INFLUENCE OF GEOMORPHOLOGY ON RUNOFF CHARACTERISTICS OF A CATCHMENT

By

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(2016-18-012)

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR – 679573

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THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR – 679573

KERALA, INDIA

2018

DECLARATION

I, hereby declare that this thesis entitled **"Influence of Geomorphology on Runoff Characteristics of A Catchment"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur

Date**:**

CHETHAN B J

(2016-18-012)

CERTIFICATE

Certified that this thesis entitled **“Influence of Geomorphology on Runoff Characteristics of A Catchment”** is a bonafide record of research work done independently by Mr. Chethan B J under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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EXTERNAL EXAMINER

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Chethan B J

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LIST OF SYMBOLS AND ABBREVATIONS

%	Percentage
°	Degree
/	Per
^{1}	Minute
3D	3-Dimensional
ARC GIS	Aeronautical Reconnaissance Coverage-Geographic Information System
ASTER DEM	Advanced Space borne Thermal Emission And Reflection Radiometer DEM
DEM	Digital Elevation Model
ERDAS	Earth Resources Data Analysis System
et al.	And others
etc.	Et cetera
Fig.	Figure
GB	Giga Byte
GIS	Geographic Information System
GIUH	Geomorphological Instantaneous Unit Hydrograph
GTM	GIS-Based Topographic Maps
ha	Hectare
ILWIS	Integrated Land And Water Information System
IRS LISS	Indian Remote Sensing Linear Imaging Self Scanning Sensor
ISRO	Indian Space Research Organization
km	Kilometre
km^2	Square Kilometre
LANDSAT	Land Satellite
LANDSAT ETM	Landsat Enhanced Thematic Mapper
m	Meter
m^2	Square Meter
m^3	Cubic Meter
NRSC	National Remote Sensing Centre
PCA	Principal Component Analysis
PLSR	Partial Least Squares Regression
WGS	World Geodetic Survey
SCS-CN	Soil Conservation Service Curve Number
RAM	Random Access Memory
RS	Remote Sensing
R^2	Coefficient Of Determination
SOI	Survey Of India

SPSS	Statistical Package For The Social Sciences
SRTM	Shuttle Radar Topography Mission

CHAPTER I

INTRODUCTION

India is vast country with abundant natural resources. Land and water are the two most important natural resources. Due to the interaction between land and water, its characteristics will change spatially and temporally. The effect can be viewed in two different axes, for land and water characteristics respectively. This effect leads to the change in the characteristics of the land water. Land characteristics changes results in flow and quality of water. The effect on water is measured by sediment deposition, mean annual flow in the river or stream, peak discharges (floods) and water pollution. Due to climatic change, the geospatial changes will occur within the watershed geomorphology which leads to change in rainfall pattern. To measure all these effects the basic knowledge of hydrologic cycle especially surface water system within the watershed geomorphology are necessary.

The ever-growing demand of water due to the increasing consumption and the decreasing quality of water by various contaminations calls for better management of the water available in the rivers. This requires the study of the hydrological response of the catchment to precipitation and its relation to the catchment characteristics.

1.1 Hydrological response from a watershed

The continuous movement of water from surface, sub surface of earth and atmosphere is given by the hydrological cycle. The key feature of this hydrological cycle are the rainfall and the runoff. In case of hydrology especially surface hydrology, the process like rainfall, runoff and soil erosion process are very important. Because of climatic and topographic condition, these hydrological processes are nonlinear. Rivers are the major source or primary source for transporting water from remote area to the ocean or sea. In the present water scarcity situation, better water management can be done by the management of the river (Swain *et al.*, 2015). The predicting or estimation of response by the rainfall-runoff within the basin plays major role in water resources planning, development and operation of various projects or conservation structure. Most of Indian condition are ungauged, where the data is limited, or data is not sufficient for analysis and in thus situation rainfall-runoff modelling is difficult job. For understanding entire hydrological process in this condition, a system is required. Watershed act as hydrological system, in which hydrological cycle are studied under a single unit.

Watershed covers all the land that drains directly into river or its tributaries. It is the area of land from which runoff drains to a stream, river, lake, or any other body of water (Sindhu *et al*, 2015). Its boundaries can be identified by locating the highest points of lands around the water body. Small streams and rivers drain water from the land as they flow from higher to lower elevation. Since watershed act as unit for hydrological processes, the integration of hydrology and watershed can be termed as watershed hydrology.

A watershed can consist of several sub-watersheds or can be part of a larger watershed or river basin. The characteristics of a watershed (topography, geology and land cover) play an important role in determining the quantity, quality and time of concentration at its outlet. The hydrological processes within the watershed is mainly influenced by surface feature of the earth. In this condition, the study of watershed hydrology gets difficult because of irregularities in these surface feature. If the concept of irregularities of the surface feature is understood, then it is easy to analyse the hydrology in watershed and that concept is named as geomorphology.

1.2 Concept of Geomorphology

The surface feature is nothing but landforms and the landforms includes hills, rivers, mountains, plateau etc. The study of these landforms defines geomorphology and the term which is derived from three Greek words: geo means earth, morpho means form and logy means discourse (Worcester, 1948). The science of geomorphology involves the study of origin, classification, description of the landforms.

The understanding of geomorphology can be done by two ways, one is description and another one is mathematical representation. Description form which includes the field description, morphological mapping, and mathematical representation which includes geomorphometry. Suppose the action or movement of water is associated with geomorphological feature then the term is given by hydro geomorphology (Scheidegger, 1970).

Now a days it is easy to understand the concept of hydrogeomorphology through geomorphometry because terrain analysis and surface modelling are easy with modern tools and software. The basic idea behind the geomorphometry is relationship is developed among the geography and topography. Using geomorphometry the land surface parameters are derived and land surface parameters are obtained under three categories; first one is morphometric parameters and object; second category includes parameters and object specific to hydrology and last category includes parameters and object specific to climate and meteorology. First category includes physical characteristics (slope, gradient, aspect, curvature etc.) are obtained. In case of second category, the flow accumulation parameters which can have potential to movement of material over the land surface are obtained. The last category the parameters are obtained to calculate surface relief by adjusting climatic and meteorological quantities. In view of hydro geomorphology first two category of land surface parameters are derived from the geomorphometry and this parameter is called geomorphological parameter. These parameters play a key role in the transformation of rainfall into runoff.

1.3 GEOMORPHOLOGICAL PARAMETER OF THE BASIN

The geomorphological parameter of a basin or watershed represent the physical and morphological attribute that will contribute to the runoff (Bhat *et al.*, 2015). It is derived from landform equation which can be considered to reflect the surface roughness. The morphological parameters of the watershed are derived and then use landform equation for getting geomorphological parameters and these parameters are driving force for which rainfall is converted into runoff at the outlet of the watershed which is nonlinear. The parameters are stream frequency, bifurcation ratio, elongation ratio, drainage density etc. which exhibits the characteristics of the watershed geomorphology. All the parameters measurement is performed under three aspect: linear, areal and relief parameters using defined mathematical equation. These parameters are strongly related to the rainfall and streamflow in the watershed. In other words, geomorphological characteristics are signature of hydrologic response. The study of response and influential geomorphological parameter on runoff involves, finding which parameter is more significant contribution to runoff. Identification of significant parameter can be done by application of statistical analysis. If the large number of data exist, then factor analysis can be better solution for the analysis of this kind of data.

1.4 FACTOR ANALYSIS

Factor analysis is a statistical technique used to identify a relatively small number of underlying dimensions, or factors (internal attribute), which can be used to represent relationships among interrelated variables (Jayakumar *et al.*, 1996). These underlying “factors” measurement is the main objective for the finding influential parameter. In factor analysis factors referred to linear composite of the variables. Since factors analysis used for identifying underlying factor, it also applied to bring down large number of variables into fewer ones, data summarization or data reduction. It is also applied for developing relationship among large number of variables and that relationship is obtained with the help of regression analysis.

1.5 MULTIPLE REGRESSION

A regression analysis describes the statistical relationships between a given dependent variable and one or more independent variables and regression analysis can also evaluates relationship between the variables. Regression is the technique used to predict unknown value of variable (dependent) from the known value of variables (independent) also called as predictors. The relationship between dependent variables and one independent variable are given by univariate regression whereas more than one independent variable gives the multiple linear regression. The study also given the assumption of multiple linear regression which are linearity, normality, no extreme values and missing value are also examined. Hence, linking of the geomorphologic parameters with the hydrologic characteristics of the basin can lead to a simple and useful procedure to simulate the hydrologic behaviour of various basins, particularly the ungauged ones. First step is to obtain the geomorphological parameters of the watershed by quantitative analysis, from that data the parameters are subjected to factor analysis. With the help of factor score the hydrological response from these parameters are modelled.

For finding the influence of these geomorphology on the runoff response from the catchment and estimation of runoff especially in ungauged stations are the major subject in the field of the surface hydrology. Hence the present study has been conducted.

Keeping in this view, the study is undertaken with following objectives

1. To evaluate the geomorphological parameters of a catchment using GIS.

2. To study the influence of geomorphological parameters on runoff characteristics of a catchment.

3. To identify the suitable method to link the geomorphological characteristics of the catchment to its response to rainfall.

CHAPTER Ⅱ

REVIEW OF LITERATURE

This chapter deals with the review of previous research carried out by many research workers, scientists and students. It also comprises of the works done to study of the geomorphology, geomorphological characteristics of watershed, applications of GIS and RS in morphometric analysis, principal component analysis and factor analysis. Review on multiple regression using factor score are elaborately presented.

2.1 WATERSHED HYDROLOGY

The watershed of any river or stream covers all the land that drains directly into it or into its tributaries. It is the area of land from which runoff (from precipitation) drains to a stream, river, lake, or any other body of water. Its boundaries can be identified by locating the highest points of lands around the water body. Streams and rivers drain water from the land as they flow from higher to lower elevation. Every watershed has their own geology, land use, topography, size, shape, geomorphology, drainage characteristics. Hence watershed is adopted as a basic developmental planning or management unit especially for natural resources. A watershed can consist of several sub watersheds or can be a part of larger watershed or the river basin.

The watershed hydrology is the integration of hydrologic processes such as precipitation, snow melt, interception, evapotranspiration, surface runoff, infiltration and sub surface runoff takes place within individual watersheds. The hydrology as well as the development strategy depends on the size of watershed (Sindhu *et al.*, 2015).

The size of watersheds vary from few hectare to thousands of hectare. Watersheds can be classified on the basis of area as: micro watershed (0 to 10 ha), small watershed (10 to 40 ha), mini watershed (40 to 200 ha), sub watershed (200 to 400 ha), macro watershed (400 to 1000 ha) and river basin (above 1000 ha).

The watershed characteristics (size, shape, geomorphology, topography, geology and land cover) play an important role in determining the quantity, quality, and timing of stream flow at its outlet as well as groundwater outflow. The geomorphology and its analysis within the watershed defines the watershed geomorphology (Singh, 1995).

2.2 GEOMORPHOLOGY

Valadkhani *et al.* (2017) stated that geomorphology is the branch of geography which deals with description of relief feature of earth surface features. It does not include only description of relief feature of earth surface but also factors involved, qualities and origin in changing shapes or new formation of earth surface feature.

Huggett (2011) describes geomorphology as is the term which is derived from three Greek words: geo means earth, morpho means form and logy means discourse. He defined geomorphology is discourse on earth forms. Also, he defined geomorphology as morphology of earth surface.

According to Worcester (1948) geomorphology can be defined as the science of landforms. It can also be defined as the science that describes interpretative description of relief features that are present on earth. Also, he stated that geomorphology defines the origin, description and classification of relief feature on the earth. He found that geomorphological study can be used to understand the irregularities in the surface of lithosphere which is called relief feature.

Water and sediment are transported by a river system. The river system exhibits the combined effect of the changes caused by the atmosphere and terrestrial systems. The physical form of the river system is created by the complex network of processes formed as a result of the exchange of dynamic forces between sediment load and water and the hydrology and geology of the surroundings, while the river flows through its course. Fluvial geomorphology is defined as the interdisciplinary science that attempts to understand these processes and process-form relationships in river system (Newson and Sear, 1995).

Garde (2001) described "fluvial geomorphology as the science of landforms produced by river action; a branch of geomorphology that deals with forms of streams and adjoining areas as brought by erosion, transportation and deposition of sediment by the running water". It deals with the streams and streams system produced by the action of flowing water. The feature produced on the land surface by flowing water is called fluvial landscape. Morphology of the streams changes as the erosion cycle proceeds.

According to Scheidegger (1970) hydrogeomorphology is defined as the integrated study of landform associated with the action of water. This study is mainly based on the concept of geosciences. Hydrogeomorphology gives linkage between hydrologic process and the landforms. Morphometric analysis of drainage basin is important in any hydrologic investigation such as assessment of groundwater potential, watershed delineation, groundwater management.

Ramaiah *et al.* (2012) suggested that hydrogeomorphological mapping can give an idea about occurrence and flow of ground water. He stated that delineation of the watershed and mapping of various landforms, drainage characteristics and structural features are included in hydrogeomorphological investigations which is useful to study the flow of groundwater and all these hydrogeomorphological mapping can be done by process called geomorphometry.

2.3 GEOMORPHOMETRY

Huggett (2007) describes landform as the natural features on the earth surface which include river, mountains hills, plains, beaches, sand dunes etc. He has given two approaches of landforms in geomorphology, one is description and another one is mathematical representation. Description part includes, filed description and morphological mapping whereas mathematical representation includes geomorphometry. He suggested that terrain analysis and surface modelling can be easy through geomorphometry.

According to Chorley (1957) geomorphometry is defined as the science which treats geometry of landscape. He stated that qualitative description of land surface is easy with attempts of geomorphometry and it is sub discipline of geomorphology. According to him drainage basin represents fundamental geomorphic unit.

Pike *et al.* (2009) defines geomorphometry is the science which describe the quantitative land surface analysis. He has given complete information about the principles, implementation steps, inputs-outputs, etc. in the process of geomorphometry. Based on the land surface parameter derivation from the DEM (digital elevation model) he grouped into two types, one is primary parameter, and another is secondary parameter.

Based on the purpose, geomorphomretry can be classified as land surface parameter and object into three groups, first one is basics morphometric parameters and object, second one is the parameters and object specific to hydrology and last one is parameters and object specific to climate and meteorology. Basic morphometric parameters and objects of land surface includes slope, gradient, aspect, curvature etc., parameters and object specific to hydrology are mainly based on flow accumulation parameters which can have potential to movement of material over the land surface and the last group of parameters mainly calculated to surface relief by adjusting climatic and meteorological quantities.

Coblentz *et al.* (2014) studied the relationship between topography and geology by quantitative analysis of the land surfaces. In this study relationship between subsurface geology and surface topography are related and the relationship are gives the topographic character and nature of drainage pattern. The process of this quantitative analysis of land surface feature is called geomorphometry. The study describes the general geomorphometry which evaluates continuous land surface feature using DEM of 1m and 0.25m.

2.4 GEOMORPHOLOGICAL PARAMETERS OF THE WATERSHED

Strahler (1957) defined watershed geomorphology as landform analysis applied to the developed watershed. Landform analysis in watershed can be done to measure the size and characteristics of the drainage basins. The description of landform is given by two types of measurement one is linear scale measurement which includes the parameters describes which geometry are measured these are one dimensional and this category is also called morphological parameters. Another is dimensionless numbers which includes angles, ratios of length measures are computed using mathematical equation. The parameters are dimensionless and also called as geomorphological parameters.

Jain *et al.* (2009) stated that streamflow in river is related to characteristics of the rainfall and the watershed geomorphology. For understanding of this relation, integrated study of channel network and geomorphology are done and study is conducted to derive geomorphological parameters. According to him geomorphologic parameters are defined by relation between channel network and surrounding landscape.

According to Jarrar *et al.* (2007) geomorphological parameter are the parameter which describes the channel network, topography, landscape and land use. Geomorphological parameters are driving parameters for which rainfall is converted into outflow hydrograph at the outlet of the watershed and these parameters are strongly related to the rainfall and streamflow in the watershed.

According to Seldomridge and Prestegaard (2012) geomorphologic characteristics are used as scaling parameter and this characteristics can be used to predict runoff and sediment. The study stated that geomorphic measurement are analysis to find the channel characteristics and marsh surface area.

Swain *et al.* (2015) conducted experiment on stream flow prediction in ungauged river basin using GIUH approach. The study stated that geomorphological parameter are time invariant in nature and therefore the study also suggest geomorphology based approach is good approach for rainfall-runoff modelling especially in ungauged watershed.

Mark (2004) reviewed that geomorphological parameters are landform equation which can be considered to reflect the surface roughness. The measure of all land surface form can considered to be representation of roughness where roughness is the irregularities in topographic surface. The parameters are classified under three groups: horizontal variation which includes texture and grain, vertical variation relief parameters and last one is the dimensionless numbers.

