75°54’40.74” to 76°54’29.09” East longitudes and it covers Malappuram, Thrissur and Palakkad districts of Kerala state, India. The study area has a total drainage area of 3844.32 km^2.

3.2 Maps Used

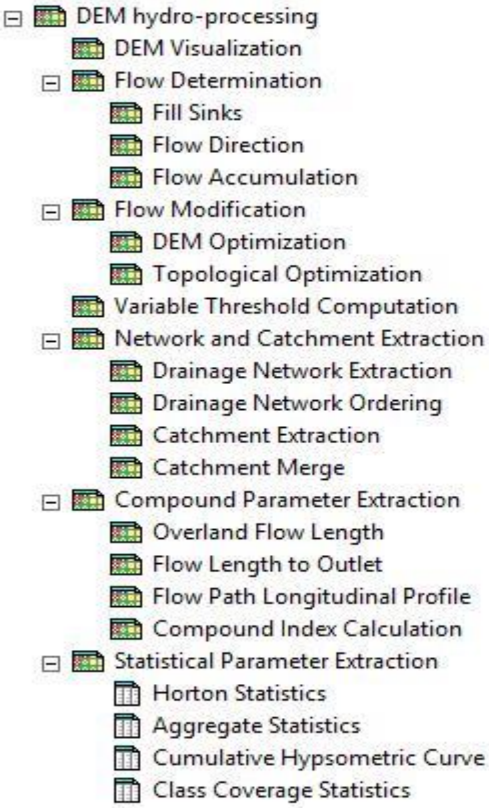
1. Boundary map of Bharathapuzha watershed.
2. DEM of Bharathapuzha watershed generated from Contour map.

3.3 Digital Terrain Analysis Software

ILWIS 3.31 software was used for the analysis.

3.4 DEM- Hydro processing

DEM parameters relevant for hydrological analysis are obtained using the DEM Hydro-processing module in the ILWIS. The tools as given below are available in the Operation-tree of the DEM Hydro-processing module in the ILWIS software.



- DEM hydro-processing
  - DEM Visualization
  - Flow Determination
    - Fill Sinks
    - Flow Direction
    - Flow Accumulation
  - Flow Modification
    - DEM Optimization
    - Topological Optimization
  - Variable Threshold Computation
  - Network and Catchment Extraction
    - Drainage Network Extraction
    - Drainage Network Ordering
    - Catchment Extraction
    - Catchment Merge
  - Compound Parameter Extraction
    - Overland Flow Length
    - Flow Length to Outlet
    - Flow Path Longitudinal Profile
    - Compound Index Calculation
  - Statistical Parameter Extraction
    - Horton Statistics
    - Aggregate Statistics
    - Cumulative Hypsometric Curve
    - Class Coverage Statistics

3.4.1. DEM Visualization

The DEM Visualization script creates a colour composite from a DEM. First, three shadow maps are created by the script, using three different shadow filters. The combination of them in a colour composite gives a very good impression of the relief in your area.

When DEM is displayed with a special elevation representation, and then the output colour composite shadow map is added with transparency, the relief of the study area really stands out very nicely. Drainage network can also be add on top of the other layers.

Dialog box options:

DEM : Select a raster map with height values, i.e. DEM.

Output Map : Type a name for the output colour composite raster map that is a combination of three different shadow maps.

Short explanation of the calculations by the script:

- First three shadow maps are created using the shadow filters Shadow W (West), Shadow (North-West) and Shadow N (North).
- The three shadow maps are stretched using linear stretching, ignoring 5%.
- The three shadow filters that are used are defined as follows:

ShadowW (West)

-2	-1	2
-3	1	4
-2	-1	2

Shadow (North-West)

-3	-2	-1
-2	1	2
-1	2	4

ShadowN (North)

-2	-3	-2
-1	1	-1
2	4	2

- The colour composite that is created from these stretched shadow maps is a 24-bit colour composite with linear stretching.
- Finally, temporary raster maps are removed and the output colour composite is displayed.

3.4.2 Flow determination

3.4.2.1 Fill sinks

Before using the Flow Direction operation, clean-up of Digital Elevation Model (DEM) may be done, so that local depressions (sinks) are removed from DEM.

The Fill sinks operation will 'remove' the following from a DEM:

- depressions that consist of a single pixel, i.e. any pixel with a smaller height value than all of its 8 neighboring pixels,
- Depressions that consist of multiple pixels, i.e. any group of adjacent pixels where the pixels that have smaller height values than all pixels that surround such a depression.

Process:

When a depression of a single pixel is encountered:

- then the height value of this pixel will be increased to the smallest value of its 8 neighbour pixels.

When a depression of multiple pixels is encountered:

- then the height values of this depression will be increased to the smallest value of a pixel that is both adjacent to the outlet for the depression, and that would discharge into the initial depression.

The height values of the following pixels will never be changed in the output map:

- pixels at the border of the map,
- pixels that have the undefined value,
- pixels that are adjacent to pixels with the undefined value.

Output:

The resulting output map of the Fill sinks operation is a so-called sink-free or depression-free DEM. This means that for every pixel in the DEM, a flow direction will be found towards the edges of the map.

In this way, it is ensured that, when using the Flow direction operation on the output DEM of the Fill sinks operation, and a subsequent Flow accumulation operation on the output map of the Flow direction operation:

- outlets will always be found towards the edges of the map,
- Lakes and flat areas will not act as 'consuming' reservoirs of water but will still discharge towards an outlet.

Input map requirements:

The input map should be a value map; the input map is expected to be a DEM.

Domain and georeference of output map:

The output map will use the same domain and the same georeference as the input map.

3.4.2.2 Flow direction

In a (sink-free) Digital Elevation Model (DEM), the Flow direction operation determines into which neighbouring pixel any water in a central pixel will flow naturally.

Flow direction is calculated for every central pixel of input blocks of 3 by 3 pixels, each time comparing the value of the central pixel with the value of its 8 neighbours. The output map contains flow directions as N (to the North), NE (to the North East), etc.

Choice may be taken whether to calculate the flow direction for the central pixels:

- by steepest slope: find the steepest downhill slope of a central pixel to one of its 8 neighbour pixels, or
- by lowest height: simply find the neighbour pixel that has the smallest value of all 8 neighbours, while this value should also be smaller than the value of the central pixel.

When the position of the steepest-slope-neighbour pixel or the lowest-height-neighbour pixel is determined, the flow direction for the central pixel is known.

Input map requirements:

The input map should be a value map; the input map is expected to be a sink-free DEM.

Domain and georeference of output map:

- The output map will use system domain Flow direction.
- The output map will use the same georeference as the input map.

3.4.2.3 Flow accumulation

The Flow accumulation operation performs a cumulative count of the number of pixels that naturally drain into outlets. The operation can be used to find the drainage pattern of a terrain.

- As input the operation uses the output map of the Flow direction operation.

- The output map contains cumulative hydrologic flow values that represent the number of input pixels which contribute any water to any outlets (or sinks if these have not been removed); the outlets of the largest streams, rivers etc. will have the largest values.

Input map requirements:

The input map should be a raster map that is produced by the Flow direction operation, i.e. a raster map using system domain Flow Direction.

Domain and georeference of output map:

- The output raster map will always use system domain Value. The operation sets the value range of the output map from 0 to 9999999, and sets the step size to 1.
- The output raster map uses the same georeference as the input raster map.

3.4.3. Flow Modification

3.4.3.1 DEM optimization

The DEM optimization operation can be used to enhance a Digital Elevation Model (DEM), on which you wish to use the Flow direction operation later on. The DEM optimization operation will 'burn' existing drainage features into your Digital Elevation Model (DEM); a subsequent Flow direction operation will thus better follow the existing drainage pattern.

The DEM optimization operation offers the following possibilities:

- Gradual drop of (drainage) segments in the output DEM, over a certain distance to the (drainage) segments.
- Gradual raise of (watershed-divide) segments on the output DEM, over a certain distance to the (watershed-divide) segments.
- Additional sharp drop or raise of segments on top of the gradual drop or raise.
- Simple drop or raise of polygons in the output DEM.
- The result of using the DEM optimization operation is a 'corrected' DEM in which existing drainage features are more pronounced.

Fig.1 shows the cross sections through the terrain. The dotted line shows the original height value(s) in the input DEM, the blue line shows the position of the drainage. The Buffer distance is shown in pink, the influence of Smooth drop in greenish and the influence of Sharp drop in red.

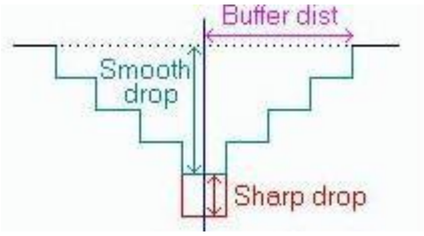


Fig. 1 Cross sections through the terrain

Buffer distance: Buffer distance determines the width at either side of a segment where height values should be adapted.

Smooth drop: Smooth drop determines the height with which segments and their surroundings (as specified by the Buffer distance) should be gradually dropped (positive value) or raised(negative value) in the terrain.

Sharp drop: Sharp drop determines the height with which segments themselves should be dropped (positive value) or raised (negative value) in the terrain.

Input map requirements:

- An input Digital Elevation Model (DEM) is required (value raster map).
- An input 'drainage' map (vector map) is required:
- We can use a segment map (domain type Class or ID) and optionally an attribute table for the segments.
- Segments may represent genuine drainages, for instance when the position of segments should be dropped in the output DEM.
- Segments may also represent watershed-divides, for instance when the position of segments should be raised in the output DEM.
- An attribute table should be used when you wish to apply specific buffer distances, smooth drop and/or sharp drop values for individual segment classes or IDs.
- For the 'drainage' map, you can also use a polygon map (any domain) to drop or raise areas in the output DEM.

Domain and georeference of output map:

- The output map will use system domain Value; the value range for the output map is automatically calculated.
- The output map will use the same georeference as the input map.

3.4.3.2 Topological optimization

When a DEM and/or a flow direction map have undefined values, e.g. when there are lakes in the study area, the Topological Optimization operation can improve the results of a previous Flow direction operation and a Drainage network extraction operation to ensure a proper flow through this lake.

As input, this operation requires:

- an existing output map of the Drainage network extraction operation,
- an existing output map of the Flow direction operation,
- a segment map with one or more segments that connect the inlet(s) of a lake with the outlet(s) of lake (down-flow).

As output, the operation delivers:

- a new continuous drainage network raster map, and
- a new flow direction raster map.

The output of this operation can serve as a new basis for the other hydrologic operations, e.g. to obtain new Strahler or Shreve order numbers, new catchments etc.

Using Topological optimization:

The idea is to create one or more segment maps that will connect drainages through lake areas, so that the drainages that flow into a lake are connected to the drainages that flow out of the lake. The operation works best, when it is used several times; each time with new connecting drainages, and using the output of a first pass as input in a second pass.

1. To start, following is needed:
    - a previous flow direction map containing areas without a flow direction;
    - a previous drainage network extraction map or a drainage network ordering (segment) map, in which not all drainages seem connected.

    To prepare for the first pass:
    - create a segment map containing one or more *main drainage* segments.
    - A segment map can be created in a map window, using the input flow direction map and the initial drainage network ordering segment map as background.

    The output of the first pass is an updated flow direction map, and an updated drainage network extraction map.
2. Then move on to the second pass:
    - create another segment map where you connect loose drainages to the

main drainage line you digitized in the first pass;

- keep in mind to connect drainages in a down-flow direction to the main drainage line;

As input for the second pass, you use:

o the output maps of the first pass ; o the second segment map.

The output of the second pass is again an updated flow direction map, and an updated drainage network extraction map.

3. For a third pass, prepare another segment map.

For the third pass, use the output maps of the second pass and the new segment map.

The output of the third pass is again an updated flow direction map, and an updated drainage network extraction map.

Input map requirements:

- the output map of a previous Drainage network extraction operation,
- the output map of a previous Flow direction operation,
- a segment map with one or more segments that connect *drainages upstream of a lake* with *drainages downstream of a lake*; segments should be (screen-) digitized in a down-flow direction.