Bhat *et al.* (2015) described the geomorphological parameter of a basin or watershed are the parameters which represent the physical and morphological attribute that will contribute to the runoff. Study suggested that to derive geomorphological parameter, first step is to measure the morphological parameters and then geomorphological parameters are derived by mathematical equations. Geomorphological parameter are attributes which have direct impact on floods, hydrologic regime, land use, soil erosion and peak flow.

2.4.1 MORPHOMETRIC ANALYSIS OF THE WATERSHED

Kabite and Gessesse (2018) suggested that geomorphology and hydrology are important components of any river basin. For understanding hydro-geomorphology in the Dhidhessa river basin, morphometry is a good approach because the morphometric characteristics of the river basin describes topographical, hydrological and geological behavior of the any river basin.

According to Rahaman *et al.* (2015) the process of measurement and mathematical analysis of the landforms, its shape and dimensions of the landforms are defined by morphometry. Since it deals with the description of landforms, morphometric analysis of a watershed provides complete quantitative description of the drainage characteristics of the river basin and this description of the drainage system is an important aspect in the field of watershed characterization.

Zende and Nagarjun (2011) stated that the parameters derived from the morphometric analysis are reflective of the hydrological response from the rainfall. Study stated that geologic structure, their formation and their role can be better understood by morphometric analysis of the watershed. This analysis also provides nature and type of drainage pattern which is an important aspect in the field of watershed planning and management.

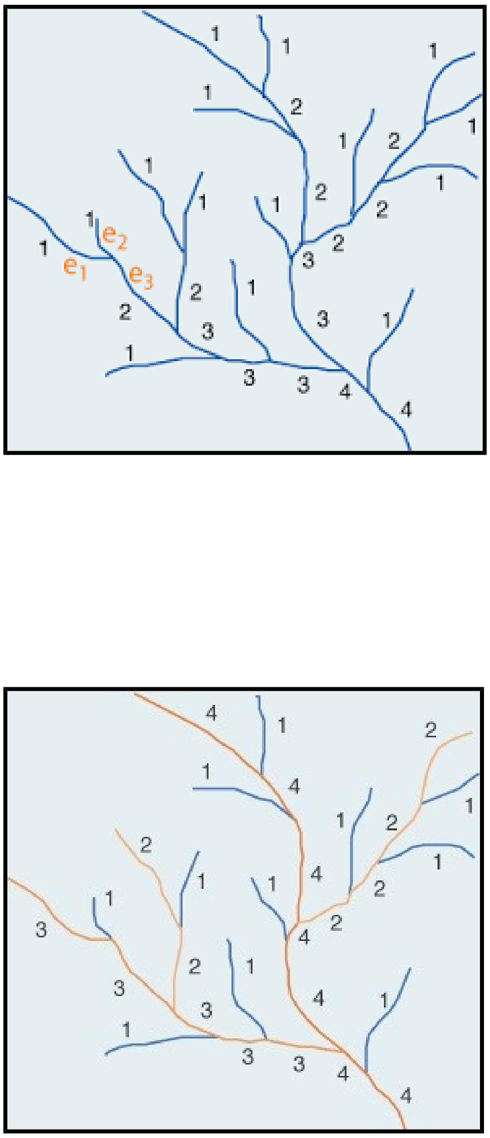
Smart (1968) studied the geomorphology of a drainage basin. According to him Horton laid the foundation for quantitative description of landforms. Horton has made two major contribution one is stream ordering or classification and another is law involved in stream ordering.

The study of drainage network begins in 19th century. The quantitative description of stream network starts with classical work of Horton (1945). He expressed the stream network system in terms of stream order, and the dimensionless numbers. According to him 1st order stream network are fingertip unbranched tributaries of the stream network, 2nd order streams receives 1st order tributaries and the 3rd order stream network streams receives both 1st and 2nd order stream tributaries. Finally the main stream is considered as the highest order also called trunk order of the watershed. He explained the laws involved in connecting the number of streams and length of stream are

- ✓ Law of stream numbers-According to this law, the number of streams with their order and highest stream order are related in terms of geometric series. For this series bifurcation ratio is the base.

- ✓ Law of stream lengths- According to this law the average length of stream can be expressed in terms of stream length ratio and average length of streams of their orders.

Horton’s method of stream ordering is revised because the stream ordering system referring not only interconnections and not the lengths, shapes (Strahler, 1957). In the Strahler method of stream ordering the main channel is not determined and in this system stream ordering can be done by assigning the order one to initial links. The difference between these stream ordering can be shown in Fig. 2.1



(a) (b)

Fig. 2.1 (a) Strahler method of stream ordering and (b) Hortan method of stream ordering

2.4.2 APPLICATION OF GIS AND RS IN GEOMORPHOMETRIC ANALYSIS

Geographic Information System (GIS) has emerged over the past decade as widely used software system for input, storage, manipulation and output of the geographically referenced data (Stewart and Godchild, 1993).GIS is currently used to assemble and manage the large database to manage to perform the spatial and statistical analysis and to produce effective visual representation of the model results.

- ❖ GIS was used as a preprocessor of data, making the use of its functions for projection change, re sampling, generalization, windowing and other data extraction tasks, map digitizing and editing. Reformatting was often needed to meet the requirement of simulation packages.

- ❖ GIS was used for storage of data, database management facilities of GIS for keeping track automatically of many housekeeping functions such as simple documentation and provide a uniform mode of access.

- ❖ GIS was used for statistical analysis of data and for the model results.

- ❖ GIS was used for visualization, particularly for presenting the results of simulations in map form often in combination with other data.

Finally this study examined the status of GIS as a technology to support environmental simulation modelling in the atmospheric, hydrologic and ecological sciences.

Ma (2004) studied about GIS applications in watershed management and stated that the capability of GIS to integrate and analyses spatial data made it more advantageous than other software's such as multitude of graphics, computer aided design, drafting and mapping software systems. GIS can be used effectively for environmental applications such as best management practices, watershed management, storm management, forestry management, wetlands delineation, wildlife habitat management etc. He stated that GIS made us to understand the past and present state of watershed, landscapes which make it widely acceptable by the resource managers to deal with water management issues. Finally he concluded that GIS technology will greatly help the managers to provide communities with the tools to inform their watershed situation and to realize the impacts of various situations.

Gangodagamage (2001) used the RS and GIS techniques to extract the land surfaces, which exist as a threshold in early days to approach reasonable results in hydrological modeling. From during the last decades. Accurate modeling will require estimation of the spatial and temporal distribution of the water resource parameters. GIS and RS have become efficient tools to integrate the spatial and non-spatial databases for the hydrologic modeling. In this study hydrologic model was developed for the Bata river basin, which is one of the tributary of the Yamuna river basin India. Infiltration losses, unit hydrograph and river routing were the main components of the model. ILWIS, ERDAS and AUTOCAD software were used. (SOI) topo maps, field data, IRS LISS III multi temporal satellite for *rabi* and *kharif* seasons and IRS pan data were used. SCS CN method, unit hydrograph are used for infiltration losses and synthesis of unit hydrographs respectively. Watershed was divided into 10 sub areas. Muskingum method was used for river routing. Finally the model was capable of forecasting the runoff for given event of rainfall and deriving hydrographs for the required duration.

Jadhao *et al.* (2009) suggested that the tediousness and time consuming nature of extraction of watershed parameters can be eliminated by means of remote sensing technology and GIS in addition to obtaining high accuracy. Input data for the model can be extracted with the use of GIS mainly from the map layers including land use/cover, DEM, soil, slope, drainage and watershed and sub-watershed boundaries. Many studies have applied SCS-CN model for estimating the surface runoff by deriving curve numbers using satellite data and GIS technique. Knowing the importance of empirical models, remote sensing data and GIS techniques the study was undertaken with the use of a widely used empirical model (SCS-CN) using these techniques. The watershed parameters such as area, channel length, drainage density, slope and area under different soil textures could be derived accurately using various maps *viz.* DEM, drainage map, watershed and sub watershed boundaries and soil texture map in GIS environment.

Remote sensing procedure utilizing satellite images and aerial photos are convenient tools in morphometric investigation of a drainage basin (Nautiyal, 1994). Morphometric parameters of Khairkuli drainage basin area, Dehradun were worked out in this study. The parameters worked out involved bifurcation proportion, stream length, shape factor, circulatory ratio and elongation ratio, drainage density, constant of channel maintenance and stream frequency. The geomorphometric parameters indicates that the region was secured by safe porous rocks and area is influenced by tectonic activities.

Sharma *et al.* (2014) studied about a comparative appraisal of hydrological behaviour of SRTM DEM at catchment level. They studied the hydrological behaviours of SRTM DEM and TOPO DEM in terms of catchment response to runoff and sediment yields. They used the Arc SWAT model to simulate runoff and sediment yields and predictions were done at monthly time step for monsoon season during the years from 2002-2005. Initially they calibrated the model using TOPO DEM and the same calibrated model was run with same spatial data except SRTM DEM in place of TOPO DEM. Their final calibration statistics indicated that runoff was predicted more accurately than sediment yield by using both DEMs. They also found that runoff prediction was more accurate when using SRTM DEM, whereas in case of sediment yield prediction, reverse case was observed. The reason behind the greater runoff prediction accuracy by SRTM DEM was it facilitated delineation of drainage network, basin boundary and micro watershed more accurately when compared to TOPO DEM. But the variation in the prediction of runoff values using the two DEMs was only marginal. They finally concluded that SRTM DEM can be a valuable data for hydrological analysis/applications.

Magesh *et al.* (2013) conducted morphometric analysis on Bharathapuzha river basin using GIS software. The analysis was carried out by geoprocessing in the GIS environment where SRTM-DEM is used for the extraction of the morphological characteristics. The basin having a higher stream order of 7. Basin having well drained in nature. From this study it is found that the basin is steep slope and moderate relief due the low elongation ratio (0.7).

In this study, geomorphologic parameters of Damlica basin are evaluated by using the Geographic information system (GIS). The parameters were extracted from the Digital elevation model (DEM) downloaded from the ASTER-GDEM web page. The morphometric parameters of the study area are calculated Arc Hydro tool in the ArcGIS software. The parameters extracted from the DEM are perimeter, area of basin, its river length, slope etc. The extracted parameters from the DEM are compared with the conventional method (Gunal and Guven, 2014).

Kaliraj *et al.* (2014) quantified the morphometric analysis of river Thamirabarini sub basin in Kanyakumari district, India. The study was conducted using digital elevation model (DEM), Landsat ETM+image and survey of India topographical map. All these input parameters were used to delineate slope, relief and drainage characteristics of the basin. Also surface structure such as stream order, drainage slope, stream network, stream length of the sub basin is extracted using Arc GIS. For complete understanding of the quantitative geographical characteristics the hypsometric analysis and denudation rate were estimated. From the study it was found that the geological and geomorphological structures are strongly controlled by the drainage network.

Raj and Azeez (2012) evaluated morphometric characteristics of the Bharathapuzha river basin using GIS and RS. In this study toposheet and LANDSAT imageries are used to extract the morphological characteristics. It was found that the Bharathapuzha river basin covers a catchment area of 6,186 km2 and it is 7th order drainage basin with dendritic drainage pattern. In this study basin area, perimeter, bifurcation ratio, form factor, drainage density, stream frequency etc. parameters were calculated in the GIS environment. Drainage texture also evaluated in this study which is the prime feature of the geomorphology.

National institute of hydrology (1998) reported that geomorphological parameters are parameters which relates hydrology. These parameters are classified into three groups, such as linear aspect, areal aspect, and relief aspect. Linear aspect included one dimensional parameters *viz*. stream length ratio, length of stream, bifurcation ratio etc. and these are. Areal aspect relates to the basin area, shape, drainage, texture and relief aspect includes relief ratio, ruggedness number. Linear and areal aspect parameters are planimetric i.e. properties projected upon hydrological datum plane and relief aspect parameters treats vertical inequalities within the drainage basin. The conventional method includes extraction of geomorphic parameters from the toposheet. It was found that absolute error between parameters obtained from DEM and toposheet of the parameters such as basin area, perimeter, and river length are 0.63 km^2, 0.3 km, and 0.1 km respectively.

Saeedrashed and Guven (2013) derived geomorphologic parameters using GIS-based DEM and GIS-based Topographic Maps (GTM). Study is conducted to derive and compare the geomorphologic parameters obtained from the DEM and the GTM of Lower Zab watershed located in Iraq. 15.600 km^2 is the extracted area of watershed from the DEM, while the 15.390 km^2 is the area obtained watershed from the topographic maps. The study suggested that DEM method gives more accurate than GIS based topographic map which is digitized process and also he suggested that geomorphologic parameters derived from the DEM can be used for many hydrologic modelling, hydraulic structure and research related to flood routing.

Himanshu and Garg (2013) predicts the flood hydrograph from geomorphologic parameters and storm data. Geomorphologic parameters are estimated from 30 m resolution ASTER DEM using ARC GIS 9.3. In this study the parameters were used derive the synthetic unit hydrograph.

Jothish *et al.* (2011) conducted study on rainfall runoff modelling in the ungauged watershed. The study was taken in Barak basin in Assam with an area of 26.13 km^2. Since the watershed was ungauged the relationship is obtained by linking quantitative geomorphology and the watershed characteristics with rainfall events. The characters of quantitative geomorphology and watershed characteristics is given by geomorphological parameters and runoff or discharge estimation is found out by method called geomorphological instantaneous unit hydrograph (GIUH).

2.5 INFLUENCE OF GEOMORPHOLOGICAL PARAMETER

Statistical analysis can be applied in the field of geomorphologic research (Strahler, 1957). The study of statistical analysis in geomorphology can be done under four categories: frequency distribution analysis; analysis of variance, significance of sample mean difference; correlation; linear regression; and finally nonlinear regression. He described each categories by taking his own geomorphic research.

Tanavade and Hangargekar (2016) carried out study on the influence of geomorphometric parameters on hydrologic response of Sangola watershed in Maharashtra, India. The drainage network which is dendritic in nature. In this study morphometric description of the Sangola watershed are derived using Arc GIS and ERDAS imagine. Various linear, areal and relief parameters were extracted from the toposheet and digital data. These parameters have been analysed and their hydrologic response over the watershed are examined. The study gives the idea about morphometric analysis can be utilised for the hydrologic response, mainly runoff which is needed for the planning, conservation structure, development and management of water resource.

2.5.1 Principal Component Analysis (PCA)

Bothale *et al.* (2012) developed a procedure for the extracting eco watershed by combination of RS and GIS strategies for management of land and water. Eco watershed can be defined as homogenous watershed which have comparative similar characteristics for natural resources development and management practices. Study was conducted in the Erau Watershed of Bajaj sagar dam sub catchment in Mahi drainage basin having topographical region of 736 km^2. Remote sensing and GIS technology were utilized as a part for the analyses the 135 small scale watershed of the study area. The watershed characteristics such as land use/land cover, geomorphic units and morphological parameters were subjected to PCA for data redundancy

According to Gajbhiye and Sharma (2017) PCA is the mathematical procedure in which large number of correlated variables are transformed into smaller uncorrelated variables. In this study morphometric analysis is conducted and the parameters are prioritize based on the PCA approach. The shape parameters are lower values which is given as rank 1 and similarly rank is given for the other parameter also. According to rank highest priority is given for prioritizing the watershed.

Sharma *et al.* (2015) applied principle component analysis in grouping of the geomorphic parameters for the hydrological modelling. He stated that principal component analysis (PCA) is good statistical analysis for the elimination of the insignificant parameters. The parameters such as bifurcation ratio, drainage texture, drainage density etc. Like that 13 parameters of the 8-sub watershed of the Kanhiya nala watershed are derived from the SOI toposheet in the GIS environment. The grouping of parameter is based upon the significant correlation. He has given step by step procedure for principal analysis in grouping of parameters. The parameters which Eigen values which is greater than 1 with total variance of 91.45% is taken in the principal component loading matrix.

Sharma *et al.* (2013) used GIS software for deriving geomorphological parameter Uttala nala watershed of Madhya Pradesh. Eleven parameters are derived and based on the properties, the parameters are grouped into slope, shape and drainage component. The parameters are strongly correlated, and the correlation matrix can be derived by applying the concept of PCA. Screening of large number of inter related variables can be done by using PCA.

Among eleven parameters, ten parameters are strongly correlated with correlation coefficient 0.9 to 0.75 and stream frequency didn't show any correlation among the parameter, so the parameters stream frequency can be screened out. Ten parameters having strong correlation with variance of 93.71% and correlation matrix is obtained by using formula

$$X = \frac{(xij - xj)}{Sj} \quad \text{--} \quad (1)$$

Where, X = Matrix of standardized parameters x_{ij} i^{th} observation on j^{th} parameters

x_j =mean of the j^{th} parameters

S_j =standard deviation of the j^{th} parameters

Principal component loading matrix is used for understanding how much the parameter is correlated with different parameters and that is given by the formula

$$A = Q * D^{0.5} \quad \text{---} \quad (2)$$

Where, A = Principal component loading matrix,

Q =Characteristics vector of the correlation matrix,

D =Characteristics value of the correlation matrix,

Abrahams (1972) derived morphometric parameter of the basin in five different landscape in eastern Australia. The study area is third order basin and the parameters derived are basin area, stream length, basin relief, basin perimeter and stream number. The parameters are then analysis by data reduction methods like conducted factor analysis. PCA is used to derive initial factor matrix which indicates each principal component can be treated as the correlation coefficient. The three factor derived are planimetric, relief, and area.