Domain and georeference of output maps:

The operation produces:

- an updated drainage network raster map (as if the Drainage network extraction operation was used); this output map uses system domain Bool, and
- an updated flow direction raster map (as if the Flow direction operation was used); this output map uses system domain Flow Direction.

The output maps will use the same georeference as the input maps.

3.4.4 Network and catchment extraction

3.4.4.1 Drainage Network Extraction

The Drainage Network Extraction operation extracts a basic drainage network (Boolean raster map). The output raster map will show the basic drainage as pixels with value True, while other pixels have value False.

As input required is the output raster map of the Flow accumulation operation, this map contains a cumulative drainage count for each pixel.

Subsequently, you can choose to use either:

- a *threshold value,* i.e. a value for the minimum number of pixels that are supposed to drain into a pixel to let this pixel remain as a drainage in the output map; the larger the value chosen, the fewer drainages will remain in the output map;
- a *threshold raster map* that contains variable threshold values. A threshold map can for instance be based on geological units, on height values, or on an internal relief map, etc.
    - when using a threshold map, also the output map of a previous Flow direction operation is required. The program then uses the flow direction

map to automatically fill possible gaps between extracted drainage lines. Depending on the flow accumulation value for a pixel and the threshold value for this pixel, it is decided whether true or false should be assigned to the output pixel.

If the flow accumulation value of a pixel exceeds the threshold value, the output pixel value will be true; else, false is assigned.

For instance, when a stream threshold value of 1000 is used:

- if a pixel in the flow accumulation map has a value > 1000, this pixel will be assigned value True in the output drainage network map;
- else value False will be assigned to the output pixel.

Input map requirements:

- The required input map is a raster map produced by the Flow accumulation operation, i.e. a raster map using system domain Value.
- Optionally, a raster map containing threshold values can be used; this map should thus be a value map.
- When using such a threshold *map*, it is necessary to specify a Flow direction map. This map is used to automatically fill possible gaps between extracted drainage lines. A flow direction map always uses system domain Flow Direction.

Domain and georeference of output map:

The output map will use system domain Bool; the output map will use the same georeference as the input map(s).

3.4.4.2 Drainage network ordering

The Drainage network ordering operation:

- examines all drainage lines in the drainage network map, i.e. an output map from the Drainage network extraction operation,
- finds the nodes where two or more streams meet, and
- assigns a unique ID to each stream in between these nodes, as well as to the streams that only have a single node.

The output of this operation is a raster map, a segment map and an attribute table that all use a newly created ID domain.

The attribute table contains information on each stream, such as:

- Strahler ordering number, Shreve ordering number,
- stream length, calculated along the drainage, and calculated as a straight line between XY-coordinates,
- slope values in degrees and in percentages, calculated along the drainage and calculated as a straight line between XY-coordinates, and elevation,
- sinuosity of the drainage path as a measure of meandering,
- total upstream drainage length, i.e. the total length of the streams that drain into the current one, etc.

The output maps and the attribute table of the Drainage network ordering operation are used as input in many other DEM-hydro processing operations, among others:

- the Catchment extraction operation,
- the Catchment merge operation, and
- the Overland flow length operation.

Principles of Strahler and Shreve network ordering:

In the attribute table, a Strahler column and a Shreve column will be found. These columns contain values that reflect the position of a stream between its adjacent upstream and downstream streams. The ordering systems have a different manner of calculation.

- First, the streams are found that form the upper-most starting points of the drainages in the network. These streams obtain ordering number 1 (both in the Strahler and in the Shreve ordering system), until a node is found that connects the stream with a following stream (down-flow).

- For next streams down-flow, *Strahler ordering numbers* are calculated as follows: When two (or more) streams of equal order join each other, the stream order value is increased by 1.

  For example, when two streams with order number 2 join each other, the next stream will receive order number 3.

- When a higher-order stream joins a lower-order stream, the order number for the next stream does not increase; instead, the largest order number of the streams that contribute to it is assigned.

  For example, when a stream with order number 1 joins a stream with order number 2, the next stream will also be assigned order number 2.

- For next streams down-flow, *Shreve ordering numbers* are calculated as:

  the sum of the Shreve ordering numbers of the streams that directly contributes to this stream. For example, when a stream with order number 1 joins a stream with order number 2, the next stream will be assigned order number 3.

  Below, you will find two pictures explaining the Strahler and Shreve ordering systems.

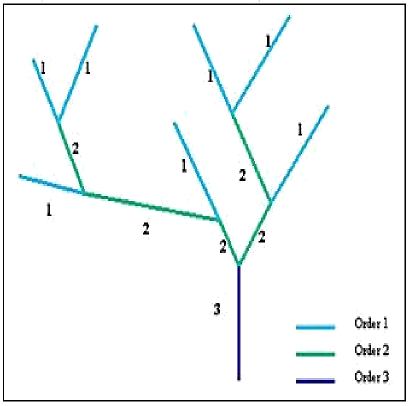


Fig. 2 Strahler network ordering

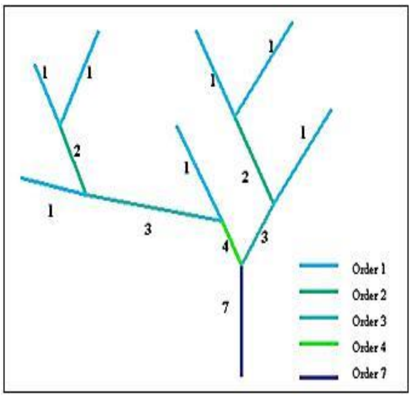


Fig. 3 Shreve network ordering

- **Input map requirements:**
  - A raster map containing height values (DEM);
  - a raster map that is the outcome of a previous Flow direction operation;
  - a raster map that is the outcome of a previous Drainage network extraction operation.

Specify the value called Minimum drainage length (in meters); segments with a length smaller than this value will not remain in the output maps. By choosing a larger value, fewer streams will remain in the drainage network; this will speed up the operation.

Domain of output maps and attribute table:

- An output raster map and an output segment map will be created; these maps will use a newly created ID domain.
- The new ID domain will obtain the same name as the output raster map.
- An output attribute table will be created, using the same ID domain.

- The output raster map and the output segment map are both linked to the output attribute table.

The output attribute table will contain the following columns:

Table 1 Drainage network ordering output attribute table.

Field Name	**Description**	**Domain**
DrainageID	Unique drainage ID number(from 1)	Number
UpstreamLinkID	DrainageID number(s) of upstream link(s). for e.g.(0) indicates no upstream links, this must be source cell link, because source cell does not receive any inflows.(1,2)- indicates two links(with drainage ID1,and 2) downstream into it,etc.	String
UpstreamCoord	X,Y coordinates at the start point of the segment	Coordinate
UpstreamElevation	Elevation at given upstream X,Y coordinate	Value
DownstreamLinkID	A stream ID number corresponding to the downstream link that it down flows to.	Number
DownstreamCoord	X,Y coordinates at the endpoint of the segment	Coordinate
DownstreamElevation	Elevation at given downstream X,Y coordinate	Value
ElevationDifference	Elevation difference between upstream and downstream coordinates	Value
Strahler	Strahler ordering	Number
Shreve	Shreve ordering	Number
Length	Length along the drainage line	Value
StraightLength	Straight line length from the upstream X, Y to downstream X,Y coordinates.	Value
SlopeAlongDrainage%	Average slope of the link computed as Elevation difference/Length in degree	Value
SlopeAlongDrainageDegree	Average slope of the link computed as Elevation difference/Length in degree	Value

SlopeDrainageStraight%	Average slope computed as Elevation difference/Length in percentage	Value
SlopeDrainageStraightDegree	Average slope computed as elevation difference/Straight length in degrees	Value
Sinuosity	Ratio computed as Length/Straight length	Value
TotalUpstreamAlongDrainageLength	Totalupstream channel length from the start node of segment.	Value

3.4.4.3 Catchment extraction

The Catchment extraction operation constructs catchments; a catchment will be calculated for each stream found in the output map of the Drainage network ordering operation. The operation uses a Flow direction map to determine the flow path of each stream.

As input is required:

- the output raster map of the Drainage network ordering operation,
- the output raster map of the Flow direction operation.

As output a raster map, a polygon map and an attribute table are produced which all use the ID domain of the input Drainage network ordering map.

The attribute table contains information on each catchment, such as:

- area and perimeter of the catchment,
- total upstream area, i.e. the area of all catchments that drain into this catchment, etc.

Input map requirements:

- The output raster map of a previous Drainage network ordering operation,
- The output raster map of a previous Flow direction operation.

Domain of output maps and attribute table:

- An output raster map and an output polygon map will be created; these maps will use the ID domain of the input Drainage network ordering map.
- An output attribute table will be created, using the same ID domain.
- The output raster map and the output polygon map are both linked to the output attribute table.

Columns in the Catchment extraction output attribute table:

Table 2 Columns showing Catchment extraction output attribute table.

Field name	**Description**	**Domain**
CatchmentID	Unique IDnumber	Number
Drainade ID	Drainage identifier, the same number with catchmentID , in this case	Number
UpstreamLinkCatchment	Catchment ID number(s) of upstream link catchments.For e.g. .(0) indicates no upstream links, this must be source cell link, because source cell does not receive any inflows.(1,2)- indicates two links(with drainage ID1,and 2) downstream into it,etc	String
DownstreamLinkCatchment	A stream ID number corresponding to the downstream link that it down flows to.	Number
DrainageLength	Length of drainage line	Value
Perimeter	Perimeter of the catchment boundary, always get a value in meter, even to map with LatLon coordinate system	Value
CatchmentArea	Catchment area , alays calculated with unit of square meters even to LatLon coordinate system	Value
TotalUpstream Area	TotalUpstreamArea,excluding the area of itself, unit is square metera as well	Value
TotalDrainagelength	Overall length of the drainage	Value
Drainage Density(m/km^2)	Drainage density in meter per quarekilometre	Value
LongestFlowPathLength	Length of longest flow path, from drainage divide tomthe outlet	Value
LongestDrainageLength	Longest drainage length, from start of a first order drainageline to the outlet	Value
CatchmentCenter	Approach as used in ILWIS point in polygon	Coordinate
DrainageCenter	Center of the catchment according to half the length of the longest flow path segment	Coordinate

3.4.4.4 Catchment merge

The Catchment merge operation is able to merge adjacent catchments, as found by the Catchment extraction operation. In fact, new catchments will be created on the basis of the Drainage network ordering map and its attribute table.

As input is required:

- the output map and table of a previous Drainage network ordering map operation,
- the output map of a previous Flow direction operation,

- the output map of a previous Flow accumulation operation.

It can be merge catchments in two manners:

- by specifying a point map that contains locations of stream outlets within a catchment; all adjacent catchments that drain into such outlets will be merged,
- by simply specifying a Strahler or Shreve ordering value: all adjacent catchments that have this Strahler or Shreve order value (or a lower value) and which drain into a common catchment will be merged.

As output a new catchment raster map, polygon map and attribute table are produced. These all use a new ID domain.

The attribute table contains information on the new catchments, similar to the output attribute table of the Catchment Extraction operation, will also find information on:

- total drainage length, total upstream area,
- drainage density,
- longest flow path length and longest drainage length. Optionally, the following are also obtained:
- a segment map with the longest flow path per catchment and a linked attribute table,
- a segment ordering map and attribute table, that only contain the segment streams within the new catchments; other streams will not appear anymore; output is similar to the segment map and attribute table of the Drainage Network Ordering operation.

The last option is only available when an input point map with outlets is used.

Finally, this operation also has an option to include undefined pixels (from the Flow direction map) into a catchment. Then, a point map that only contains a single point is required.

Other general options for the Catchment merge operation:

- Longest flow path segment map:

Optionally, an additional segment map (and attribute table) containing the longest possible flow path within each new catchment, based on the flow direction and flow accumulation input maps can also obtained. The attribute table will contain information like Length and StraightLength and Sinuosity for each longest flow path. Specify a name for this segment map; the attribute table will obtain the same name.