Gavit *et al.* (2016) derived 13 geomorphologic parameters in 11 watershed of the upper and middle Godavari river basin. Arc GIS 10.2 is used for deriving the parameters and these parameters are subjected to PCA. The study gives that screening large number of interrelated variables can be done with the help of multivariate analysis called PCA and in this study the analysis is done in SPSS software. The parameters which having greater than 0.9 is taken for strong correlation parameters and it is existed between average slope of watershed and Elongation ratio (Re). The principal component obtained are slope component and shape component.

2.5.2 Factor analysis

Jayakumar *et al.* (1996) applied factor analysis technique to a set of terrain parameters that contributes to ground water recharge. According to them, factor analysis is data reduction or summarization method gives underlying parameters or insignificance variables. The analysis used to bring down large number of variables to fewer ones.

According to Nikam *et al.* (2014) the integrated study of geomorphological parameter with PCA helps in predicting runoff and sediment yield from the basin. In this study, the parameters which are less significant are screened by PCA with orthogonal rotation. In this study the unrotated factor loading matrix and rotated factor loading matrix are calculated in SPSS software. The formula for finding these is given by

$$A = Q \times D\,0.5 \quad \text{-------------------------------} \quad (3)$$

Where, A is unrotated factor loading matrix, Qis the characteristic vector of correlation matrix and D is the characteristic value of correlation matrix. When the transformation matrix is multiplied with unrotated factor loading matrix, the rotated factor loading matrix is obtained.

$$B = A \times H \quad \text{------------------------------------} \; (4)$$

Where B is the rotated factor loading matrix, A is unrotated factor loading matrix and H is the transformation matrix.

Yakubu and Idahar (2009) defined factor score is the measure rank on a given factor obtained from the correlation matrix between variables and the factor. The scores were used to fit multiple linear regression equation as the scores were independent variables.

Bhaskaran and Kumaraswamy (2002) identified the influential geomorphometric parameter using numerical analysis in the Bhavani sub basin. Statistical analysis is done to find the influential parameter and he suggested that factor analysis is useful in the interpreting morphometric parameters. Fourteen geomorphic parameters are evaluated from the thirty-four-minor basin. The parameters are grouped into four categories. The first categories related to the basin size, the second categories relate to the runoff characteristics of the sub basin, the third category explain about the drainage parameters and the last category described the shape of the sub basin. The correlation matrix was computed for the fourteen parameters. It was found that the first category parameters i.e. basin perimeter, basin area, channel length and maximum length are greatest influence on the size of the basin which indicate 81.94% variance. In the second category drainage density, constant of channel maintenance, length of overland flow is more correlated. Third component is strongly correlated with bifurcation ratio and stream length ratio and the last category is moderately correlated with form factor, circulatory ratio, elongation ratio. The study suggest that the results of factor analysis can be used in multiple regression.

2.6 MULTIPLE REGRESSION

Multiple linear regression (MLR) is the technique used to predict unknown value of variable (dependent) from the known value of two or more variables (independent) also called as predictors (Giacomino *et al.* 2010). In multiple linear regression the relationship between dependent and independent variables are expressed in mathematical function. The general form is given by

$$y = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n$$

Where y is dependent variables, $b_0. . .b_n$ are the regression coefficient and $x_1x_2\ldots x_n$ are independent variables. Since MLR predicts from known variables, it can be used in amount of micronutrient available for crops, parameters affecting soil properties, etc.

Uyamk and Guler (2014) conducted study on multiple linear regression analysis to find the streamflow simulation United Kingdom and also they defined regression analysis is a statistical analysis for which relationship among the variables is developed. The relationship between dependent variables and one independent variables are given by univariate regression whereas more than one independent variables gives the multiple linear regression. The study also given the assumption of multiple linear regression which are linearity, normality, no extreme values and missing value also examined.

Thompson (1978) reviewed that selection methods of variables in multiple linear regression. In this study the large number of independent variables are selected various methods like Bayesian approach, sequential procedure(forward ranking, backward ranking, forward selection, backward elimination, stepwise regression), rigid regression and multiple correlation coefficient.

Beauducel and Hilger (2016) stated that factor score can be determined by correlation or squared correlation between the factor and the factor predictor. The coefficient of determinacy can be defined as the correlation between predictor and factor corresponds to multiple regression the observed variables and factor. The study also suggest that factor score method of linear regression are best method of predicting by observed variables.

Niyas and Demirbas (2017) studied to find the factors that affecting the opinions fruits and vegetables in terms of food safety. Study is conducted by collecting data from the 166 consumer’s opinions. The data are subject to factor analysis and binary logistic regression to analyses the data in terms of food safety. In this study Eigen values which are greater than one is considered to find the number of factors. There are 11 factors obtained from 35 different opinions from the consumer. The naming of those factor is based on the factor score. The factor score which are greater than 0.30 is considered for regression analysis and that score can be used as the independent variables in the regression analysis. The factor includes insufficient control, income, freshness, certified products, price, quality products, standardization bad appearance, physical fraud, local product and chemical fraud. From this analysis the factors physical quality fraud, chemical fraud and quality problems are proved negative impact on opinions of fruits and vegetables in terms safety while locally produced fruits and vegetables shown positive impact on the consumer opinion.

Eyduran *et al.* (2009) studied the use of factor scores in multiple regression analysis. In this study the body weight is estimated from the body measurement using multiple regression. Factor analysis is conducted to rank the measurement according the significance and that rank can be derived by factor scores. The regression equation is given by

$$\text{Body weight} = a+b_1FS_1+b_2FS2+b_3FS_3+e$$

Where a is regression constant, $b_{1,}$ b_2 and b_3 are regression coefficient of factor score, FS is the factor score and e is the error term. Regression coefficients are tested by t-test and all these are analyzed in Minitab. In this study three factors are derived and 98.45% of variation is explained among the three factors. The variance explained by first, second and third factor are 0.362, 0.289 and 0.235 respectively.

Luo and Weiss (2002) forecasted standard error while doing regression analysis. The standard error is calculated by building a function in Microsoft excel and this method is used when linear regression models are used for prediction of future events.

Sakar *et al.* (2011) conducted experiment on to determine the relationship between kernel weight and fruit-kernel characteristics. In this study 7 fruit kernel characteristics are subjected to the factor analysis and the obtained results are used for multiple regression analysis. Eigen values more than one is taken into consider to find the number of factors. According to that 3 factors are derived and basic factor analysis equation can be given as

$$Z_{px1} = \lambda_{pxm} F_{mx1} + \varepsilon_{px1}$$

where Z is a px1 vector of variables, λ is a pxm matrix of factor loadings F is a mx1 vector of factors and ε is a px1 vector of error (unique or specific) factors. The three factors fruit measurement, kernel measurement and shell measurement explained about 84.4 % of variance and the factor loading also higher which means the variable is pure measure of factor. The variables which indicates of highest value of communalities having greater than 0.2 factor score coefficient is taken for the multiple regression analysis. The study suggested that regression analysis having more than one variables is easy in Minitab software.

Young (2005) stated that multiple linear regression is data driven models in which the discharge or runoff are estimated through calibration of stream flow data. In this study, the stream flow is estimated in two approaches one is regression based approach and another one is nearest neighbour approach. In nearest neighbour approach, the calibrated parameter groups are retained as single entity whereas in regression based analysis communalities with the region of influence are considered. The study gives regression analysis gives best predictive results compare to nearest neighbour approach.

Zhao *et al.* (2012) assessed the damming effect on the runoff characteristics in Manwan dam on the Lancing River. In this study the correlation are investigated between monthly runoff and meteorological data with a time lag of 0-3 months(lag0,lag1,lag2,lag3) and then stepwise multiple regression is employed between monthly runoff and meteorological data is established.. The largest value of runoff is obtained in the month of August which is about 70.4×10^8 m^3 and the least value in the month of February which is about 9.3×10^8 m^3. The correlation between runoff and rainfall has highest in all time lags with highest correlation of 0.83. The performance evaluation of multiple linear regression can be done by the coefficient of determination (R^2) and the Nash-Sutcliffe coefficient which is obtained as 0.84 and 0.82 respectively.

McIntyre *et al.* (2009) applied regression analysis to predict the hydrologic response from arid and semi-arid areas in Oman. In this study, hourly data of 36 events from 1966 to 1999 rainfall- runoffs data are collected in Wadi Ahin of 734 km^2, which are subjected to regression analysis. The study aims to predict peak flow, runoff volume, runoff coefficient from independent variables of rainfall like peak average rainfall, total event rainfall volume, base flow, distance of rainfall centroid from flow gauge and rainfall spatial variability index. The variables having higher R2 with significance level more than 95% is considered. The peak rainfall is obtained as more significance because of high correlation coefficient of 0.91 with rainfall volume. The linear relationship is obtained between peak runoff and volume, and rainfall volume. The value of R^2 obtained from the regression analysis for the peak flow and runoff volume is given by 0.49 and 0.6 respectively.

Zhang *et al.* (2015) stated that geomorphological parameters are parameters which are affecting runoff, sediment, energy fluxes and mass movement. In this study sediment yield is estimated inn terms of geomorphological parameters and rainfall. The yield is estimated by partial least squares regression (PLSR). The principle behind PLSR is it combine the method of PCA and multiple linear regression and this is multivariate analysis because independent variable is more than one. The study is taken with 29 parameters of 16 watershed in china. The first order factor is determined through PLSR and that factor is used for calculating the variable importance for projection (VIP) which means that variables influencing more in that factor.

From this PLSR analysis, watershed shape and relief parameters are found as VIP which is mainly loaded on sediment load and the VIP values of the parameter plane curvature, highest order channel length, hypsometric integral, rainfall, basin relief, slope, sediment transport capacity index, length ratio, profile curvature and divide average relief are 1.87, 1.53, 1.49, 1.44, 1.06, 1.01 and 1.00 respectively. Regression coefficient are used to determine the relationship between the dependent and independent variables.R^2 also used to find the optimal balance between explained variance and R^2 also used to goodness of the predictive parameter. The highest sediment yield obtained from number 2 watershed about 97.9 t ha^{-1} and lowest sediment yield is about 2.5 t ha^{-1} in the watershed number 16. It was found that prediction error decreases with increase in the number of independent variables by obtaining RMS value which is minimum and variance explained is about 67.9%.

CHAPTER Ⅲ

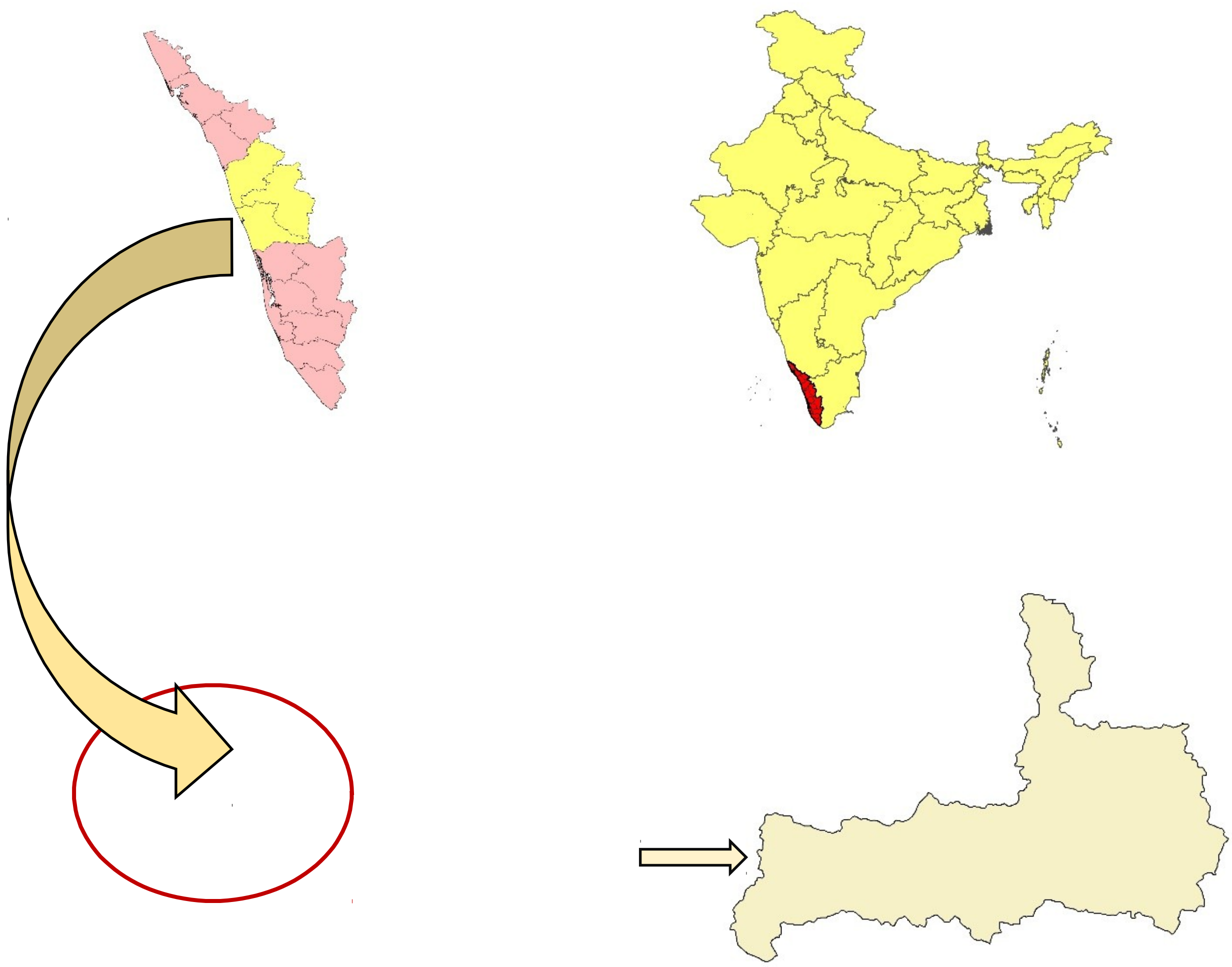
MATERIALS AND METHOD

3.1 DESCRIPTION OF THE STUDY AREA

3.1.1 Location

The watershed located from the central part of Kerala, India has been used for this study. In this part Bharathapuzha is one of India's medium rivers which is flowing towards west and reaches Arabian Sea at Ponnani. Bharathapuzha River is the second longest river (251 km) in the south west coast area and it is originates from the Anamalai hills and it falls in the rain shed region of the Western Ghats. The total catchment area of the river basin is about 5,397 km^2 in which 1593 km^2 are lies in Tamil Nadu and remaining area lies in Kerala and the river is strongly influenced by south west monsoon.

The river is life line water for almost one-eighth of Kerala’s population residing in the district of Malappuram, Thrissur, Palakkad. Eleven irrigation projects and several surface dams in the river basin cater 493064 hectare agriculture lands. The four major tributaries of the river are Kalpathipuzha, Gayathripuzha, Thuthapuzha and Chitturpuzha. The Thuthapuzha river basin which is tributary of Bharathapuzha has been used for the study. Thuthapuzha River is one of the main tributary which lies between $10^{\circ}\ 50^{1}$ to $11^{\circ}15^{1}$ North latitude and $76^{\circ}5^{1}$ to $76^{\circ}40^{1}$ East longitude. The sub basin lies in 43 zone in UTM projection and distributed among three districts. The hydrological response of the watershed to the inputs and how these are influenced by various geomorphological parameters are studied in this sub basin.



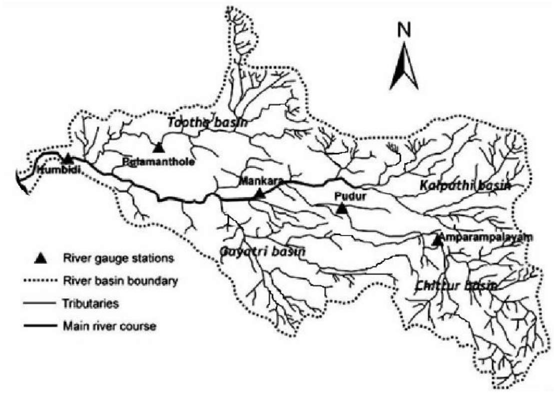


Fig. 3.1 Location of Thuthapuzha river basin

3.1.2 Physiographic and Meteorological Information in Thuthapuzha Sub Basin

3.1.2.1 Rainfall

Daily rainfall data and climatic parameters such as temperature, humidity, wind speed, solar radiations and sunshine hours have were taken from RARS (Regional Agriculture Research station) Pattambi. The sub basin receives maximum rainfall during southwest monsoon.

3.1.2.2 River flow

Daily river flow has been collected from Central Water Commission i.e. Pulamanthole gauging station and the gauging station is managed by the Central Water Commission.

3.1.2.5 Digital elevation model (DEM)

One of the most useful types of geospatial data is digital terrain. Hydrologic quantities can be derived from a DEM. The terrain attributes such as slope and drainage direction are derived from a DEM. A model of terrain traditionally relies on contours of equal elevation that define watershed boundaries, channel slope and other features. Within a GIS, representation of terrain can be accomplished with contours. Watershed characteristics such as slope and drainage length can be derived from a digital model of the terrain. A raster DEM consists of group of numbers indicating the spatial distribution of elevations.

DEM of the study area has been downloaded from the Cartosat-1: DEM - Version-3R1 1 arc sec (~ 32 m) resolution was downloaded from ISRO, National Remote Sensing Centre (NRSC), India Geo-platform Bhuvan website (http://bhuvan.nrsc.gov.in).

3.2 SOFTWARE AND TOOLS USED

3.2.1 Hardware

Personal computer with Intel Core i3-5005U CPU processor 2.00 GHz, 4 GB RAM is used.

3.2.2 Software

- ✓ Geographic information system(GIS)
- ✓ Microsoft Office
- ✓ Minitab

3.2.2.1 Geographic information system (GIS)

GIS is computer based system used for capturing, storing, retrieving, analysing and displaying which are spatially referenced to earth. GIS has a wide application in a variety of civil and environmental applications, including demography, meteorology, transportation and urban planning. In this study GIS is used for application in hydrology because it is an important tool or software in the field to study and manage earth's water resources and also it is having an ability to deal spatial data with the analysis of variables such as slope, aspect within watershed. In the past three decades, hydrologic applications have been revolutionized by GIS, making it an indispensable technology for digital terrain and hydrologic analysis of watersheds. The geomorphological parameters of the watershed gives better understanding of the watershed. For deriving these geomorphological parameter, GIS technology gives a better output compared to other traditional methods. The output or the results from the GIS includes; Attribute or feature information in the form of database format, location of these attribute or feature and analysis functions for deriving new information on spatial relationships

In hydrology, GIS is used for runoff estimation, flood plain modelling and hydrologic and hydraulic modelling and also to study the hydrological cycle within the watershed. All this information is stored and represented in the digital format. This digital representation of topography, soils, land use/land cover and precipitation may be accomplished using GIS data and methodology. The applications are enhanced through the use of GIS, because hydrology is inherently spatial in nature. In this study Arc GIS of 10.2 version is used because it is a proprietary software. ArcGIS provides a common frame to work with different spatial data obtained from various sources. The ability of GIS to work with spatial data in multiple formats made it more advantageous than other technologies. ArcGIS was developed by Environmental Systems Research Institute (ESRI) and was initially released at New York in 1999. ArcGIS for desktop includes number of integrated applications such as ArcCatalog, ArcMap, ArcToolbox. ArcMap is used for primary display application i.e., to display, querry, edit, create and analyse the geographically referenced data. Arc catalogue helps to browse, search, explore, and view and also to manage the data. Arc Tool box is a geoprocessing tool used to perform geoprocessing operations such as data conversion, buffering, overlay processing and proximity analysis, map transformations etc. ArcGIS 10.2. which was released in 2014 was used in this study for deriving the geomorphological parameters.

3.2.2.2 Microsoft Office

The morphometric parameters of Thuthapuzha sub basin obtained from the GIS can be used for computing geomorphometric parameters. The computation can be done in Microsoft excel. In this study Microsoft excel of 2013 version is used for computing and making tables.

3.2.2.3 Minitab

The study of influential parameters on runoff involves finding which parameter is more significant contribution to runoff. Identification of significant parameter can be done by application of statistical analysis. PCA and factor analysis are multivariate statistical analysis are the effective methods to find more significant geomorphological parameters. Here PCA can be used to find the number of factor in factor analysis. The results from factor analysis can be used as dependent and independent variables. If the dependent and independent parameters are known, then it is easy to know the relationship between these dependent and independent parameters and that statistical procedure is given by regression analysis. For all these statistical analysis (PCA, factor analysis, regression analysis), a computer software called Minitab can do work well because the tools in this software give calculations with more accuracy. Minitab is statistical software used for creation of graph, analysis of the data and interpretation of results. It was developed by Pennsylvania State University.

3.3 DERIVATION GEOMORPHOLOGIC PARAMETERS

The response of a watershed to the hydrological input depends on various watershed characteristics. The basic watershed characteristics which are important with respect to the hydrological studies are discussed below.

3.3.1 Extraction of morphometric parameters using DEM

For the present study Cartosat 1 version 3 is downloaded from the BHUVAN website. The morphometric parameters of the sub basin such as number of stream segments, stream order, drainage pattern, sub basin length, perimeter and area were delineated from DEM. These parameters are involved in computing the geomorphological parameters such as drainage density, form factor, length of overland flow, circulatory ratio etc. Using mathematical equation in the GIS environment, the extraction of stream network and watershed parameters can be done under separate categories. The flow chart for the morphometric analysis is given Fig. 3.2

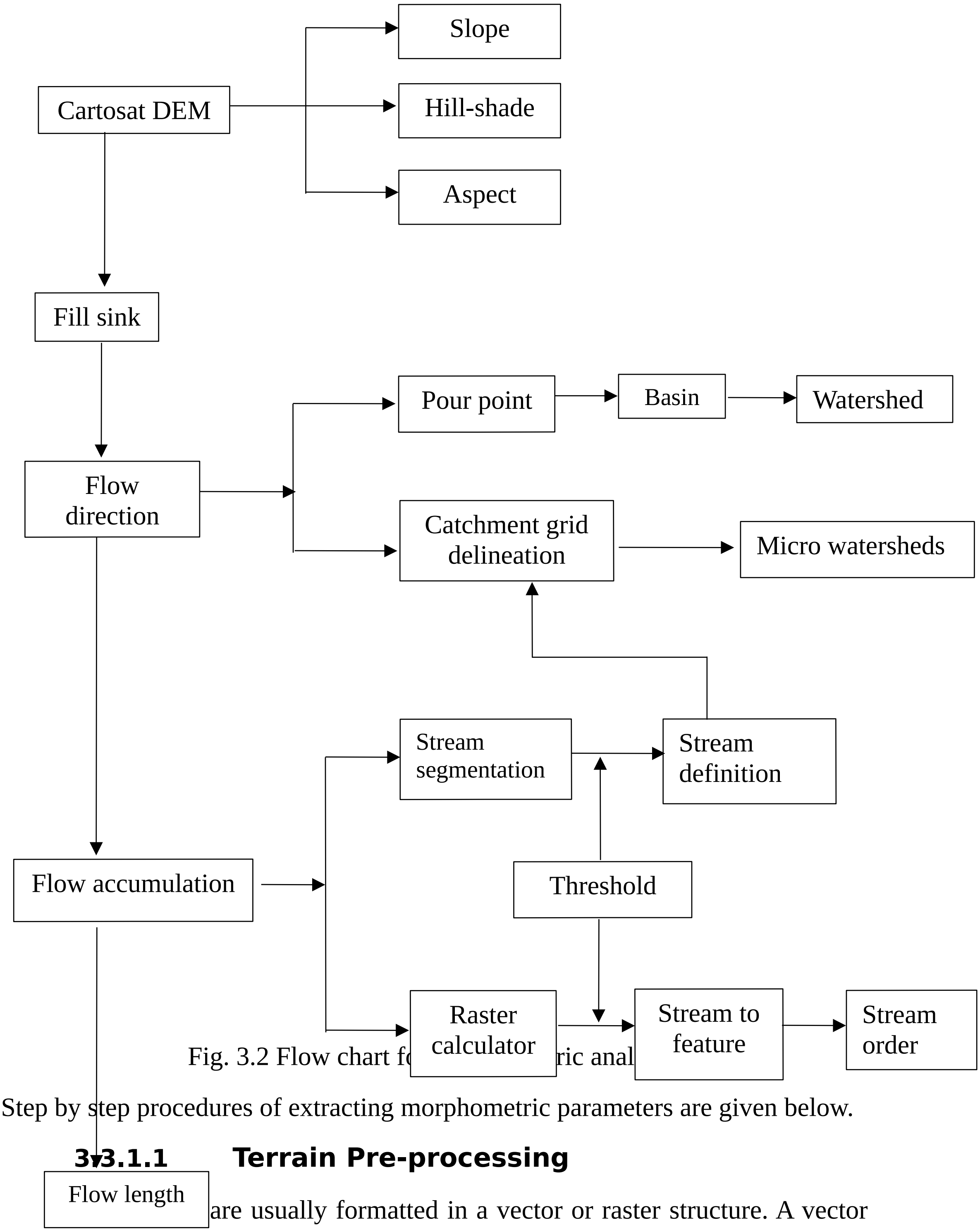


Fig. 3.2 Flow chart f ric anal

Step by step procedures of extracting morphometric parameters are given below.

3.3.1.1 Terrain Pre-processing

are usually formatted in a vector or raster structure. A vector dataset maps a geographic feature using lines drawn between points or coordinate pairs. An advantage of vector formats is that a database containing multiple attributes may be associated with any given point, line, or polygon. Whereas in the raster format, only a single attribute is usually associated with a grid cell. Vector data sets are used to show rain gages as points, streams as lines, and the watershed boundary as a polygon. A raster of grid cells represents rainfall in relation to the watershed and other features in the map.

Terrain Pre-processing should be performed in chronological order. All of the pre-processing must be completed before watershed processing functions using the model. DEM reconditioning and filling sinks might not be required depending on the quality of the initial DEM. DEM reconditioning involves modifying the elevation data to be more consistent with the input vector stream network. This shows an assumption that the stream network data is more reliable than the DEM data, so we need to use the knowledge of the accuracy and reliability of the data sources when deciding whether to do DEM reconditioning.

Open Arc Map. Create a new empty map. The Spatial Analyst Extension has to be activated, by clicking Customize->Extensions…, and then check the box next to Spatial Analyst.

Click on the Add icon to add the raster data. In the dialog box, we can locate the data; select the raster file containing the DEM for dem_clip and click on the Add button. The added file will then be listed in the ArcMap Table of contents. Step by step procedure for extraction morphometric parameter is given below.

(a) Fill sink

Fill sink function fills the sinks in a grid. If the cells with higher elevation surround a cell in model, the water is trapped in that cell and it cannot flow. This tool will help to fill all the artificial sinks in the DEM. The artificial sinks which are not part of the DEM will have to be filled up in this tool.

Right click on spatial analyst tool in catalogue option and select hydrology. In the Hydrology click on fill sink tool. There will be option given for specifying the DEM by default the selection and rename as per requirement

Confirm that the input for DEM is dem_clip. The output is the DEM layer (Named default Fill_dem). This Leave the other options unchanged.

Then Press ok. Upon completion of the successful process, the Fill layer is added to the map. This process takes a few minutes.

New Digital elevation model will have formed that will used for the further process. There couldn't find too much difference between the old DEM and new DEM.

(b) Flow Direction Grid

Every pixel has eight neighbors and the water falls into one pixel has probability of flowing in eight direction. This tool will determine eight flow direction map. This flow direction map has eight different colors because every pixel has eight neighbors. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell.

On the Hydrology Toolbar, select Flow Direction.

Confirm that the input for Hydro DEM is Fil. The output is the Flow Direction Grid, (default Flowdir_fill). And then Press ok. Upon completion of the successful process, the flow direction grid Flowdir_fill is added to the map.

(c)Flow Accumulation Grid

This function computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid. The traces of drainage network can be obtained from this tool.

On the Hydrology toolbar, select Flow Accumulation

Confirm that the input of the Flow Direction Grid is Flow_direc. The output is the Flow Accumulation Grid (default name FlowAcc_flow).

Press Ok. Upon successful completion of this process, the flow accumulation grid FlowAcc_flow is added to the map. This process may take several minutes for a large grid.

(d)Flow length

This tool helps to calculate length of the longest flow path within the watershed. This tool also helps to find the time of concentration of watershed.

On the Hydrology toolbar, select Flow length and make them default.

3.3.1.2 Extraction of stream network

(a) Raster calculation

Objective methods for the selection of the stream delineation threshold to derive the highest resolution network is consistent with geomorphologic river network properties. There is option for selecting threshold for defining a stream that means number of cell to start a river or stream. The threshold given for this condition is 25 which means that twenty five pixels are arranged in a manner that looks like river should be delineate as river. If it is less than 25 do not delineate it as stream.

On the spatial analyst tool, select map algebra in that select raster calculator

New window will be open for stream extraction, in that select flow accumulation and enter value FlowAcc >25 for deriving stream network and make output file as raster_calc.

Press Ok. Upon successful completion of this process, the raster layer is added with name raster_calc to the map.

After completion of raster calculation stream network is obtained but it is very difficult to see because it in grid format. To getting proper stream network grid format is converted into shape file. For converting grid format to shape file use spatial analysist tool, in that go for hydrology and select stream to feature tool. Select input raster such as raster_calc . The streams of this DEM is given below

For the complete defining of stream network ordering is necessary. For that defining go for the same spatial analyst tool and select the stream order tool.

Confirm that str and flow_direc are the inputs for the stream raster and flow direction grid and save in the target folder. For extracting stream order, Strahler method of ordering system is used.

Upon successful completion of stream order process convert the stream grid format to shapefile. This can be done by selecting Spatial analysist tool→ hydrology → stream to feature. Confirm that Stream order and Flow_ are the inputs of stream raster and flow direction raster and save the stream order shapefile has StreamTorder.

The identification of stream order difficult, because the stream order map is not classified. For the classification double click on streamTorder layer→ symbology →categories →unique values, select grid code in the value field and click add all values and make it as default.

b) Stream Definition Grid

On the Arc-Hydro toolbar, select Terrain Pre-processing -> Stream Definition.

Confirm that the input for the Flow Accumulation Grid is Fac. The output is the Stream Grid named Str (default)

Objective of this method is the selection of the stream delineation is to give threshold to derive the highest resolution network is consistent with geomorphologic river network properties. It has been developed and implemented in the Tau DEM software (http://www.engineering.usu.edu/dtarb/taudem). For this exercise, chose 4500 Km2 as the threshold area, and then click OK.

c) Stream Segmentation Grid

This function creates a grid of stream segments that have a unique identification. Here either a segment may be a head segment, or it may be defined as a segment between two segment junctions. All the cells in a particular segment have the same grid code that is specific to that segment.

On the Arc-Hydro toolbar, Select Terrain Pre-processing -> Stream Segmentation.

Confirm that Flow_direc and Str are the inputs for the Flow Direction Grid and the Stream Grid respectively. Otherwise if we are using our sinks for inclusion in the stream network delineation, the sink watershed grid and sink link grid inputs are Null. The output is the stream link grid (default name Str Lnk).

Press ok. Upon successful completion of this process, the link grid Str Lnk is added to the map. At this point, we can notice how each link has a separate value. Then Save the map document.

3.3.1.2 Extraction of basin and micro watersheds

a) Extraction of basin

For extracting watershed basin, pour point method was used. In this method basin delineation can be done from the point which is located at the outlet. Here pour point or outlet means the area or pixel that accumulates all the water from the area. Here it is used to delineate all the surface area that contributes water to pixel.

The selection of pour point involves creating new shape file and editing that file to locate point that accumulates in flow accumulation map and save the file. After editing pour point file, watershed delineation can be done in same spatial analyst tool.

On the hydrology tool select basin tool->

Confirm that the input flow direction map as flow_direc and input feature pour point as pour point. The output is the watershed. Then Press ok. Upon completion of the successful process the new raster format file watershed layer is added to the map. The perimeter and area of the watershed is obtained from the attribute data.

b) Extraction of micro watershed

To extract micro watersheds ArcHrdro tools are used. Right click on the menu bar to see the context menu showing available tools and then check the Arc hydro tools to add the toolbar to the map document. We can see the Arc Hydro toolbar added to Arc Map.

c) Catchment grid delineation

This function creates a grid in which each cell carries a grid code (value) indicating that to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid.

On the Arc Hydro toolbar, select Terrain Pre-processing -> Catchment Grid Delineation.

Confirm that the input to the Flow Direction Grid and Link Grid are Flow_direc and Lnk respectively. The output is the Catchment Grid layer. The default name (Cat).

Press OK. Upon successful completion of this process, the Catchment grid Cat is added to the map. Colour the grid format can be changed with unique values to get a nice display (use properties->symbology)

The file is in grid format and this file is converted into vector file by the tool raster to polygon in conversion tools. The perimeter and area of the individual micro watershed is obtained from the attribute data.

Towards the end of the section we will have the following datasets:

Raster Data:

1. Raw DEM (File name: **dem_clip**)

2. Fill DEM (File name: Fil)

3. Flow Direction Grid (File name: Flow_direc)

4. Flow Accumulation Grid (File name: Flow_acc)

5. Stream Grid (File name: Str)

6. Stream Link Grid (File name: Str Lnk)

7. Catchment Grid (File name: microwartershed)

8. Flow length (File name: flow_length)

9. Stream order (File name: streamorder)

10. Raster calculation (File name: rastercalc)

Vector Data:

1. Outlet (File name: pourpoint)

2. Stream order (File name: streamtorder)

3. Watershed (File name: watershed)

4. Micorwatershed (File name: microwatersehd_vec)

In addition to this datasets, drainage density, slope, aspect, Hill-shade map also derived.