Extract stream segments and attributes:

Optionally, obtain an additional segment map (and attribute table) that only contains those segment streams that fall within the new catchments; other streams will not appear anymore. The attribute table for this segment map will contain information like the drainage network ordering attribute table.

Compared to the previous drainage network ordering attribute table:

- stream IDs are kept the same,
- records of streams that no longer fall within a new catchment are simply deleted.

This segment map will obtain the same name as the output catchment merge map. The attribute table (and the domain of this segment map and attribute table) will generally obtain the same name, followed by __1.

This option can only be used when we selected the option Use Outlet Locations. Determination of whether an outlet point in a point map is close enough to a stream: When using one or more outlet points: any outlet point should be within a 5x5 pixel window near an existing drainage line, otherwise the outlet point will be ignored. We can check whether a point is close enough to a stream in a map window; and adjust the position of points in the Point editor.

Input map requirements:

- the output map and attribute table of a previous Drainage network ordering operation,
- the output map of a previous Flow direction operation,
- the output map of a previous Flow accumulation operation.

Domain of output maps and attributes tables:

Standard output of the Catchment merges operation:

- an output raster map and an output polygon map will be created containing one or more catchments; the maps will use a newly created ID domain;
- the new ID domain will obtain the same name as the output maps;
- an output attribute table will be created, it also uses this ID domain;
- the output raster map and the output polygon map are both linked to the output attribute table.

When the option Longest Flow Path Segment Map is used:

- an additional segment map is created containing the longest possible flow path within each new catchment, based on the flow direction and flow accumulation input maps;
- an additional attribute table is created containing information like Length, StraightLength, and Sinuosity for these longest flow paths;
- the name of this segment map is specified by the user; the attribute table will obtain the same name;
- the additional segment map and the table use the same domain as the maps and table that are standard output of Catchment merge.

When the option Extract Stream Segments and Attributes is used:

- an additional segment map is created containing only those segment streams that are located within the new catchments; other segments will not appear anymore;
- these segments will keep their 'original' (input) IDs from Drainage network ordering;
- an additional attribute table is created containing the same information as the Drainage network ordering output attribute table;
- as the segments keep their 'original' (input) IDs, there are *no* records in the table for segments that do *not* fall within the new catchments;
- the segment map will use the same name as the standard output of Catchment merge;
- the attribute table will use a similar name as the segment map, generally followed by __1;
- the segment map and the attribute table will use a new ID domain;
- this new ID domain has a similar name as the segment map, generally followed by __1.

Columns in the Catchment merge output attribute table:

Table 3 Catchment merge output attribute table.

Domain	The IDs of the table's domain, every record (ID) represents a new catchment
DrainageID	A column listing the IDs of all streams located within a new catchment
UpstreamLinkCatchment	The ID(s) of the new catchments that directly contribute to this new catchment, e.g. when catchments 1, 2, 3, and 4 flow together into catchment 5, then the UpstreamLinkCatchment column will read for the record with ID 5: {1, 2, 3, 4}
DownstreamLinkCatchment	The ID of the new catchment into which a current new catchment will flow (down-flow), e.g. when catchment 5 flows into catchment 6, then the DownstreamLinkCatchment column will read for the record with ID 5: 6. This column is a value column
Perimeter	The perimeter of each new catchment.
CatchmentArea	The area (m^2) of each new catchment
TotalUpstreamArea	The total area (m^2) of the catchments that directly contribute to a current catchment, i.e. the sum of the areas of the catchments listed in column UpstreamLinkCatchment.
TotalDrainageLength	The sum of the lengths of all drainages in a catchment.
DrainageDensity(m/km^2)	The drainage density within a catchment as TotalDrainageLength / CatchmentArea
LongestFlowPathLength	The length of the longest flow path found in a catchment, from the catchment's outlet to the most distant source on the catchment boundary, according to the Flow direction and Flow accumulation input maps.
LongestDrainageLength	The length of the longest actual stream within this catchment.
CenterDrainage	The XY-coordinate in the middle of a longest flow path. This column is a coordinate column.
CenterCatchment	The XY-coordinate at the center of a catchment. This column is a coordinate column.

3.4.5 Compound Parameter Extraction

3.4.5.1 Overland Flow Length

The Overland Flow Length operation calculates for each pixel the overland distance towards the 'nearest' drainage according to the flow paths available in the Flow Direction map.

As input is required:

- the output raster map of the Drainage network ordering operation and its linked attribute table,
- the output raster map of the Flow direction operation.

The operation produces a raster map that contains the overland down-flow distances towards the drainage into which a pixel will drain according to the flow direction map

Input map requirements:

- the output raster map of a previous Drainage network ordering operation and its linked attribute table,
- the output raster map of a previous Flow direction operation.

Domain and georeference of output map:

The output raster map will always use system domain Value; the precision is

automatically set to 0.001.

The output map uses the same georeference as the input maps

3.5 Morphometric parameters to be calculated from the results

Aspect

The aspect of a terrain is the direction to which it faces. Aspect influences vegetation type, precipitation patterns, snow melt and wind exposure. The compass direction of the aspect was derived from the output raster data value. 0 is true north; a 90°aspect is to the east, and so forth.

Slope

The slope of a terrain refers to the amount of inclination of physical feature, topographic landform to the horizontal surface. Slope analysis is an important parameter in morphometric studies. The slope elements, in turn are controlled by climato-morphogenic processes in areas having rock of varying resistance.

Stream order (u)

Stream ordering is a widely applied method for stream classification in a river basin. Stream ordering is defined as a measure of the position of a stream in the hierarchy of tributaries.

Stream number (Nu)

The stream length is measured from mouth of the river to the drainage divide near the source.

Mean stream length (Lsm)

Mean stream length (Lsm) reveals the characteristic size of components of a drainage network and its contributing surfaces. It has been computed by dividing the total stream length of order ‘u’ by the number of stream segments in the order. It is noted that Lsm of any given order is greater than that of the lower order and less than that of its next higher order in the basin. The Lsm values differ with respect to different basins, as it is directly proportional to the size and topography of the basin. Studies indicated that the Lsm is a characteristic property related to the size of drainage network and its associated surfaces.

Stream length ratio (Rl)

It is the ratio between the lengths of streams in a given order to the total length of streams in the next order. The Rl values are strongly dependent on the topography and the slope.

Bifurcation ratio (Rb)

Bifurcation ratio (Rb) is defined as the ratio of the number of streams of any given order to the number of streams in the next higher order in a drainage basin and it is related to the branching pattern of a drainage network. It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin. Rb shows a small range of variation for different regions or for different environments except those where the powerful geological control dominates. Low Rb value indicates poor structural disturbance and the drainage patterns have not been distorted, whereas the high Rb value indicates high structural complexity and low permeability of the terrain.

Basin length (Lb)

The basin length (Lb) is the longest length of the basin from the headwaters to the point of confluence.

Relief (R)

The relief (R) is defined as the differences in elevation between the highest and the lowest points on the valley floor of a basin. Basin relief is an important factor in understanding the denudational characteristics of the basin and plays a significant role in landforms development, drainage development, surface and sub-surface water flow, permeability and erosional properties of the terrain. The high relief value of basin indicates the gravity of water flow, low infiltration and high runoff conditions.

Relief ratio

The relief ratio has been widely accepted as an effective measure of gradient aspect of the basin, despite uncertainties surrounding definition of its component measurements and may be unduly influence by one isolated peak within the basin. Relief ratio can be defined as the ratio of maximum relief to horizontal distance along the longest dimension of a basin parallel to the main drainage line and it measures the overall steepness of the river basin.

Drainage density (Dd)

Drainage density (Dd) is one of the important indicators of the landform element and provides a numerical measurement of landscape dissection and runoff potential. Dd is defined as the total stream length in a given basin to the total area of the basin. Dd is related to various features of landscape dissection such as valley density, channel head source area, relief, climate and vegetation, soil and rock properties and landscape evolution processes. A low drainage density indicates permeable sub-surface strata and has a characteristic feature of coarse drainage, which generally shows values less than 5.0. It is noted that low drainage density is favored where basin relief is low and vice versa.

Stream frequency (Fs)

Stream frequency (Fs) is defined as the ratio of the total number of stream segments of all the orders in the basin to the total area of the basin. ‘Fs’ is an index of the various stages of landscape evolution. The occurrence of stream segments depends on the nature and structure of rocks, vegetation cover, nature and amount of rainfall and soil permeability.

Drainage texture (T)

Drainage texture (T) is a product of stream frequency and drainage density. The

‘T’ depends on underlying lithology, infiltration capacity and relief aspect of the terrain.

According to Smith’s classification of drainage texture, the texture value below 4 is designated as coarse; 4–10 as intermediate; above 10 as fine and above 15 as ultra-fine texture.

Form factor (Ff)

Form factor (Ff) can defined as the ratio of the basin area and square root of the basin length. Long-narrow basins have larger lengths and hence smaller form factors. Circular basins have intermediate form factors, which are close to one. For a perfectly circular basin, the value of the form factor will be greater than 0.78. Short-wide basins have the largest form factors.

Length of overflow (Lg)

Length of the overland flow (Lg) is the length of water over the ground before it gets concentrated into definite stream channels. ‘Lg’ can be defined as the mean horizontal length of flow path from the divide to the stream in a first-order basin and is a measure of stream spacing and degree of dissection and is approximately one-half the reciprocal of the drainage density. The high Lg value indicates that the rainwater had to travel relatively longer distance before getting concentrated into stream channels. However, low Lg values indicate that the rainwater will enter the stream quickly.

Sinuosity

It refers to the curved shape of the streams.

Table 4 Morphometric parameters of the watershed

S.No.	**Parameters**	**Formulae**
1	Stream order(Nu)	Hierarchical rank
2	Stream length (Lu)	Length of the stream
3	Mean stream length (Lsm)	Lsm=Lu/Nu
4	Stream length ratio	RL=Lu/(Lu-1)
5	Bifurcation ratio (Rb)	Rb=Nu/Nu+1
6	Mean bifurcation ratio Rbm)	Rbm=average of bifurcation ratios of all
7	Drainage density (Dd)	orders
8	Drainage texture (T)	Dd=Lu/A
9	Stream frequency (Fs)	T=Dd×Fs
10	Form factor (Ff)	Fs= Nu/A
11	Length of overland flow	$Ff=A/L^2$
12	(Lg)	Lg=1/D×2
13	Relief(R)	R=H-h
14	Relief ratio	Rr=R/L

CHAPTER IV

RESULTS AND DISCUSSION

The morphometric parameters of Bharathapuzha river basin have been examined and the results are given below. The total drainage area of the Bharathapuzha basin is 3844.320 km2. The drainage pattern is dendritic in nature. Length of the largest stream was found to be 11632.20m and that of smallest was 91.10 m.