3.3.1.4 Extraction of Slope map

Slope is an important parameter to determine the morphometric characteristics of the catchment. This represents the topographical structures with its degree of inclination with respect to a horizontal plain surface. We can also get the slope grid by using the Arc tool toolbar. To create a slope grid using Arc Toolbox, select Terrain pre-3D analyst tool->raster surface -> Slope.

Confirm that the input as dem_clip, and the output will be a slope grid with the default name (Slope). The number of classes and percentage of class interval of slope can be change in properties (use properties->symbology).

3.3.1.5 Extraction of aspect map

Aspect refers to the horizontal direction to which a slope of the surface faces and it is express3ed in terms of degree (00 to 359.90). We can also get the slope grid by using the Arc tool toolbar. To create a slope grid using Arc Toolbox, select Terrain pre-3D analyst tool->raster surface -> aspect.

3.3.1.6 Extraction of Hill-shade map

A Hill-shade is a grayscale 3D representation of the surface, with the sun's relative position taken into account for shading the image. We can also get the Hill-shade by using the Arc tool toolbar. To create a slope grid using Arc Toolbox, select Terrain pre-3D analyst tool->raster surface -> Hill-shade.

Confirm that the input as Thuthapuzha_dem and the output will be a Hill-shade grid with the default name (Hill-shade).

3.3.1.7 Extraction of drainage density map

Drainage density is an important indicator of the areal characteristics of the landforms in the stream-eroded topographical structures. It measures the relationship between precipitations and slope gradient to determine the runoff rate in the catchment. It is identified that the drainage density of the sub-basin area relates to the distribution of stream segments, length of streams, topography, relief, and climate.

Screenshot relating to this study

1. Creation of Fill sink, flow direction map

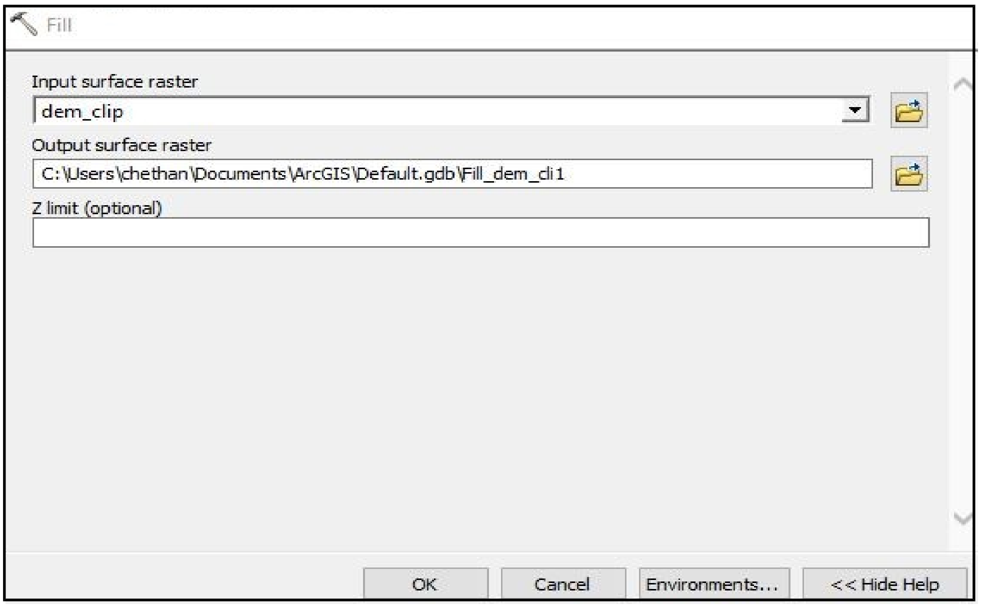


Fig. 3.3 (a) Fill sink in ArcGIS

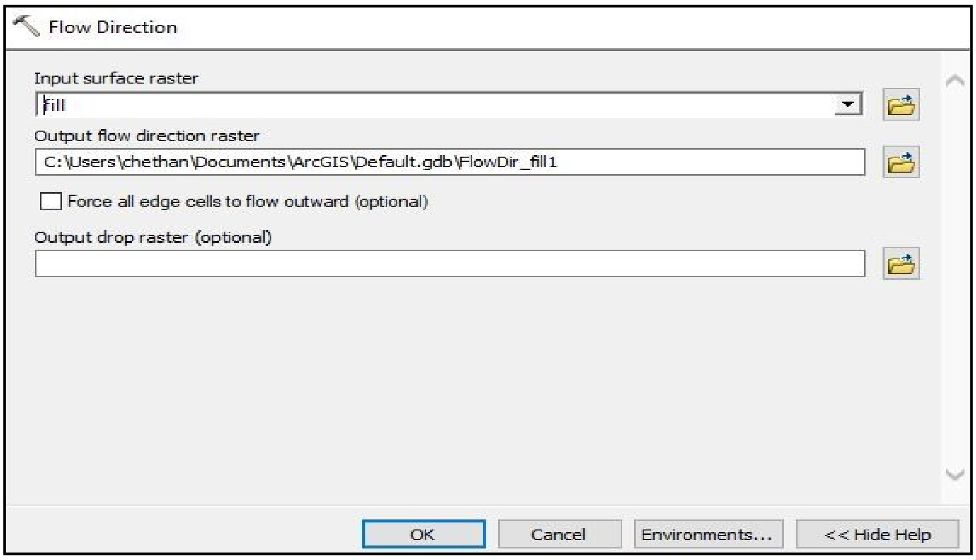


Fig. 3.3 (b) Flow direction in ArcGIS

Fig. 3.3 Snapshot of (a) fill sink, (b) flow direction

2. Creation of flow accumulation, flow length map

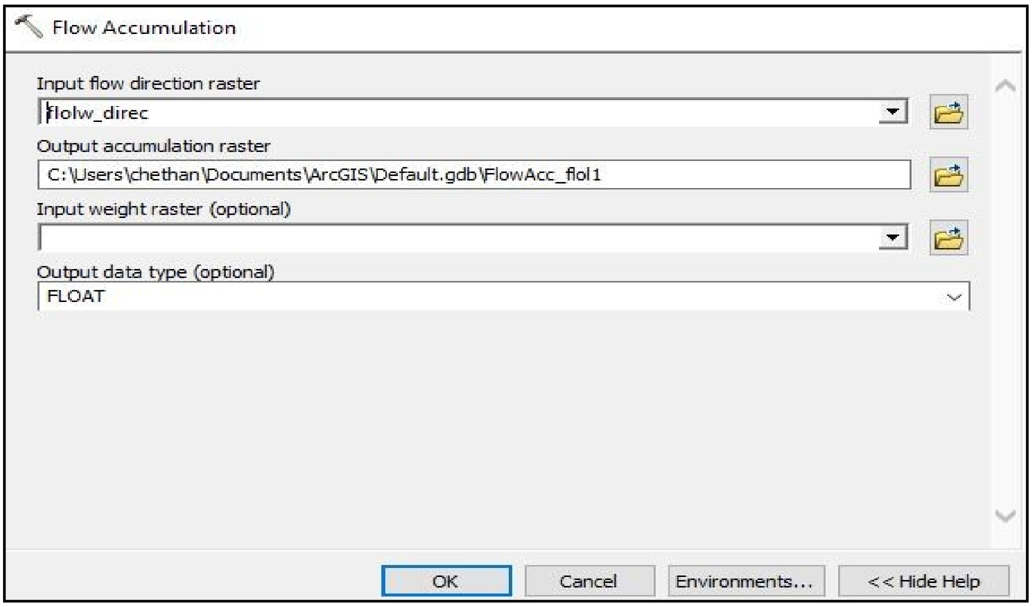


Fig. 3.4 (a) Flow Accumulation in ArcGIS

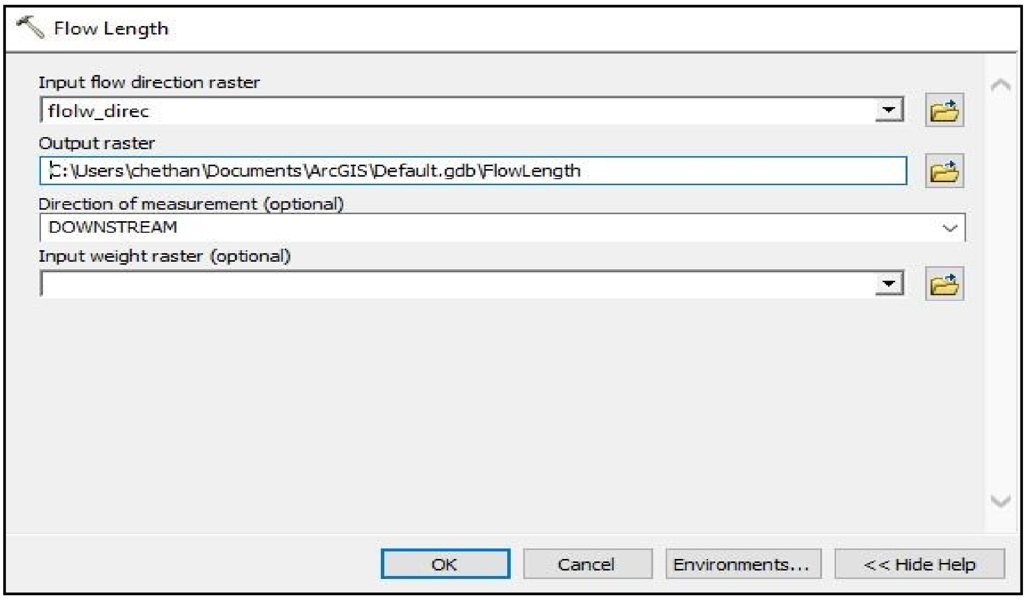


Fig. 3.4 (b) Flow length in ArcGIS

Fig. 3.4 Snapshot of (a) flow accumulation, (b) flow length

3. Creation of stream segmentation and stream order map

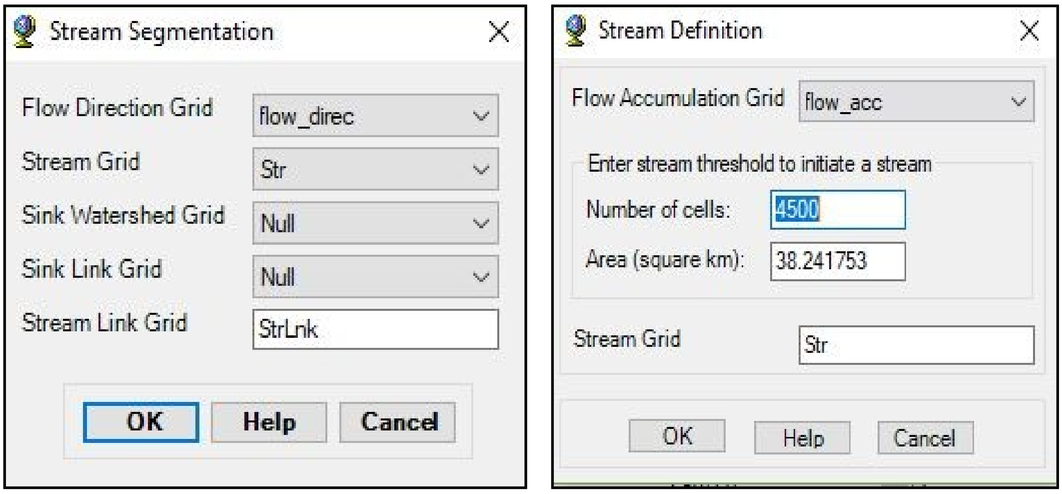


Fig. 3.5 Snapshot of stream, stream segmentation

4. Creation of stream segmentation, raster calculation, stream order map

Fig. 3.6 (a) Raster calculation in ArcGIS

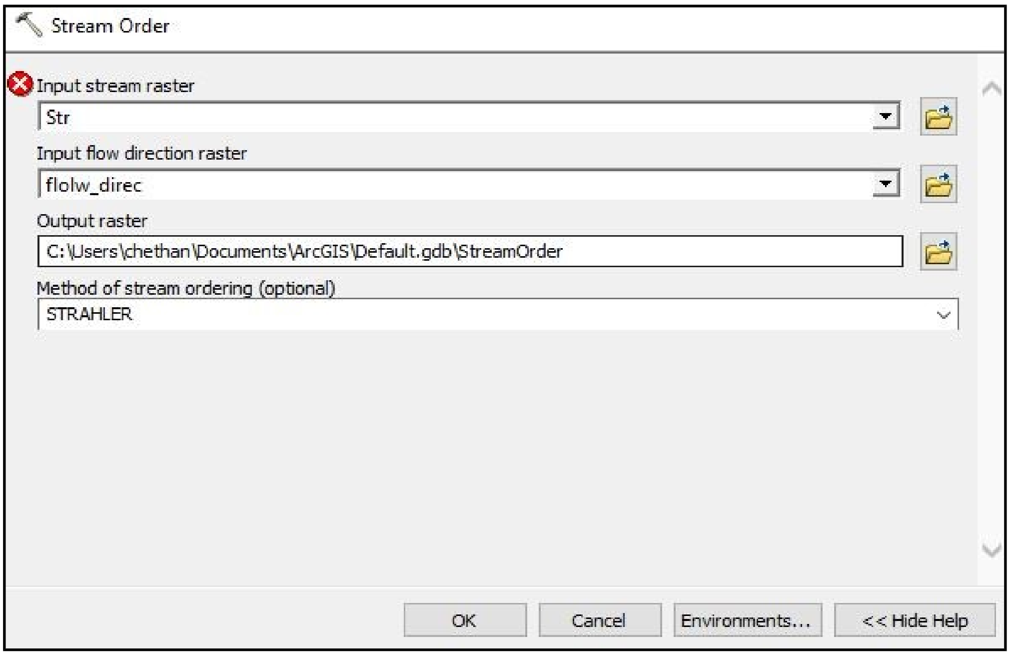


Fig. 3.6 (b) Stream order in ArcGIS

Fig. 3.6 Snapshot of (a) raster calculation, (b) stream order map

5. Creation of watershed and micro watershed map

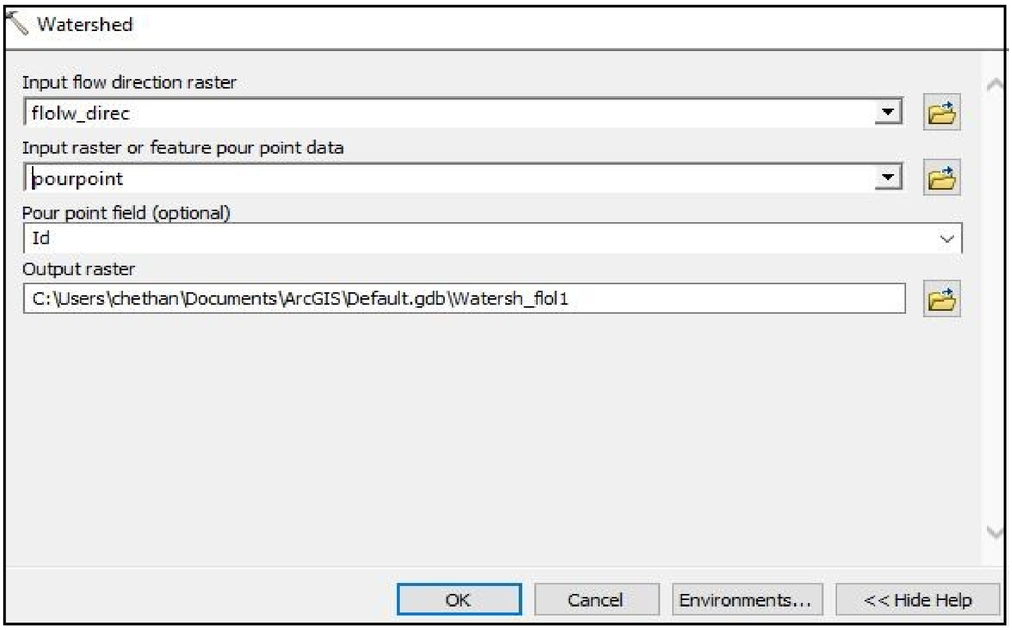


Fig. 3.7 (a) Screenshot of watershed delineation in ArcGIS

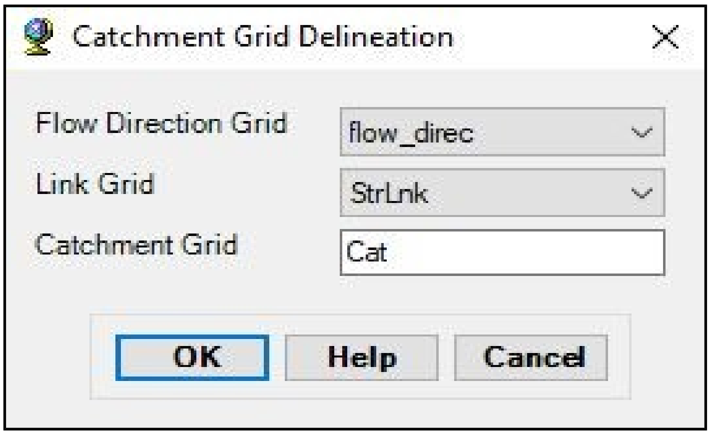


Fig. 3.7 (b) Screenshot catchment grid delineation in ArcGIS

Fig. 3.7 Snapshot of (a) watershed and (b) Catchment grid delineation map

6. Creation of slope, aspect, Hill-shade map

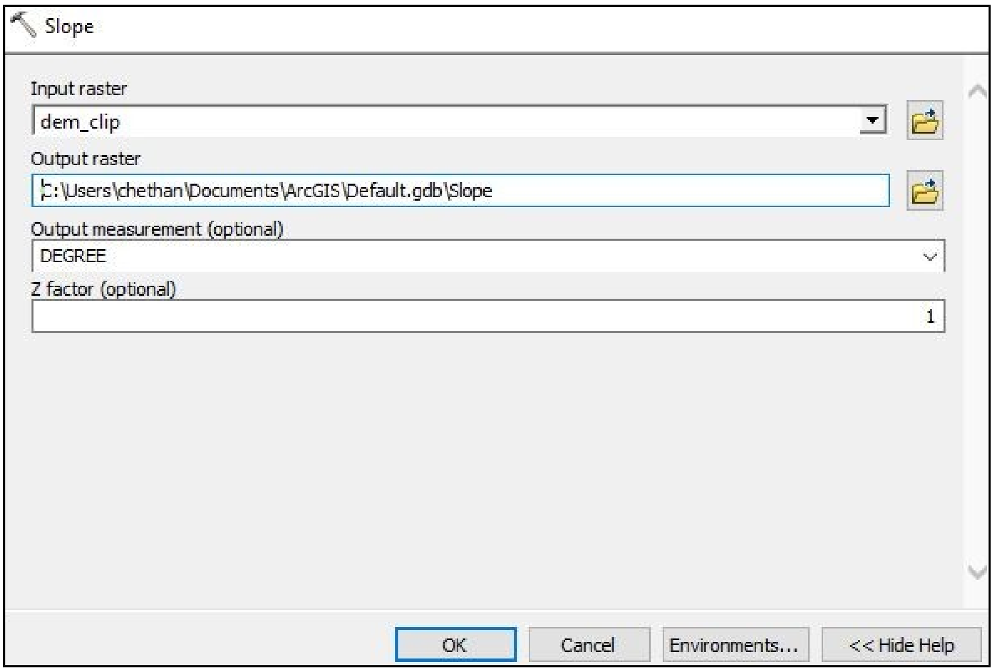


Fig. 3.8 (a) Screenshot of creating slope in ArcGIS

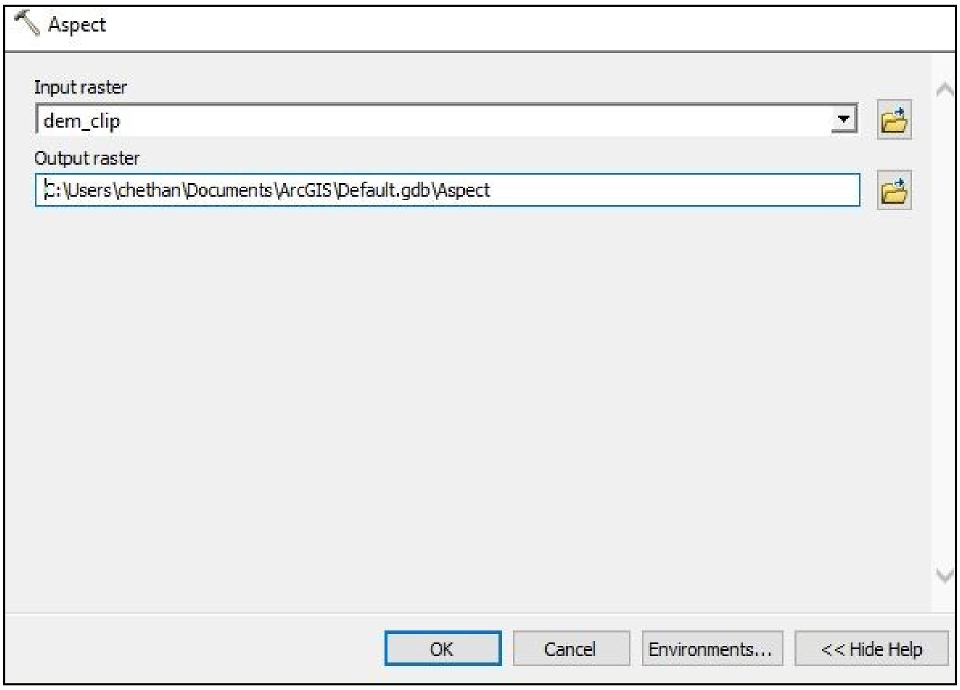


Fig. 3.8 (b) Screenshot of creating Aspect map in ArcGIS

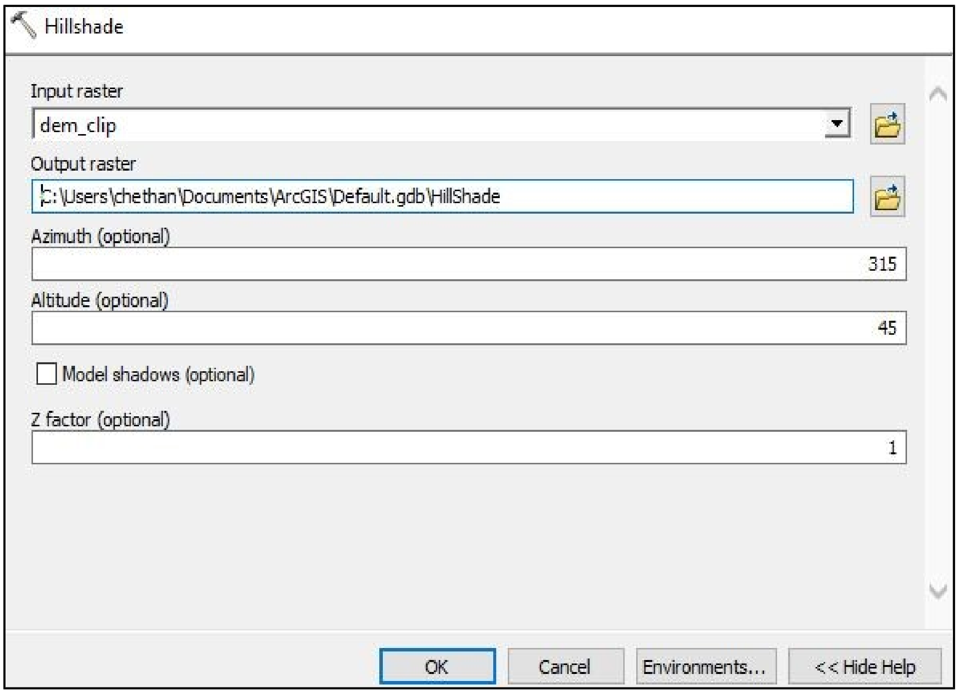


Fig. 3.8(c) Screenshot of creating Hill-shade map in ArcGIS

Fig. 3.8 Snapshot of (a) slope, (b) aspect, (c) Hill-shade map

All measurement of morphometric parameters are obtained in the attribute table. The parameters required for deriving geomorphological parameters are number of streams of order u (N_u), stream length of order u (N_l), area of the basin (A), perimeter of the basin (P), main channel length (L), maximum elevation (E_{max}) and minimum elevation (E_{min}).

3.3.2 Geomorphological parameters

Geomorphological parameters are landform equation which can be considered to reflect the surface roughness. The measure of all land surface form can considered to be representation of roughness where roughness is the irregularities in topographic surface. In other words the geomorphological parameter of a basin or watershed are the parameters which represent the physical and morphological attribute that will contribute to the runoff. In this study 14 parameters are identified and derived using morphometric analysis. All the parameters measurement is performed under four aspect: drainage network, basin geometry, drainage parameters and relief parameters using defined mathematical equation. Drainage network parameters includes bifurcation ratio, stream frequency, stream length ratio were measured to evaluate. Basin geometry involves elongation ratio, circulatory ratio, shape factor, form factor etc. In the drainage texture aspect of analysis drainage density, drainage texture, infiltration number, length of overland flow length of overland flow, constant of channel maintenance are to be measure. In case of relief aspect basin relief, relief ratio, ruggedness number are derived and all these parameters are discussed below.

3.3.2.1 Drainage network aspect

The Drainage network aspect includes parameters which transport water and sediments through single outlet. The geomorphologic parameters are

a) Bifurcation ratio(B_r)

The bifurcation ratio is calculated from the ratio of number of streams (N_u) in a given order to the number of streams (N_{u+1}) in the next higher order. It is given by

$$Bifurcation\,ratio\,(B_r) = \frac{N_u}{N_{u+1}}$$

Where, N_u is number of streams of order u, N_{u+1} is number of streams of order u+1

According to Horton (1945), the bifurcation ratio is considered as an index of relief and dissections. The high variations of bifurcation ratio in the different types of land forms indicate the formation of stream segments by the continuous runoff forces on the geological structure

b) Stream frequency(S_f)

Stream frequency is the total number of stream segments with all orders per unit area. It is also called as channel frequency. Stream frequency indicates that the origin and development of stream in the sub-basin and that is directly depend on lithological characteristics

$$Stream\,frequency\,(S_f)=\frac{N_u}{A}$$

Where, N_u is number of streams of order u, A is area of the basin in km^2

3.3.2.2 Basin geometry

Basin geometry involves the parameters which describe the shape of the river basin and it is two dimensional. The parameters are

a) Form factor (F)

Form factor is the important parameter in which it describe the shape of the basin and it is defined as the ratio of the area of sub-basin to the square of the main channel length (length of the basin). The value is vary from 0 to 1. The lower value indicates river basin is elongated where higher value indicates the basin is circular. It is given by

$$Form\,factor\,(F)=\frac{A}{L^2}$$

Where, A is area of the basin in km^2, L is main channel length in km

b) Elongation ratio (E_l)

It describes the shape parameter of the basin and this value indicate infiltration capacity along with stream flow path. Elongation ratio is the ratio of diameter of the circle having equal area to the sub-basin and the maximum length of the sub-basin. The value 0.9 to 0.8 indicates basin is circular, if it is 0.8 to 0.7 then it is oval and if tit is less than 0.7 then it is elongated. It is given by

$$Elongation\, ratio\,(E_l) = \frac{1}{(L)}\sqrt{\frac{A}{\Pi}}$$

Where, A is area of the basin in km^2, L is main channel length in km

c) Shape factor(S)

Shape factor is the ratio of square of the main channel length to basin area and describe the basin as circular, rectangular or triangular. This parameter directly impacts on the size of peak discharge and the time of concentration.

$$Shape\, factor\,(S) = \frac{L^2}{A}$$

Where, L is main channel length in km, A is area of the basin in km^2

Table 3.1 Indication of stream frequency value

Stream frequency	**Number of streams per km^2**
Low	0-5
Moderate	5-10
Moderate high	10-15
High	15-20
Very high	20-25

Table 3.2 Indication of form factor value

Form factor	**Shape**	**Nature of flow**

0	Highly elongated	Low peak for longer duration
0-0.6	Slightly elongated	Flatted peak flow for longer duration
0.6-0.8	Perfectly circular	Moderate to high peak flow for short duration
0.8-1.0	Circular	High peak flow for short duration

d) Circulatory ratio (C_r)

It represents shape characteristics of the sub basin. Circulatory ratio is defined as ratio of the area of sub-basin to the area of circle having circumference equal to the perimeter of the sub-basin. Sometimes it is also called as compactness ratio. It indicates the stage of dissection within the basin and mainly influenced by lithological characteristics of the basin. The low, medium and high values of the circulatory ratio are indications of the youth, mature and old stages of the life cycle of the tributary basins.

$$Circulatory\,ratio\,(C_r) = \frac{4 \prod A}{P^2}$$

Where, A is area of the basin in km^2, P is perimeter of the basin in km

3.3.2.3 Drainage parameters

Drainage texture analysis is includes the basin frequency, density and intensity of the drainage characteristics.

a) Drainage density (D_d)

Drainage density is defined as the ratio of total length of streams in all orders to the area of the basin. It describe the drainage characteristics of the basin. Drainage density identifies the distribution of stream segments, number of stream segments, climate, and topography.

$$Drainage\ density\,(D_d)=\frac{N_l}{\mathrm{A}}$$

Where, N_l, length of streams of all orders and A is the area of the basin.

Table 3.3 Indication of drainage density value

Drainage density	Explanation
<1	Less
1-2	Moderate
2-3	High
3-4	Very high

b) Drainage texture (D_t)

Drainage texture is total number of stream segments of all orders per perimeter of that area and it is important parameter in the field of geomorphology which describe the spacing of drainage lines.

$$Drainage\ texture\,(D_t)=\frac{N_u}{P}$$

Where, N_u is number of streams of order u, P is perimeter of the basin in km

Table 3.4 Indication of drainage texture value

Drainage texture	Significant
<2	Very coarse
2-4	Coarse
4-6	Moderate
6-8	Fine
>8	Very fine

c) Infiltration number (I_n)

Infiltration number of the basin is defined as the product of drainage density and channel (stream) frequency.

$$Infiltraion\,number\left(I_n\right)=D_d*S_f$$

Where, D_d is drainage density, S_f is stream frequency

This parameter gives idea about infiltration characteristic of the river basin and higher values of infiltration number gives lower infiltration hence higher will be the runoff.

d) Length of overland flow (L_f)

Length of overland flow is half of the reciprocal of drainage density and it defines the length of flow path projected to the horizontal of the non-channel flow. It depends on the hydrologic and physiographic condition of the basin. It inversely related to slope hence higher value of length of overland flow indicates more of stream erosion.

$$Length\,of\;overland\;flow\left(L_f\right)=\frac{0.5}{D_d}$$

Where, D_d is drainage density

e) Constant of channel maintenance (C_c)

Constant of channel maintenance is inverse of the drainage density and it is property of landforms. It indicates the relative size of the landforms and higher value indicates least erodible and vice versa. It is given by

$$Constant\ of\ channel\ maintenance\left(C_c\right)=\frac{1}{D_d}$$

Where, D_d is drainage density

Table 3.5 Indication of length of overland flow

Length of overland flow	**Significant**
<0.4	More stream erosion
0.4-0.7	Moderate stream erosion
>0.7	More sheet erosion

Table 3.6 Indication constant of channel maintenance value

Constant of channel maintenance	**Significant**
<0.2	More erodible
0.2-0.3	Moderate erodible
0.3-04	Moderately low erodible
0.4-0.5	Low erodible
>0.5	Least erodible

3.3.2.4 Relief parameters

Drainage network, basin geometry are one and two dimension parameters but in case of relief parameters, it is the three dimension parameters. By measuring the elevation of each stream segment to the point where it joins the higher order stream and dividing the total by the number of streams of that order, it is possible to obtain the average elevation(vertical fall). The parameters involved relief are

a) Basin relief (R_b)

Basin relief is defined as the elevation difference between highest elevations in the basin to the lowest elevation within the basin. More value of basin relief indicates lesser time to flow accumulation.

$$Basin\, relief\,(R_b) = E_{max} - E_{min}$$

Where, E_{max} is maximum elevation, E_{min} is minimum elevation

b) Relief ratio(R_r)

Relief ratio is defined as the ratio of maximum relief to main channel length (horizontal distance along the longest dimension of the sub-basin parallel to the principal drainage line). It describes steepness of relief in the basin.

$$Relief\, ratio\,(R_r) = \frac{R_b}{L}$$

Where, R_b is basin relief, L is main channel length in km

c) Ruggedness number(R_n)

Ruggedness number is defined as the product of the maximum basin relief and drainage density.

$$Ruggedness\, number\,(R_n) = R_b * D_d$$

Where, R_b is basin relief, D_d is drainage density

Since it depends on slope and drainage density, lower value of ruggedness number indicates lower stream flow velocity which implies less prone to soil erosion.

Table 3.7 Indication of Ruggedness number to prone to soil erosion

Ruggedness Number	**Prone to soil erosion**
<0.18	Less
0.18-0.36	Moderately low
0.36-0.54	Moderate
0.54-0.79	Moderately high
>0.79	High

The entire river basin is divided into micro watersheds and from all these sub basin, geomorphologic parameters are derived. Here also GIS software is used for deriving the parameters.

Microsoft excel 2013 version is used for doing calculation and making tables. The 14 parameters are identified and worked out for statistical analysis.