The following maps were obtained as results:

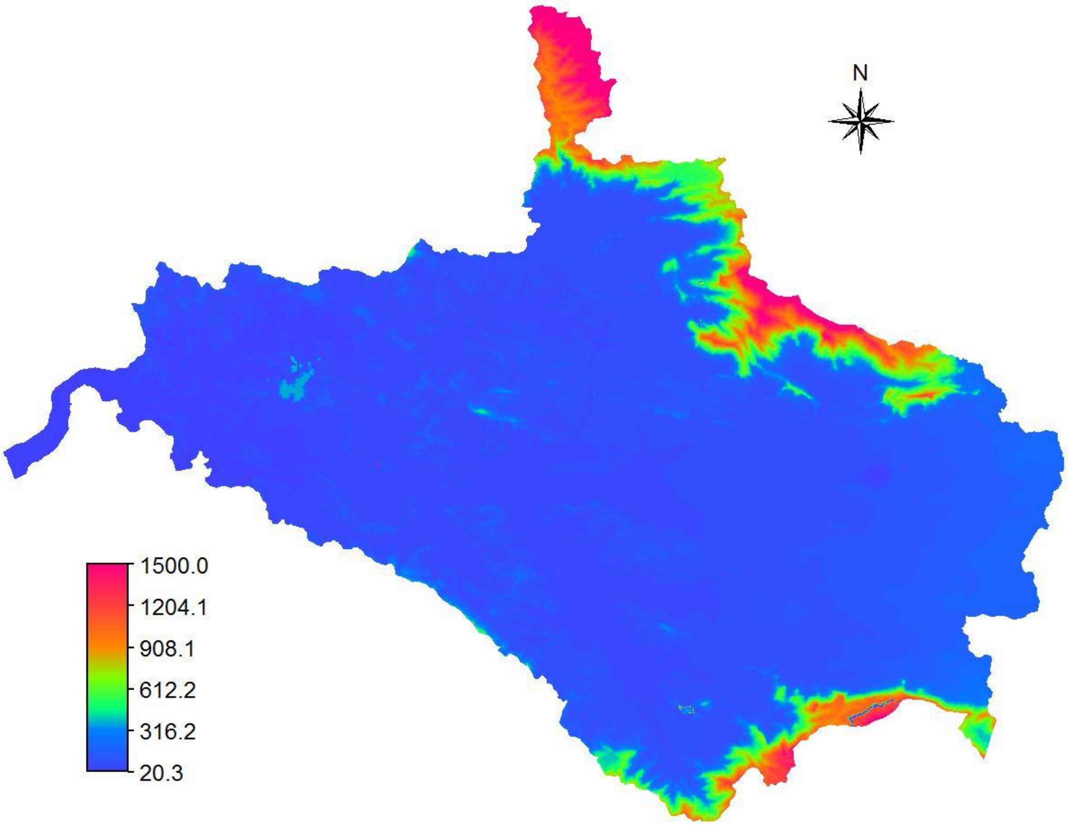


Fig. 4 Digital Elevation Model (DEM)

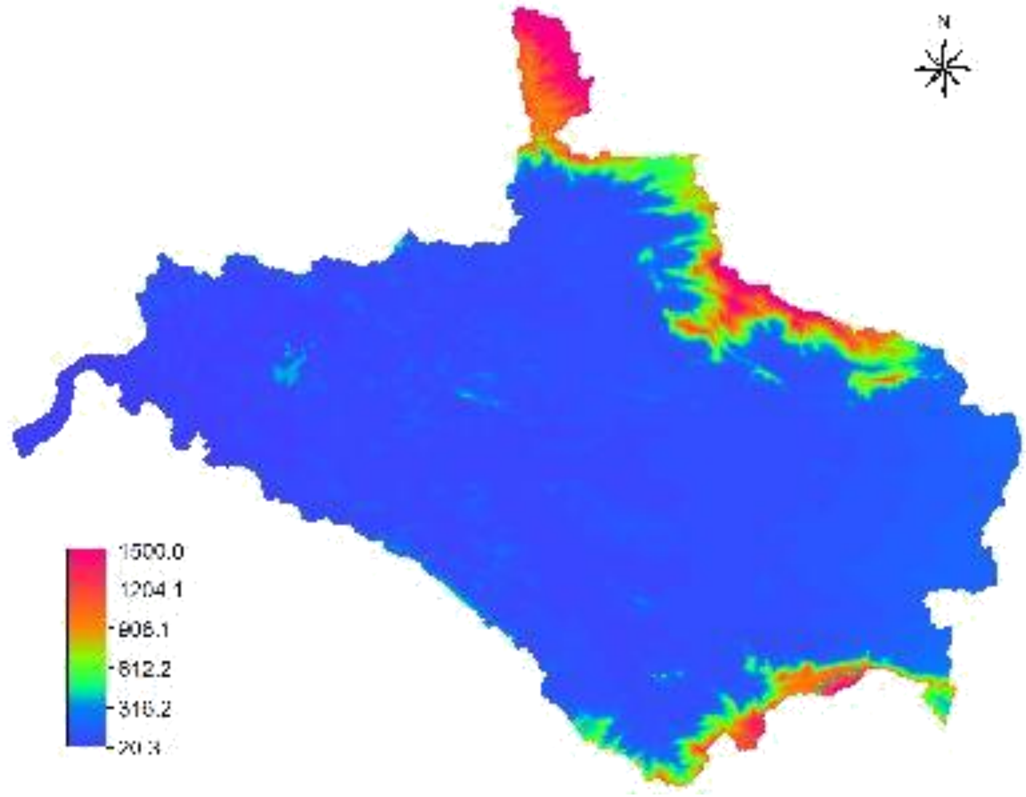


Fig. 5 DEM after Fill sink operation

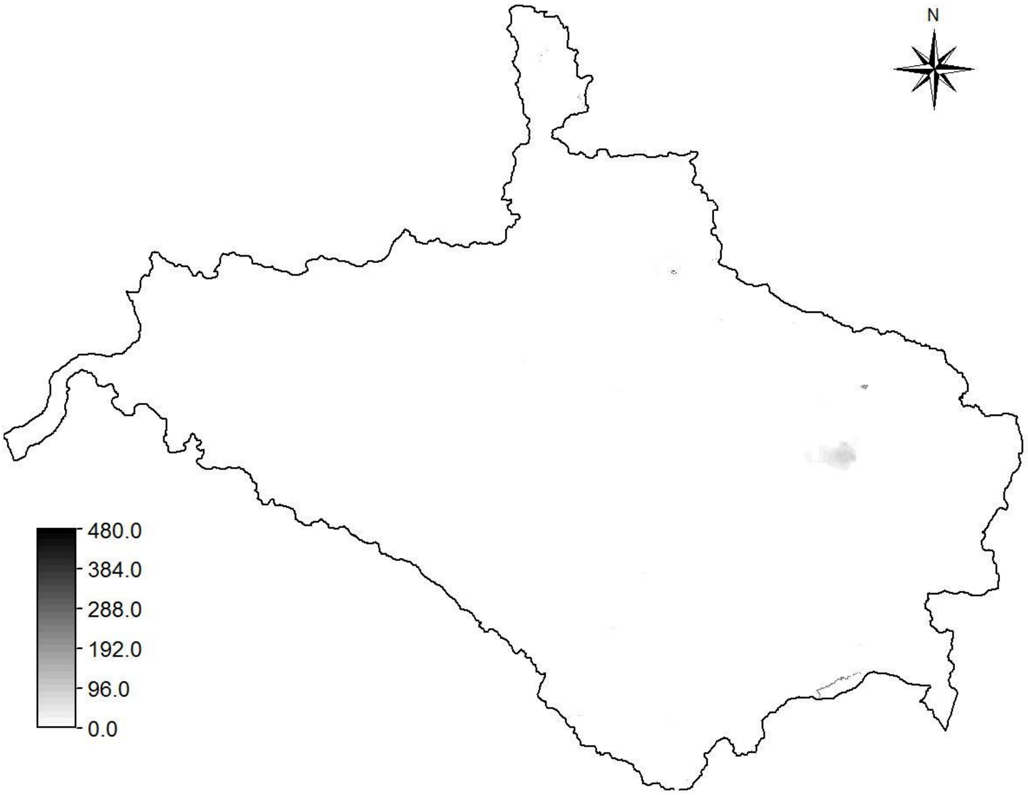


Fig. 6 Difference map of DEM and sink filled DEM

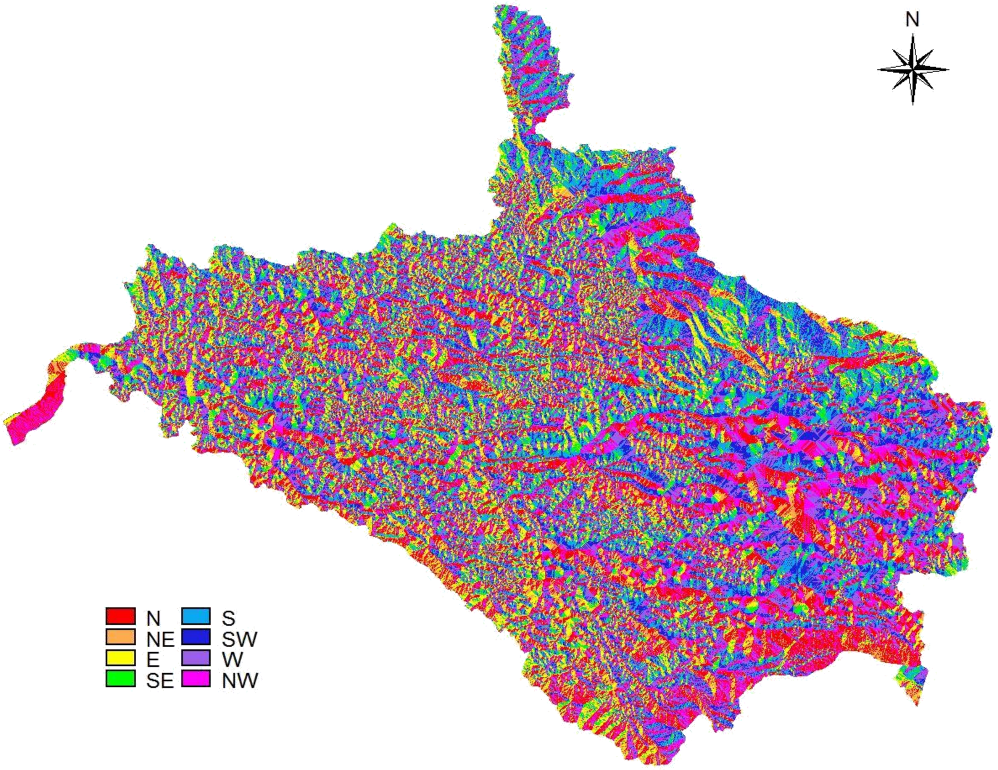


Fig. 7 Flow Direction map

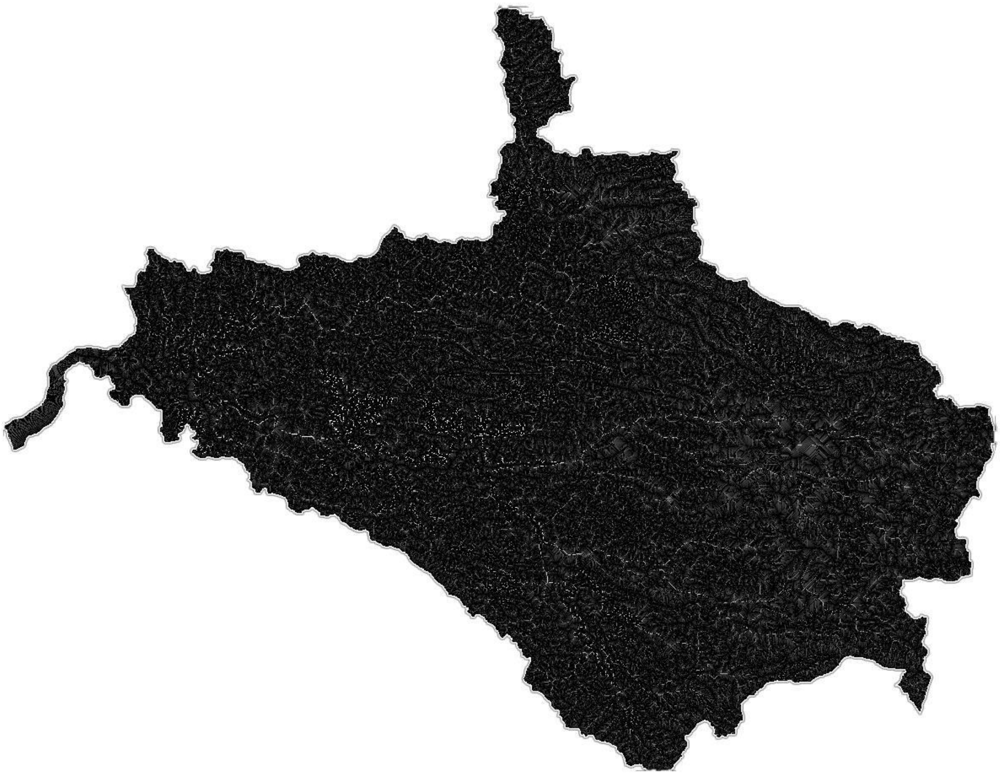


Fig. 8 Flow Accumulation map

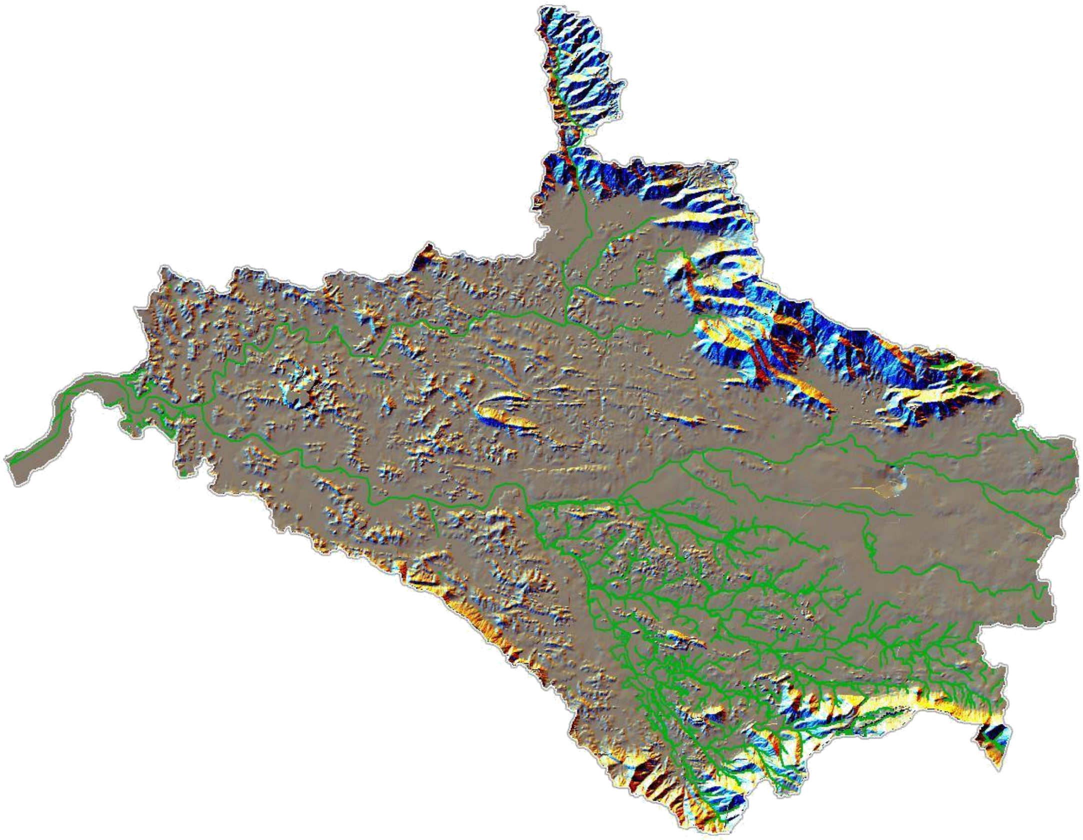


Fig. 9 Raster drainage map

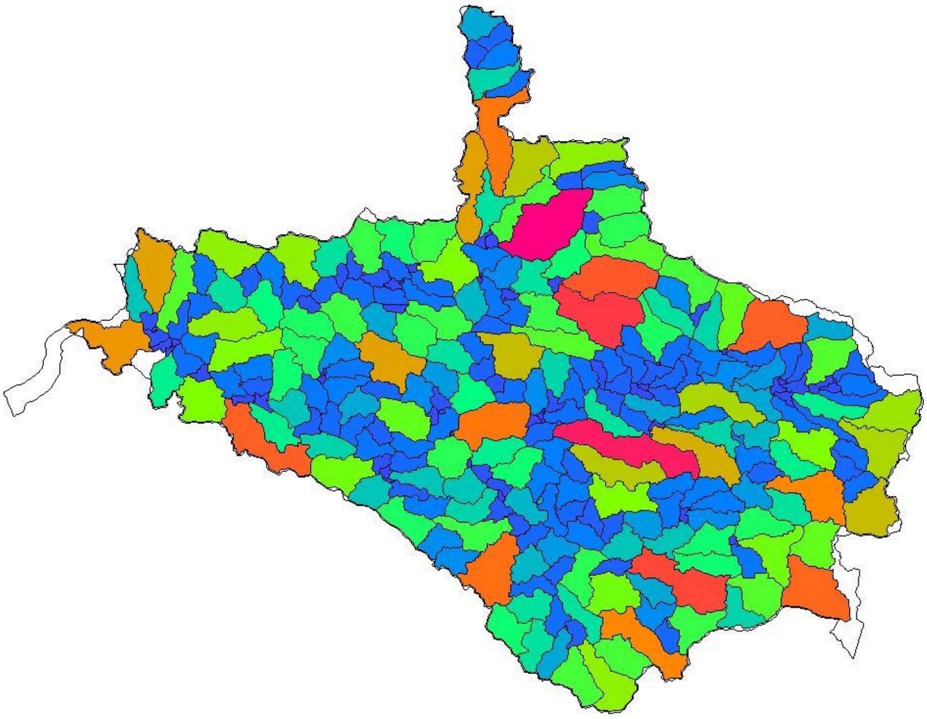


Fig. 10 Extracted Catchments map

Table 5 Catchment extraction output attribute table

DRAINNETORD	DRAINAGEID	PERIMETER	CATCHMENT AREA	LONGEST FLOW
1	1	16434.50	13096342.81	885.70
2	2	13014.30	7338200.00	1025.80
3	3	15078.60	10949876.81	2168.40
4	4	15815.56	8235309.69	2196.60
5	5	28374.16	25734138.63	7236.20
6	6	37890.37	31383507.25	11612.90
7	7	27856.76	28207054.88	6931.40
8	8	16316.99	6940883.19	924.40
9	9	18838.56	11586484.88	2430.70
10	10	20588.79	19894288.13	4859.30
11	11	18486.71	19270750.81	4176.00
12	12	21245.29	17480982.75	5952.00
13	13	20928.83	20143636.50	4207.20
14	14	21721.63	19935218.63	4943.50
15	15	25991.08	25502224.25	5306.40

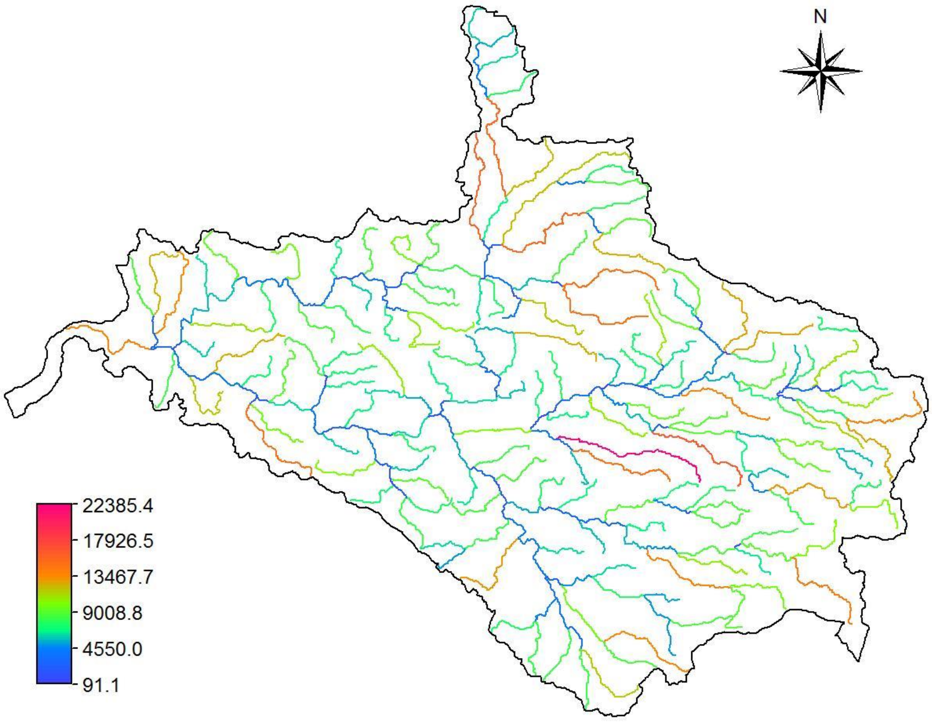


Fig. 11 Longest flow path map

Fig. 12 Extracted Sub-watersheds of the Tributaries

Bharathapuzha River Basin has 5 tributaries namely, Thuthapuzha, Bharathapuzha, Kalpathipuzha, Chitturpuzha and Gayathripuzha, the details of these sub watersheds extracted by DTA are given in the following table:

Table 6 Details of the sub-watersheds of tributaries

Tributaries	**Perimeter**	**Catchment Area**	**Total Drainage Length**	**Drainage Density km/km^2**	**Longest Flowpath Length**	**Longest Drainage Length**
1	109926.3	273029440	101200.2	0.37066	55997.0	51696.2
2	134103.9	473114582	164533.5	0.34777	49567.0	45383.3
3	183270.0	954809370	283482.4	0.29690	73454.4	67921.1
4	242534.8	1000736254	313272.2	0.31304	99158.7	94220.5
5	290620.6	983242275	321288.1	0.32676	100450.6	95726.7