3.4 STUDY OF INFLUENTIAL GEOMORPHOLOGICAL PARAMETERS

The study of influential parameter on runoff involves, finding which parameter is more significant contribution to runoff. Identification significant parameter can be done by application of statistical analysis. Since the large number of data (14 parameters from micro watersheds), factor analysis can be better solution for the analysis of this kind of data

3.4.1 Factor analysis

Factor analysis is a statistical technique used to identify a relatively small number of underlying dimensions, or factors (internal attribute), which can be used to represent relationships among interrelated variables. The emphasis in factor analysis is the identification of underlying "factors" that might explain the dimensions associated with data variability. Factor analysis uses continuous data and it is a kind of multivariate analysis where large number of variable can be analysed statistically.

Factor analysis involves relation between geomorphological parameters and internal attribute (also called as factors) and the basic principle involved in factor analysis is that, factors influences these parameters in systematic pattern. This underlying factors measurement is the main objective for the finding influential parameter. Here factors are linear composite of the variables. Factor analysis doesn’t have dependent and independent variables. Since factors influences variables, results obtained from the factor analysis can be used create depend and independent variables.

3.4.2 Application of Factor Analysis

This analysis used to bring down large number of variables into fewer ones. It is the technique for data summarization and data reduction technique. It examines the relationship among a large number of variables, and then attempts to explain in terms of their common underlying dimension. Here common underlying dimension are referred to as factors.

3.4.3 Steps in Conducting a Factor Analysis

There are five basic steps that have to be considered for a Factor analysis experiment are discussed below

a) Geomorphological parameters

In this step the identified 14 geomorphological parameters from 17 micro watershed are worked out for statistical analysis are put it in excel and make into a table.

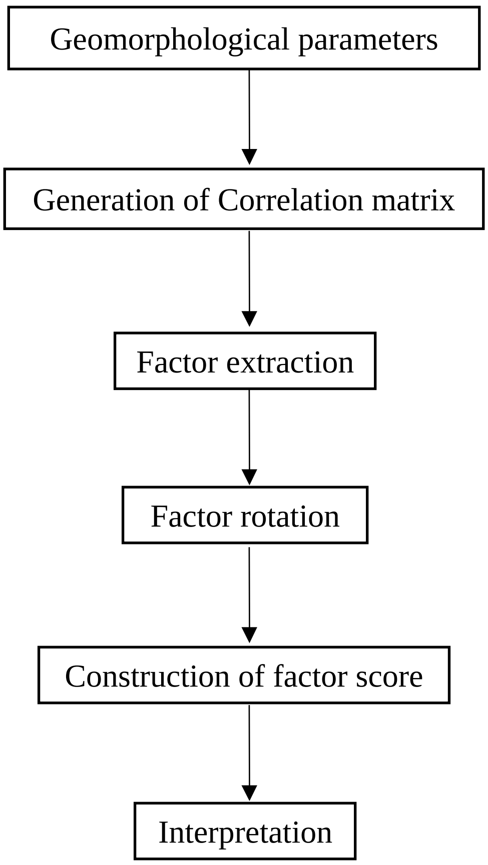


Fig. 3.9 Flow chart for the conducting factor analysis in Minitab

b) Generation of Correlation matrix

In this step correlation matrix for all variables are generated. It is also called loadings in factor analysis. Loadings are nothing but correlation of the variables with the factor. Loadings are main factor for identify the variables not related to other variables. Factor loadings to indicate up to what extent the factor can explain the variance and it is given by correlation coefficient which ranges from -1 to 1. To interpret the coefficient, square the loading and multiply by 100. The coefficients of correlation express the degree of linear relationship between the row and column variables of the matrix

c) Factor extraction

In this step the number of factors are to be extracted. Two methods are used to extract the factor, one is PCA and another one common factor analysis. Since purpose of the study is to create new variables as a linear combination with existing variables. From the principal factor analysis, the number of factors to be extracted can be found out. Eigen values and the Scree test indicates the number of factor that can be used for analysis.

I. Principle component analysis (PCA)

The analysis can be easy if the parameters are in groups and this grouping can be done by PCA. It is the mathematical procedure in which large number of correlated variables are transformed into smaller uncorrelated variables (called principal component (PC)) and this analysis used for the elimination of the insignificant parameters. The analysis of PCA is to explain maximum amount of variance with less number or few number of principal components. In PCA linear combinations of observed variables are formed. The first PC is the combination that accounts largest of variance in the sample (1st extracted factor). Successive components explains progressively smaller portions of the total sample variance, and all are uncorrelated with each other.

II. Scree test and Eigen values

Depends on the screen plot and Eigen values the number of factors are used for the analysis. Eigen values are one of the ways to extract the number of factors. Eigen values is nothing but sum of the square of the loadings across the factor. Eigen values greater than one is considered for the accepting the number of factors. Scree plot is the graph of number of factors versus its corresponding Eigen values and generally it is steep curve followed by bent and then a straight line. Scree plot shows bent at each factor and slope of this line basically gives the more variance. First factor explains highest amount of variance, second factor explains little bit less variance compare to first one and goes on decreasing order.

d) Rotation

After factor extraction, the analysis was run and the factors were inspected from different angles to see if the inference from all of them points to one output. Most of the variables are loaded at one factor for many times, in this condition we will use factor rotation. Rotation provides a structure of loadings and a pattern matrix of partial weights. By rotating the factor, the distribution of the variables is made much better across the factor. Rotation doesn't change the results of PCA but the pattern of loadings can easier to interpret the results.

There are two types of rotation: Orthogonal rotation and oblique rotation. In orthogonal rotation the factor matrix is rotated about orthogonally. Varimax is method of orthogonal rotation method in which, factor loading matrix is rotated to orthogonal simple structure. Varimax rotation attempts to maximize the dispersion of loadings between factors. Varimax rotation method gives maximization of variance of the factor loadings of the variables on the factor matrix Also, Varimax is good for simple factor analysis since it is known to be a good general approach that simplifies the interpretation of factors because of these Varimax rotation is mostly used. Two different facto matrix can be obtained while doing factor analysis. The first factor is unrotated factor matrix and another one is rotated factor matrix. The results from the rotated matrix is considered for the interpretation.

e) Construction of factor score

Factor coefficients identify the relative weight of each variable in the component in a factor analysis. Factor score also defined as measure one person's score on a given factor and this score can be used as dependent and independent variables for regression study The larger the absolute value of the coefficient, the more important the corresponding variable is in calculating the component. Minitab uses the factor coefficients to calculate the factor scores, which are the estimated values of the factors. Minitab calculates factor scores by multiplying factor score coefficients and after that data have been scaled.

f) Interpretation results from factor analysis

i. Interpretation of factor loadings

If the correlation between variables are small, it is unlikely that they share common factors (variables must be related to each other for the factor model to be appropriate). The closer to zero, the less the relationship; the closer to one, the greater the relationship. A negative sign indicates that the variables are inversely related in other word negative influencing parameter and positive sign indicates positively influencing parameter. Correlation coefficient greater than 0.7 in absolute value are indicative of acceptable correlation

ii. Interpretation of communalities

Communality is the variable contribution to each factor. It is the square of the loading or correlation coefficient of variable with respect to factor and it is same in both rotated and unrotated factor matrix. It explains variability that is explained by the factor and it is always less than one. If the communality value is nearer to 1 than better the variable explained by the factor.

iii. Interpretation of variance

Variance is squared deviation of the variable from its mean in each factor. If the variance is more, than the factor explains more variability and better will be the result.

iv. Interpretation of % variance

The percentage variance is the directly proportional to the variability explained by the factor. It ranges from 0 to 1(0% to 100%). Through the factor analysis we can determine at least 60% of variance in the study. When the variance is explained by the variable is less than 10% then neglect that factor.

v. Interpretation of factor score

It is the rank wise order of the variables within the factor in other words the important variable in each factor is given by factor score. The larger the value of variable, more important corresponding variable and that variable is used as independent variables in regression analysis.

3.4.4 Factor analysis in Minitab

Open Minitab. Two windows will be open, one is worksheet and another one session window. In worksheet all the parameters data entered into the worksheet.in session windows all the results are regarding the analysis are done in this space.

Add all the 14 parameters data into the worksheet.

On the Stat menu-> Multivariate->Factor analysis

Click on factor analysis and new window will opened for selecting the various option in the factor analysis.

Add all the parameters in variables section by dragging. Select number of factors to be analysed as four, method of extraction is selected to PCA and select Varimax for the type of rotation. The screenshot of this window is given below

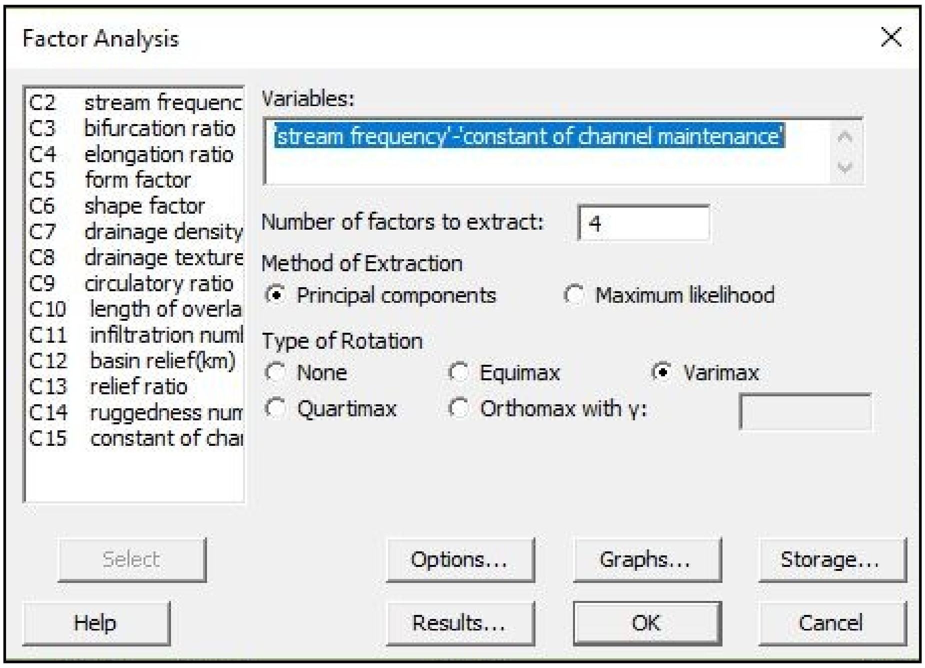


Fig. 3.10 Snapshot of factor analysis in Minitab

Select the graphs required for the analysis.

Click on scree plot, biplot plot, loading plot for first two factor, score plot for first two factors.

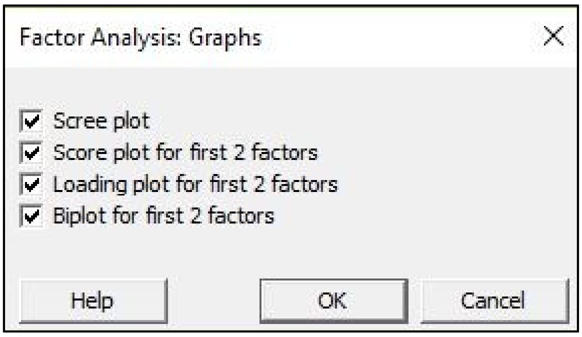


Fig. 3.11 Snapshot of selection of graph for factor analysis in Minitab

Click ok, again click ok in window of factor analysis. The results comes in the session window and there is option for saving directly into the word.

3.5 REGRESSION ANALYSIS

A regression analysis describes the statistical relationships between a given dependent variable and one or more independent variables and regression analysis can also evaluates relationship between the variables. Regression is the technique used to predict unknown value of variable (dependent) from the known value of variables (independent) also called as predictors. The relationship between dependent variables and one independent variables are given by univariate regression whereas more than one independent variables gives the multiple linear regression. The study also given the assumption of multiple linear regression which are linearity, normality, no extreme values and missing value are also examined. Hence regression is an appropriate statistical method in order to confirm or disconfirm the chosen hypotheses.

3.5.1 Dependent variable

In multiple regression model, variable which is used to predict unknown value is called dependent (also called response) variable. The results from the factor analysis is used for the multiple regression where the more variance explained factor can be used as the dependent variable in regression analysis. In this study, the monthly average rainfall is taken as dependent variables.

3.5.2 Independent variables

In multiple regression model, the known value of variables which are used to find the dependent variables is called independent variables (also called as predictors). The relationship between two or more independent variables and dependent variables gives multiple regression equation. In this study, the highest factor score obtained from factor analysis and monthly average rainfall is used for predicting by unknown variables.

The general form multiple regression is given by

$$Y = b_0 + b_1 X_1 + b_2 X_2 \ldots\ldots\ldots\ldots b_n X_n$$

Where Y is dependent variables X_1, X_2 ...X_n are independent variables and, b_0. . .b_n are the regression coefficient

A regression coefficient defines the size and direction of the relationship between independent and dependent variable and these coefficients are the numbers by which the values of the variables (independent variables) are multiplied in a regression equation.

3.5.3 Interpretation of key results of multiple regression analysis

The output from multiple regression includes the p-value, R^2, and residual plots. The p-value indicates determine whether the relationship between the response and the term is statistically significant. The value of R^2 indicates goodness-of-fit and residual plots indicates whether the model is adequate and meets the assumptions of the analysis. The detailed interpretation is given below

3.5.3.1 Interpretation of p-value

To determine relationship between the dependent and independent variables m in the model is statistically significant, compare the p-value for the variable to your significance level to assess the null hypothesis. The null hypothesis is that the term's coefficient is equal to zero, which indicates that there is no association between the variable and the dependent variable. Usually, a significance level (denoted as α or alpha) of 0.05 is considered for statistical analysis. A significance level of 0.05 indicates a 5% risk of concluding that relationship exists when there is no actual relations.

i. **p-value ≤ α: The relationship is statistically significant**

If the p-value is less than or equal to the significance level, then there is a statistically significant relationship between the response variable and the independent variable.

ii. p-value > α: The relationship is not statistically significant

If the p-value is greater than the significance level, then we cannot conclude that there is a statistically significant relation between the response variable and the independent variables. Again refit the model without or deleting that variables.

3.5.3.2 Interpretation of R^2

To determine how well the model fits your data, examine the goodness-of-fit statistics in the model summary table.R^2 is the percentage of variation in the response that is explained by the model. The higher the R^2 value, the better the model fits the data. R^2 is always between 0% and 100%. R^2 always increases when increase the number of predictors to a model. For example, the best five-predictor model will always have an R^2 that is at least as high the best four-predictor model. Therefore, R^2 is most useful when comparing models of the same size. Use predicted R^2 to determine how well model predicts the response for new observations. Models that have larger predicted R^2 values have better predictive ability.

3.5.3.3 Interpretation of residual plots

The residual plots to help you determine whether the model is adequate and meets the assumptions of the analysis. If the assumptions are not met, the model may not fit the data well. The residuals versus order verifies whether residuals are independent dependent. The plot shows no trend or pattern in case of independent residuals. Suppose the residuals falls near to center line, then the plots indicate residuals are near to each other may be correlated but not independent.

3.5.3.4 Interpretation of interaction plots for runoff

The interaction describes the how runoff changes when two independent variables are changed. The lines become curved when equation becomes polynomial.

3.5.3.5 Interpretation of model building report

Model building report shows how variables built in regression model. The report also shows regression equations, which variables contribute more to runoff and whether the independent variables are correlated each other.

3.5.3.6 Interpretation of prediction and optimization report

This report shows the assistant solution for obtaining target value. This report also shows the alternate solution as per required.

3.5.4 Multiple regression in Minitab

Open Minitab. Two windows will be open, one is worksheet and another one session window. In worksheet all the parameters data entered into the worksheet.in session windows all the results are regarding the analysis are done in this space.

Add rainfall, discharge data and the parameters having highest factor score into the worksheet.

On the Stat menu-> Assistant-> Regression ->Optimize response

Click on Optimize response and new window will opened for selecting the various option in the regression analysis.