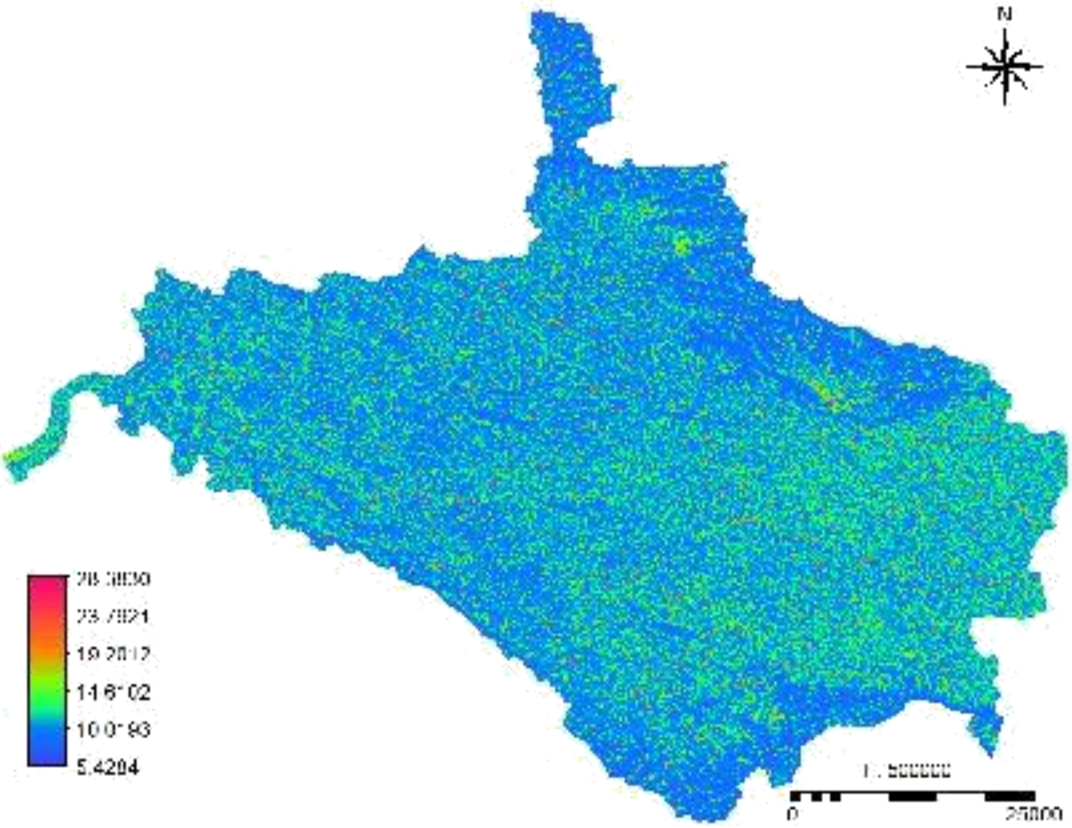


Fig. 13 Wetness index map

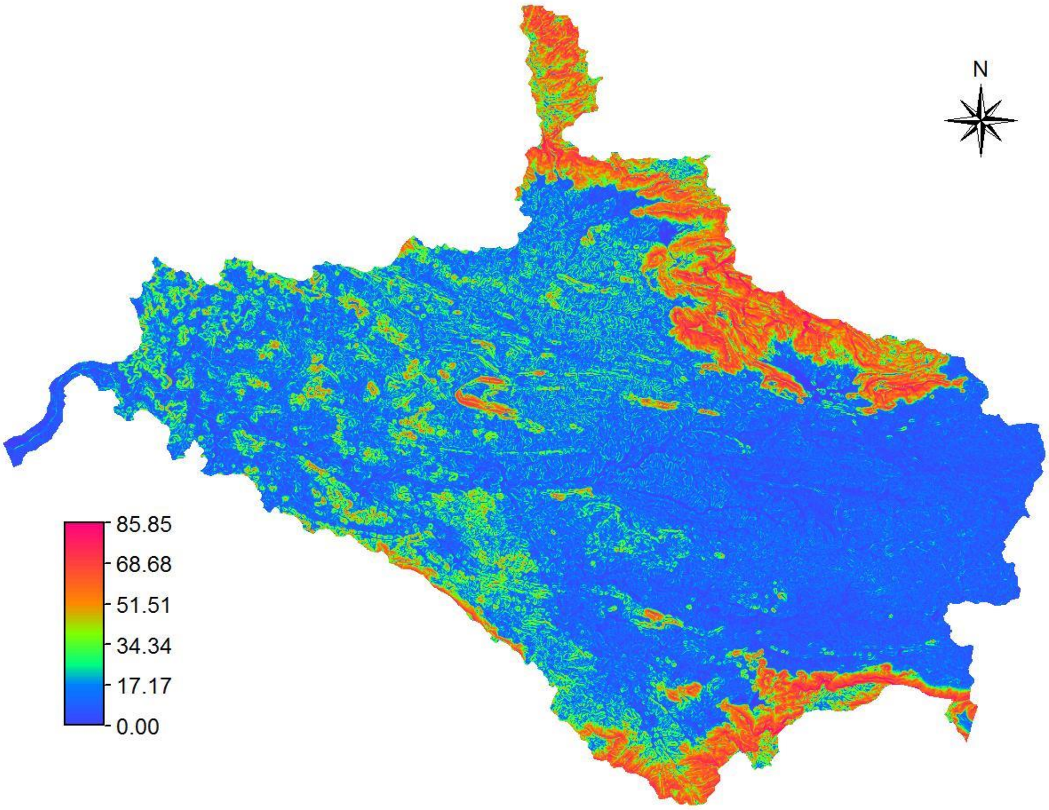


Fig. 14 Slope (degrees) map

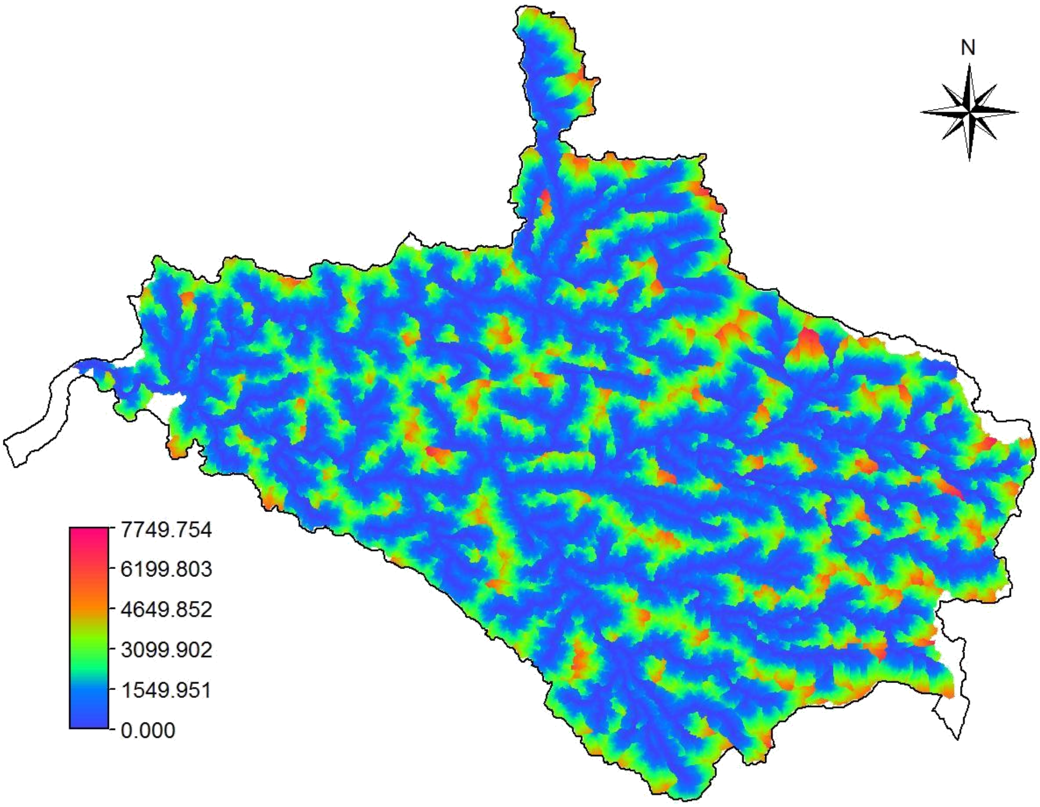


Fig. 15 Overland Flow Length map

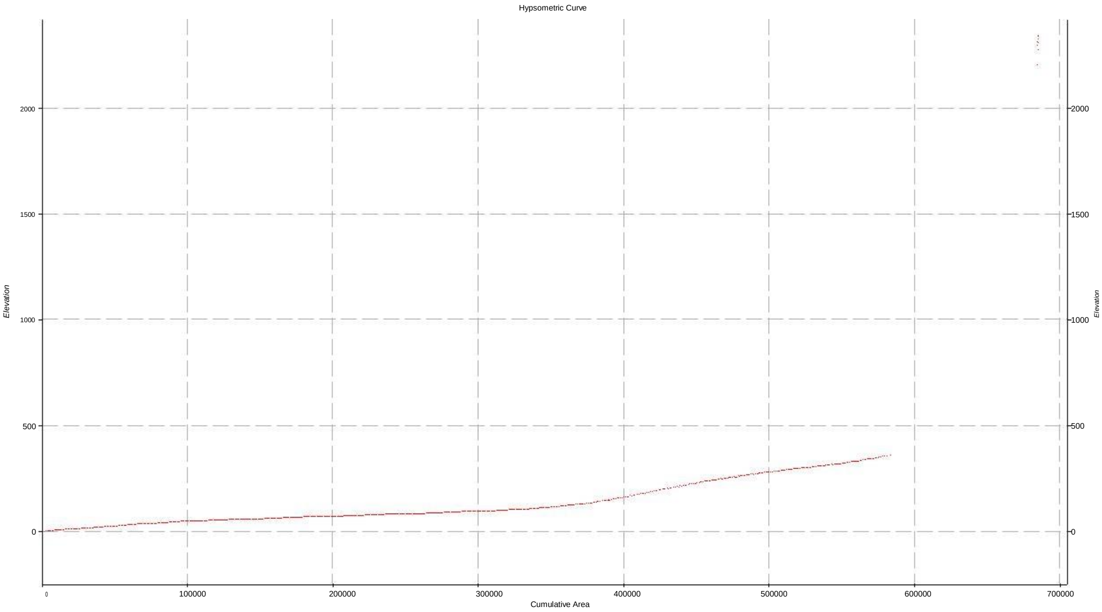


Fig. 16 Hypsometric curve

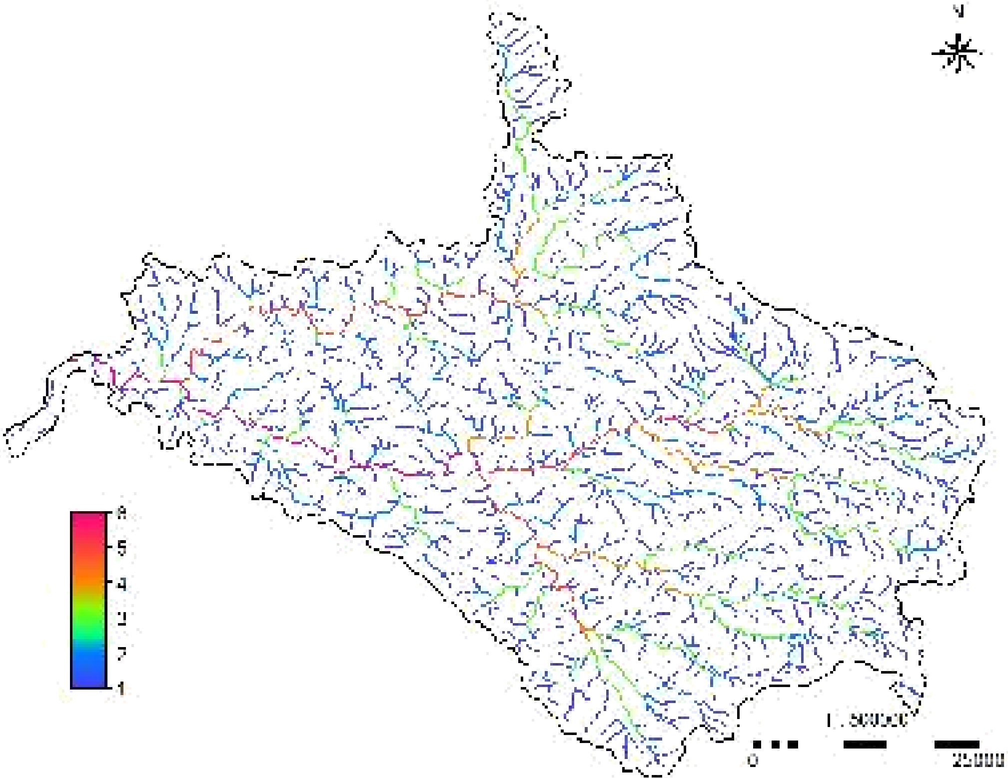


Fig. 17 Stream order map

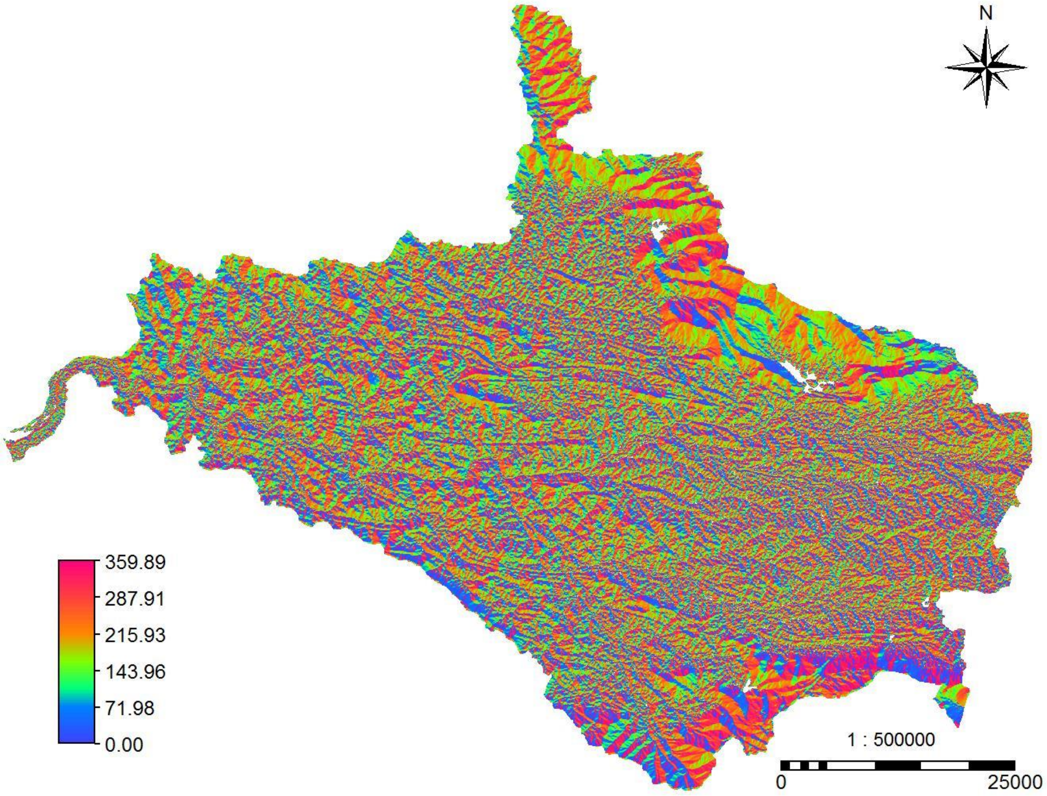


Fig. 18 Aspect Map

Morphometric Parameters obtained are as follows:

Slope

The degree of slope exhibited by Bharathapuzha river basin varies from 0° to 70.59°. Slope map of Bharathapuzha river basin is shown in the Fig. 14 above. The higher slope gradient in the study area is contributed by the hilly Western Ghats. Higher slope gradient results in rapid runoff with potential soil loss.

Aspect

The compass direction of the aspect was derived from the output raster data value. 0° is true value north; a 90° aspect is to the east and so forth. The aspect map of Bharathapuzha river basin is shown in the Fig. 18. The east flowing slopes mainly occur in the study area, which has a higher moisture content and lower evaporation rate and hence has high vegetation index.

Drainage density

A low drainage density indicates permeable sub surface strata and has a characteristics feature of coarse drainage, which generally shows values less than 5. The Dd of study area was obtained as 0.33 km/km^2; which indicates that study area has a weak or permeable subsurface material.

Stream order (u)

Steam order and the total number of stream segments in each order of the basin are shown in table. Based on the Strahler system of ordering, basin has been designated as a sixth order basin. In the study, maximum frequency is observed in the order streams. First order streams are there that do not have any tributary and there channel normally flow during wet weather. More number of first order streams is obtained in hilly regions of study area, where points towards terrain complexity and compact nature of bed rock lithology

The calculated result described that the total number of streams gradually decrease as the stream order increases. More number of stream indicate that the basin still undergoes erosion and the less number of streams indicates a mature topography

Stream number (Nu)

Number of streams of different orders and the total number of streams in the basin are counted independently. Generally the number of streams gradually decreases as the stream order increase; variation in order and size of tributary basin largely depends as physiographic and structural condition of the region.

High values of first order streams indicate that there is a possibility of sudden flash floods after heavy rainfall in the downstream.

Stream length (Lu)

Total length of stream segments is the maximum in first order streams and decreases with an increase in the stream order. The result reveals that the first order streams are short in length and are found in the upstream area. Streams with relatively short length are representations of areas of steep slopes and finer texture whereas longer lengths of streams are generally indicating low gradients.

Mean stream length (Lsm)

The Lsm value of study area ranges from 1.4 to 2.09 km with a mean value of 1.68 km. The Lsm value differ with respect to different basins as it is proportional to the size and topography of the basins

Stream length ratio (Rl)

Rl value of the study area varies between values of 0.89 to 1.2. It shows an important relationship between surface flow discharge and erosional stage of the basin .it strongly depends on topography and slope.

Bifurcation ratio (Rb)

The Rb for the study area ranges from 0.67 to 4.06. And the mean bifurcation ratio is 2.113. The mean Rb characteristically ranges from 3 to 5 for a basin when the influence of geographical structures on the drainage network is negligible. Rb differs for various orders, geological and lithological development of the drainage basin may be the reason for their variations. Low Rb values indicate poor structural disturbances and the drainage pattern have not been distorted. High Rb values indicate high structural complexity and low permeability of the terrain. Thus a low value of 2.113 indicates less structural disturbances in the basin.

Basin length (Lb)

Bharathapuzha originates from Western Ghats at an attitude of about 110m above mean sea level and drains into Arabian Sea. Lb determines shape of the basin. Study area has a Lb of 108.83km which indicates an elongated basin.

Relief(R)

It is important factor in understanding the denudation characteristics of the basin. The maximum value of relief for the study area was 1459.9. This high relief value of the basin indicates the gravity of water flow, low infiltration and high runoff conditions.

Relief ratio(R)

The study area has got a relief ratio of 0.0134. It indicates the extremity of erosion process operating on the slope of the basin.

Stream frequency (Fs)

The stream frequency of the study area is obtained as 0.4364. Fs depends more or less the rainfall and the physiography of the region; which indicates highly permeable surface and dense vegetation.

Drain texture (T)

Drainage texture of the study area was obtained as 0.11404. According to smith’s classification of drainage texture, T value less than 4was designated as coarse. The values 4-10 as intermediate, above 10 as fine and above 15 as relief fine. The T value of 0.114 which is less than 4 indicates coarse texture of the soil.

Form factor (Ff)

The study area was got a form factor of 0.368, which shows that the basin is an elongated one with lower peak flow of longer duration. For a perfectly circular basin, the value of the Ff value will be greater than 0.77. Short and wide basin has the longest form factors.

Sinuosity index (SI)

It refers to curved shape of the streams. For SI<1.05, the streams are almost straight, for SI≥1.05 and SI≤1.25, the streams are almost winding; 1.25≤SI<1.50, the streams are twisty; and basin tend to be meandering when 1.50≤SI. The study area has got an SI of 1.15 in average which indicates that streams are almost winding.

The following table shows values of parameters for various stream orders:

Table 7 Morphometric parameters for various stream orders.

Order	**Nu**	**Avg. Sinousity**	**Lsm**	**Rl**	**Rb**
1	851	1.199294947	2099.709	1.113632	2.138191
2	398	1.146256281	1885.461	1.277628	1.658333
3	240	1.166125	1475.751	0.89157	4.067797
4	59	1.17359322	1655.227	1.12898	0.678161
5	87	1.142954023	1466.126	0.969122	2.023256
6	43	1.122906977	1512.84	-	-

Table 8 Morphometric parameters of Bharathapuzha River Basin

Sl. No.	**Parameters**	**Values**
1.	Stream order(Nu)	1-6
2.	Mean stream length (Lsm)	1.68 km
3.	Stream length ratio(Rl)	0.89 - 1.2
4.	Mean bifurcation ratio (Rbm)	2.113
5.	Drainage density (Dd)	0.331 km/km^2
6.	Drainage texture (T)	0.114
7.	Stream frequency (Fs)	0.4364 streams/km^2
8.	Form factor (Ff)	0.368
9.	Length of overland flow(Lg)	1.51
10.	Relief(R)	1459.9m
11.	Relief ratio(Rr)	0.0134
12.	Basin length	108.83 km
13.	Sinuosity Index(SI)	1.15

CHAPTER V

SUMMARY AND CONCLUSION

The objective this study was terrain analysis of Bharathapuzha watershed to derive various geomorphometric parameters which are of importance in hydrological applications. The DTA (Digital Terrain Analysis) was conducted using different operations especially the DEM hydro-processing tool box of the GIS software ILWIS. The study shows the potential of using Free and Open Source Software (FOSS) like ILWIS for Digital Terrain Analysis, instead of using costly commercial GIS software.

The Digital Terrain Analysis of Bharathapuzha watershed resulted in the creation of slope map, aspect map, drainage density map, stream order map, longest flow length map, sub-catchments map, sub-watersheds of tributaries map etc. The morphometric parameters of Bharathapuzha river basin like Stream order (Nu), Mean stream length (Lsm), Stream length ratio (Rl), Mean bifurcation ratio (Rbm), Drainage density (Dd), Drainage texture (T), Stream frequency (Fs), Form factor (Ff), Length of overland flow (Lg), Relief (R), Relief ratio (Rr), Basin length, Sinuosity Index (SI) have been found. The total drainage area of the Bharathapuzha basin under consideration is 3844.32 km^2. The drainage pattern is dendritic in nature. Length of the largest stream was found to be 11632.20 m and that of smallest was 91.10 m. Bharathapuzha basin is an elongated basin with moderate relief and steep slope. The study area is well drained in nature with the stream order varying from 1 to 6. The basin is dominated by lower order streams and the total length of the stream is maximum is first order streams. The Dd appears significantly lower in Bhathapuzha river basin, which is an indicator of existence of impermeable rocks and moderate relief. The quantitative analysis of linear and relief parameters using GIS is found to be of immense utility in linear basin evolution, basin prioritization for soil and water conservation and natural resource management.

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APPENDIX

Details of the extracted catchments:

DrainNetOrd	DrainageID	Perimeter	Catchment Area	Longest flow
1	1	16434.50	13096342.81	885.70
2	2	13014.30	7338200.00	1025.80
3	3	15078.60	10949876.81	2168.40
4	4	15815.56	8235309.69	2196.60
5	5	28374.16	25734138.63	7236.20
6	6	37890.37	31383507.25	11612.90
7	7	27856.76	28207054.88	6931.40
8	8	16316.99	6940883.19	924.40
9	9	18838.56	11586484.88	2430.70
10	10	20588.79	19894288.13	4859.30
11	11	18486.71	19270750.81	4176.00
12	12	21245.29	17480982.75	5952.00
13	13	20928.83	20143636.50	4207.20
14	14	21721.63	19935218.63	4943.50
15	15	25991.08	25502224.25	5306.40
16	16	25740.27	26276232.00	4356.90
17	17	28270.57	31207900.13	8376.60
18	18	21773.67	17778146.50	3744.70
19	19	28761.11	21906668.75	9129.30
20	20	17976.40	15104715.88	2618.50
21	21	32302.05	40440803.25	10650.40
22	22	31581.86	22450304.25	9519.50
23	23	23953.28	21496419.25	5893.80
24	24	15727.85	10195304.69	2511.70
25	25	13894.29	9231278.50	887.10
26	26	16645.47	8890978.88	2594.10
27	27	21664.24	14369716.50	4010.10
28	28	16280.82	9303941.13	2520.40
29	29	19786.08	10018752.88	2795.40
30	30	16647.77	13657405.38	3231.80
31	31	14842.15	8111844.88	979.30
32	32	15040.46	11612106.94	1658.80
33	33	19222.32	16411158.75	3878.70
34	34	23934.13	22795365.50	7983.70
35	35	16760.19	13065194.63	1878.40
36	36	21041.86	20553344.88	4890.40
37	37	36957.15	46176960.63	11632.20
38	38	25546.06	20134280.88	6176.50
39	39	19802.38	15420541.63	3767.50
40	40	26844.05	25714983.50	7186.40

41	41	21544.75	18597968.50	4001.30
42	42	24396.84	19895323.38	6133.60
43	43	18371.29	12847201.81	3013.20
44	44	12380.33	7140048.81	1103.60
45	45	31024.06	38962269.00	9927.00
46	46	24798.35	18405333.00	4136.00
47	47	19665.95	19758803.13	4636.00
48	48	30317.27	25133478.63	9505.50
49	49	29122.61	22411401.63	8477.50
50	50	16117.55	10516064.25	2102.10
51	51	22483.86	18063273.25	4354.70
52	52	16954.18	11682792.81	4428.60
53	53	30953.38	31792354.38	6817.80
54	54	15799.63	9076554.50	3090.40
55	55	23524.51	22360174.00	6525.90
56	56	18430.24	15378805.25	3950.10
57	57	14720.95	8804706.31	1109.00
58	58	14863.93	8666257.00	1701.30
59	59	16750.76	8956191.88	2419.00
60	60	17685.31	7878209.13	2933.90
61	61	16809.29	10042319.38	2575.20
62	62	20099.97	16144599.13	3214.60
63	63	21509.56	17316066.75	4946.20
64	64	17754.21	14705519.63	3930.60
65	65	15022.57	8763219.13	1588.00
66	66	13493.11	7187065.19	1146.40
67	67	17714.48	10941109.38	1883.60
68	68	14346.62	7546314.06	1364.10
69	69	14217.18	6718908.38	1012.60
70	70	20027.28	12463874.88	4965.10
71	71	16194.11	12426257.56	2805.40
72	72	14855.67	10012442.69	2156.00
73	73	15834.65	7309344.69	1430.90
74	74	16817.85	10847315.38	1872.40
75	75	13803.28	7716062.88	951.90
76	76	12994.90	8097295.63	1612.20
77	77	15348.10	11788384.06	2529.10
78	78	20256.57	9166492.13	3609.20
79	79	18373.59	13006063.63	3068.70
80	80	20665.10	12841318.50	3393.50
81	81	31398.48	28112138.38	9400.80
82	82	18622.12	9653307.13	3075.80
83	83	23902.43	24916441.00	6889.10
84	84	16948.26	9074584.63	2957.30
85	85	28657.81	27180613.38	8588.00

86	86	23717.18	8456316.88	3509.20
87	87	23998.66	15670960.13	5377.80
88	88	20589.11	10821186.88	3980.10
89	89	22899.16	16256484.00	5408.20
90	90	19952.12	14964612.00	1220.40
91	91	16027.11	9563976.88	2942.20
92	92	14097.05	8488704.94	1286.30
93	93	29025.75	27528335.88	8248.30
94	94	14031.40	7803247.00	757.60
95	95	48611.61	50411408.81	17661.40
96	96	19785.60	15984762.13	3455.80
97	97	14883.97	7782219.38	1902.10
98	98	36157.52	30472032.50	11746.60
99	99	42654.98	39092417.00	11160.30
100	100	21581.87	15734290.75	4608.40
101	101	21873.40	17279713.25	5443.10
102	102	14711.95	7923888.63	1181.00
103	103	24037.84	24108563.88	6858.20
104	104	34008.28	28937913.38	10242.90
105	105	12610.97	7321249.38	830.50
106	106	21463.80	14015764.50	5121.20
107	107	18349.69	10648083.25	3177.50
108	108	17546.25	14182105.13	2511.00
109	109	16813.24	10698772.25	2888.90
110	110	16348.48	14393469.50	2271.90
111	111	14988.76	8675587.75	1954.90
112	112	18420.11	11140103.50	3505.70
113	113	19190.11	11128575.31	2135.30
114	114	26655.54	29544210.63	5637.20
115	115	18738.02	11249851.38	3585.90
116	116	19532.61	15622301.69	4071.90
117	117	17965.69	11019911.63	3276.90
118	118	20598.72	14608574.88	4407.20
119	119	19201.72	11605550.50	2678.40
120	120	22522.88	18870291.63	5133.50
121	121	16222.61	12372676.44	2132.40
122	122	15063.22	10864510.75	2135.40
123	123	22247.35	18142511.25	3071.50
124	124	17256.11	11925849.25	2977.40
125	125	23760.25	22864343.75	4963.00
126	126	17732.76	12218215.50	830.70
127	127	15206.64	9751690.75	1493.20
128	128	17245.05	11532584.06	870.10
129	129	25382.71	17552379.50	6297.50
130	130	14493.66	6671129.75	845.00

131	131	23207.17	22632867.63	5760.70
132	132	32347.80	36662829.88	8598.40
133	133	30938.28	38465385.38	9145.90
134	134	19623.48	12935574.56	936.20
135	135	21209.52	14653724.13	3778.80
136	136	22004.72	17831605.75	3733.80
137	137	24600.91	20293785.00	2885.80
138	138	12602.57	7389527.06	1126.40
139	139	20310.98	15616061.88	3585.20
140	140	18233.38	12727221.00	4559.80
141	141	37860.99	33809748.75	9341.80
142	142	22325.63	20853035.00	3595.80
143	143	22014.99	21597731.75	3712.80
144	144	28206.50	26137833.75	7886.30
145	145	10368.25	5989871.00	4280.50
146	146	11300.48	5937008.69	4130.40
147	147	9912.84	4871622.81	3413.20
148	148	8524.69	3462348.13	2360.90
149	149	7189.27	2045855.19	1637.10
150	150	9758.01	3171460.81	2162.10
151	151	7758.46	2137264.88	1787.30
152	152	18410.47	14598132.19	4210.50
153	153	7839.62	2436554.56	2990.80
154	154	3281.67	382180.77	767.50
155	155	3589.44	429460.19	441.50
156	156	11657.66	6570990.44	3245.50
157	157	8173.36	2077059.22	2573.20
158	158	3273.50	575432.88	740.30
159	159	9744.73	2836243.25	1744.90
160	160	24288.48	16218565.25	7354.30
161	161	9797.27	2581203.88	1459.40
162	162	29186.58	24848776.88	9910.30
163	163	19642.44	13495714.00	5819.40
164	164	34438.26	33214960.63	13148.60
165	165	6539.75	1578974.28	1051.40
166	166	15004.32	6626308.00	2311.40
167	167	27684.88	20754777.75	8268.20
168	168	42083.81	43391394.75	13851.00
169	169	21871.89	11992934.88	4928.80
170	170	23288.32	15221335.00	9791.40
171	171	20210.28	14914659.38	4043.70
172	172	35148.34	21677542.25	12034.80
173	173	37731.94	55441843.25	15567.10
174	174	22629.85	15351497.88	5822.30
175	175	12108.53	3953891.56	2475.00

176	176	599.04	15749.17	91.10
177	177	27415.25	29153128.00	6732.00
178	178	17130.40	11711730.56	5216.60
179	179	4001.76	751836.28	1310.60
180	180	15459.56	10071535.56	3637.90
181	181	8890.98	2312359.19	2197.50
182	182	18431.29	10719566.56	2506.70
183	183	3831.49	524159.75	665.50
184	184	19256.99	12630839.63	4347.40
185	185	30407.44	24198340.25	8953.20
186	186	24505.16	23794028.75	7671.70
187	187	12077.58	5700489.44	3714.00
188	188	20549.80	11199000.25	4837.60
189	189	6411.12	2221870.97	1835.40
190	190	41822.66	36126162.25	15443.80
191	191	26425.22	15575191.50	6885.40
192	192	13087.81	7303057.44	3059.40
193	193	1583.25	139649.05	388.90
194	194	11315.86	4101597.56	3728.60
195	195	14451.33	7762380.00	3862.80
196	196	22285.26	11094650.38	6948.30
197	197	16804.46	9955853.88	4416.50
198	198	4514.45	940324.25	1067.70
199	199	23522.28	17562559.88	8592.80
200	200	24648.51	18983106.50	4839.70
201	201	19201.71	15225133.25	4658.10
202	202	17894.46	11569279.75	4042.50
203	203	8042.10	2039252.19	1846.20
204	204	29695.32	15001806.88	8906.30
205	205	13204.28	6822496.19	2394.00
206	206	941.81	48304.90	259.30
207	207	8350.41	1888109.16	1826.70
208	208	14991.77	5850742.63	4515.60
209	209	21886.45	13021601.25	7044.50
210	210	6038.21	1104830.66	2468.10
211	211	14637.29	7578225.94	5886.30
212	212	5419.11	1517815.28	1753.30
213	213	30618.84	25161233.88	8845.00
214	214	21592.93	14344373.88	4678.20
215	215	16427.35	8566052.25	4249.50
216	216	18368.35	13882338.13	5453.00
217	217	17641.20	11012326.50	3303.80
218	218	18647.61	8844659.38	3218.30
219	219	18224.89	13610114.25	4272.70
220	220	1104.20	67175.82	365.50

221	221	21852.08	11830674.75	5555.50
222	222	12598.74	6733420.56	4484.40
223	223	9294.25	3603776.38	2453.10
224	224	13319.49	6575637.06	3236.50
225	225	15337.86	7219900.63	3823.00
226	226	8479.84	3762384.25	2938.10
227	227	16191.48	6995272.56	3833.00
228	228	1693.76	132257.52	388.80
229	229	14291.60	6726709.50	3404.60
230	230	2451.49	350593.41	311.80
231	231	28687.41	24887802.00	8405.30
232	232	20096.43	16510835.00	6205.70
233	233	12245.59	6148400.50	3819.80
234	234	17168.43	10137492.13	4173.00
235	235	13911.96	6890464.06	3260.70
236	236	4604.05	1052785.00	1548.10
237	237	13377.87	7544767.88	2244.90
238	238	9644.62	3947434.94	2503.60
239	239	20859.68	10470648.63	2558.70
240	240	11173.12	5119489.44	4093.40
241	241	12984.24	5395539.25	2567.80
242	242	8752.63	2068956.25	2053.00
243	243	4204.70	824311.13	1598.00
244	244	20741.80	13639872.00	5204.60
245	245	11454.20	5001704.06	3642.90
246	246	8665.45	2891969.06	806.10
247	247	3883.19	747940.92	1682.40
248	248	11933.78	4470393.75	2038.90
249	249	7853.80	3131142.63	1832.30
250	250	12038.63	6236336.88	3315.30
251	251	9382.29	3709109.31	1682.40
252	252	12438.26	7348022.19	3937.30
253	253	8542.62	3900951.53	3013.00
254	254	14740.95	7791106.88	3399.40
255	255	10902.60	3850442.19	1103.80
256	256	8549.10	3711036.69	3238.20
257	257	15276.47	8573481.44	2103.30
258	258	16522.02	10647676.00	4086.40
259	259	12529.91	6692769.63	4045.80
260	260	16550.06	8281004.88	3560.50
261	261	3228.30	504172.91	571.20
262	262	18332.32	15568539.25	5683.50
263	263	10437.11	3323684.44	2767.80
264	264	5382.31	757183.75	1103.90
265	265	20314.18	19546754.99	5284.10

266	266	15772.69	8234453.13	5465.50
267	267	5925.56	1614160.25	1794.70
268	268	29382.50	35650491.13	10169.20
269	269	16530.18	9438333.19	3140.70
270	270	14155.49	7147301.38	3874.90
271	271	4337.72	768536.52	1531.00
272	272	8975.11	2336659.13	1703.40
273	273	22216.03	22791333.88	6330.00
274	274	12263.10	6184888.56	3560.90
275	275	15439.22	8443837.13	3119.30
276	276	13505.97	7637059.75	2769.90
277	277	14369.10	6360116.19	4170.70
278	278	17869.77	14143487.63	6175.50
279	279	9549.27	2754499.56	1874.50
280	280	11958.58	6054741.13	2444.60
281	281	16835.77	9502015.25	4661.20
282	282	8635.25	3035638.38	2922.40
283	283	13877.66	8653984.56	3935.50
284	284	4224.43	711862.72	388.80
285	285	8594.05	2225843.06	2743.90
286	286	34886.06	32441129.25	14092.20

TERRAIN ANALYSIS BY GIS FOR HYDROLOGICAL APPLICATIONS

By

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Abstract of the project report

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in
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ABSTRACT

The terrain of Bharathapuzha watershed has been analysed using (DTA) to derive various geomorphometric parameters which are of importance in hydrological applications. The DTA was conducted using different operations especially the DEM hydro-processing tool box of the Free and Open Source Software (FOSS) GIS software ILWIS. The Bharathapuzha river basin taken for the study was of an area of 3844.32 km2. The Digital Terrain Analysis of Bharathapuzha watershed resulted in the creation of slope map, aspect map, drainage density map, stream order map, longest flow length map, sub-catchments map, sub-watersheds of tributaries map etc. The morphometric parameters of Bharathapuzha river basin like Stream order (Nu), Mean stream length (Lsm), Stream length ratio (Rl), Mean bifurcation ratio (Rbm), Drainage density (Dd), Drainage texture (T), Stream frequency (Fs), Form factor (Ff), Length of overland flow (Lg), Relief (R), Relief ratio (Rr), Basin length, Sinuosity Index (SI) have been found. The slope of the basin varied from 0 to 70. The basin was found to be of elongated nature with moderate relief and slopes. The extracted drainage network was classified according to Strahler system of classification and it reveals that the terrain exhibits dendritic drainage pattern. The study area is well drained in nature with the stream order varying from 1 to 6. The basin is dominated by lower order streams and the total length of the stream is maximum is first order streams. The quantitative analysis of linear and relief parameters using GIS is found to be of immense utility in linear basin evolution, basin prioritization for soil and water conservation and natural resource management.