Add runoff as response variables then select for the maximum response as response goal. Add all the parameters in variables in continuous X variables by dragging. Make it default and press Ok. The screenshot of this window is given below

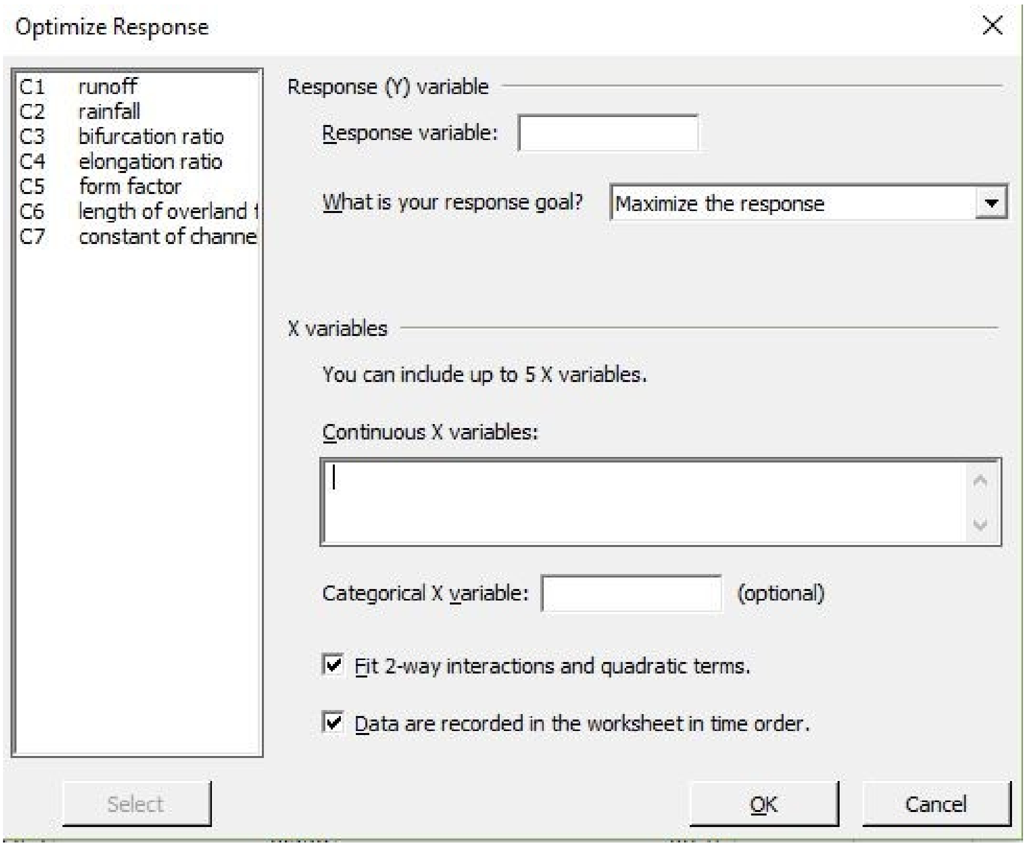


Fig. 3.12 Snapshot of multiple regression analysis in Minitab

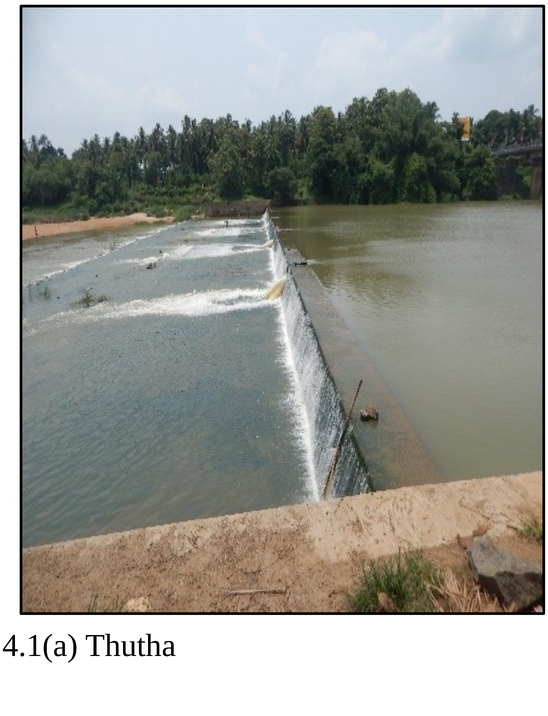
CHAPTER IV

RESULTS AND DISCUSSION

This study was aimed at deriving the geomorphological parameters using GIS and finding which parameters are influencing more to runoff. Factor analysis and regression analysis is employed to find influencing parameter statistically. The Minitab was used for this purpose. The geomorphological parameters, factor analysis, regression analysis were elements present to find out influence of geomorphology on runoff. The results of the study and their inferences are presented in this chapter.

4.1 CATCHMENT CHARACTERISTICS OF THUTHAPUZHA RIVER BASIN

Thuthapuzha River in different places are shown in Plates 4.1(a), (b) and (c)



4.1(a) Thutha

4.1(b) Pulamanthole

(c) Outlet near Kuttippuram

Plates 4.1 Location of Thuthapuzha River at different location at (a) Thutha

(b) Pulamanthole (c) Outlet near Kuttippuram

4.1.1 Terrain characteristics

Terrain characteristics involves DEM, flow direction, flow accumulation, stream grid and all raster format as shown below

The digital elevation model of the Thuthapuzha watershed is presented in Fig. 4.1. The study area falls within three physiographic zones of Kerala state. The basin having the highest elevation of 2326m with a lowest of -4 meters.

Fig 4.1 DEM of the Thuthapuzha river basin

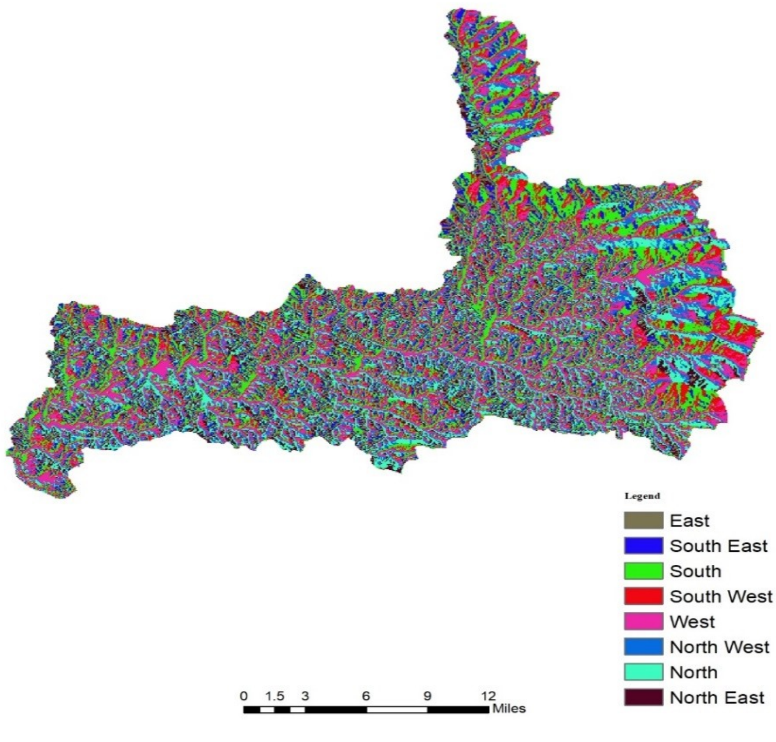


Fig 4.2 Flow direction map in ArcGIS

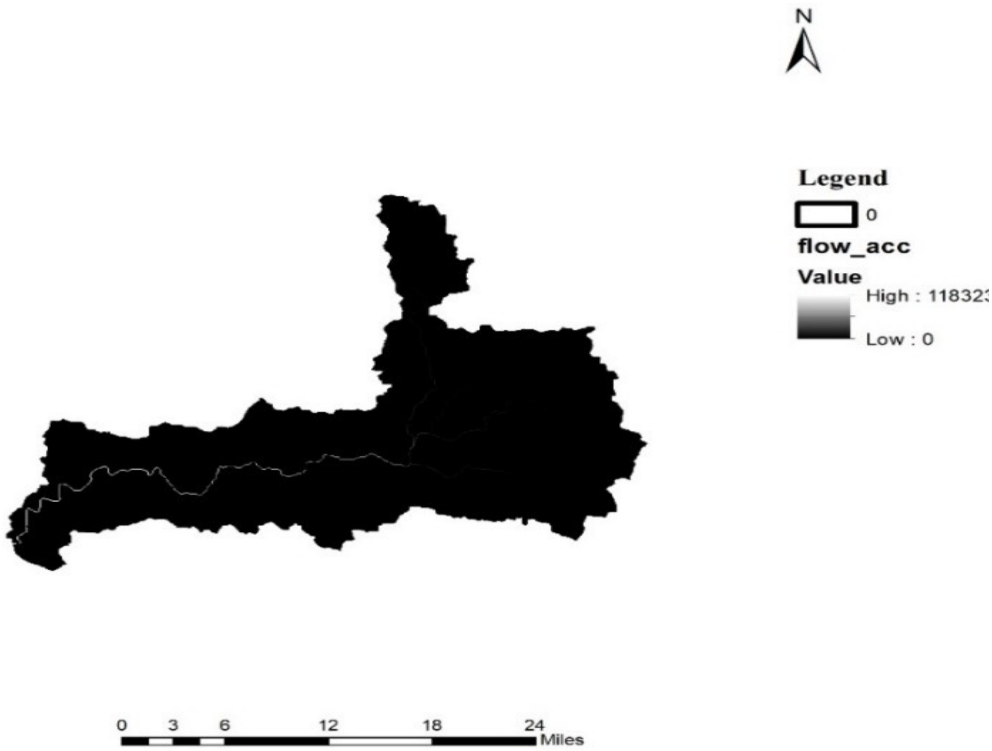


Fig. 4.3 Flow accumulation map in ArcGIS

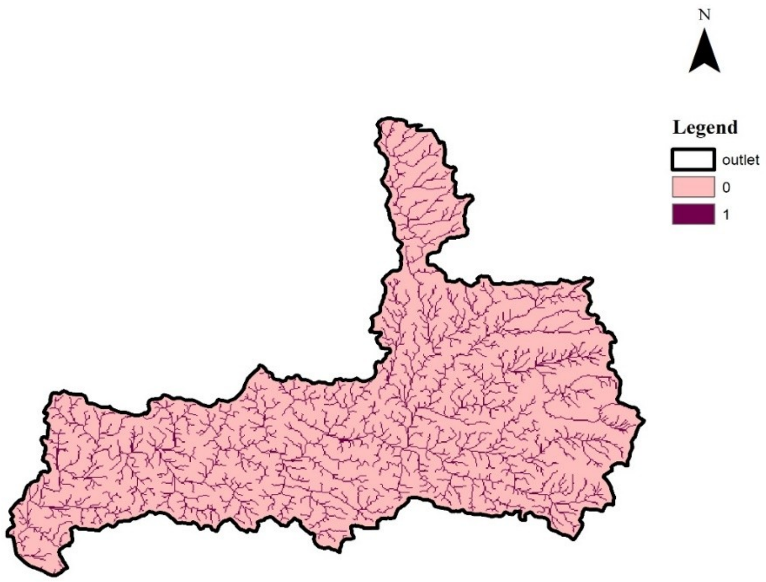


Fig. 4.4 Stream grid map in ArcGIS

4.1.2 Morphometric evaluation of Thuthapuzha sub-basin.

The morphometric parameters were measured quantitatively. The morphometric data were obtained with the help of attribute data. From that attribute data basin having area of 1005 km^2 with a perimeter of 240 km. Length of the main channel is about 99.64 km are obtained. The streams in the basin exhibits dendritic in nature which means that the basin is having many streams which are then joined which is called the tributaries of the river and this nature of drainage pattern develop where river channel follows slope of terrain. The streams of different orders is shown in Fig 4.4.

a) Stream number (N_u) and stream order (U)

The stream order is defined as the origin of streams and the interconnections among them. It is useful to understand the stream shape, size, length, width and discharge amount of the streams. In this study, the stream order was classified according to Strahler's ordering system (Strahler, 1957). Based on this ordering system, the sub-basin area having six orders of streams. Small, narrow streams originating from high elevated hilly terrains and designated as first-order stream, the total number of which obtained from morphometric analysis is 1216. The second order streams are formed from where the two first-order streams join and form as a single outlet. Here, in this sub basin, the total number of these streams is 567. The sub-basin consists of six orders of streams with a total of 2414 stream segments in all orders. Out of these, the first stream order was found in larger numbers than the next hierarchical orders except sixth order, revealing that the terrain obviously had steep slope and short flow length in nature. The number of streams with their order is given Table 4.1

Table 4.1 Number of streams with their order

Stream order	**Number of streams**
1	1231
2	567
3	252
4	192
5	69
6	103

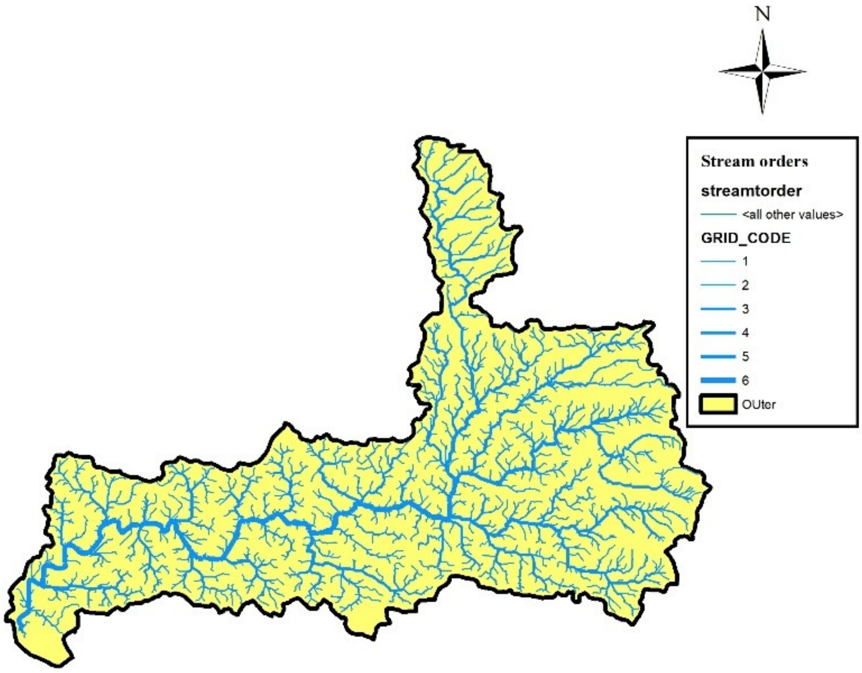


Fig 4.5 Stream order map of the Thuthapuzha river basin

b) Stream length (S_L)

The length of the stream in the sub-basin area was measured from the attribute data table of the stream order layer. Stream length is a direct indicative factor to measure the drainage density and the contributing area of runoff in the sub-basin. The total length of streams in all hierarchical order is 1469.52 km. Among them, stream segments in the first order occupied a length of 778.29 km and the second order about 334.79 km. The stream lengths of all order are given in Table 4.2

Table 4.2 Stream length with their orders

Stream order	Stream length (km)
1	778.29
2	334.79
3	149.91
4	107.9
5	39.81
6	58.82

c) Length of the main channel (L)

The main channel is the longest drainage line from the outflow point to the upper limit of the catchment area. This has been measured from the flow length layer and the value is 99.64 Km.

4.1.3 Slope of Thuthapuzha river basin

Slope is an important parameter to determine the morphometric characteristics of the catchment. This represents the topographical structures with its degree of inclination with respect to a horizontal plain surface. The slope of the study area was derived from DEM using surface analyst tool of ArcGIS 9.3 software. The slope range of this sub-basin is estimated from 0 to 67.52%. It is observed that the slope faces down in a southerly direction; however, the ridged structural hills in the northern parts consist multi-faceted slope directions. The slope gradient of this hilly surface directly influences the flow direction of drainage networks. The spatial variation of consequent slope gradients has direct influences on the runoff and denudation activities in the sub-basin area. The slope map of Thuthapuzha River is shown in Fig 4.6.

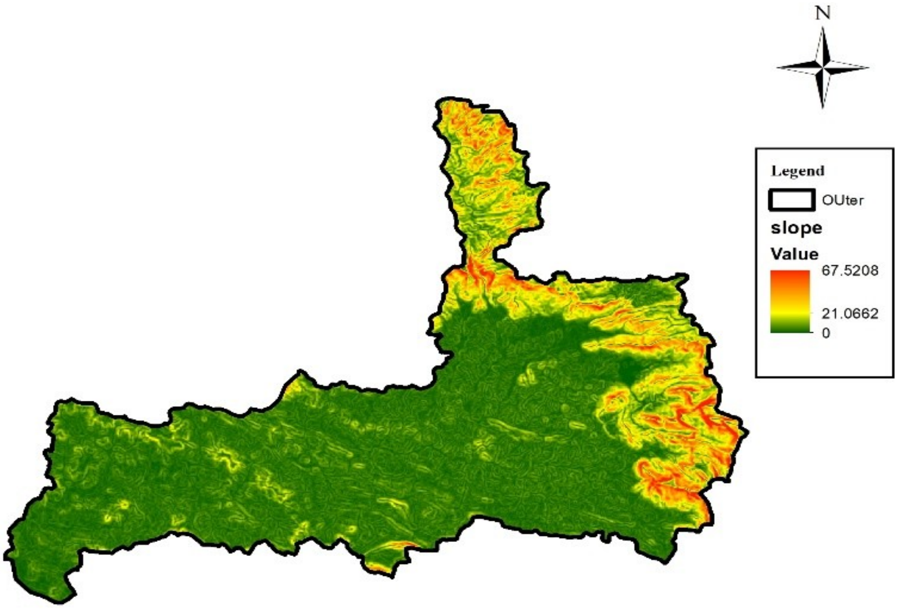


Fig. 4.6 Slope map of Thuthapuzha river basin

4.1.3 Aspect map of Thuthapuzha river basin

Aspect refers to the horizontal direction to which a slope of the surface faces. The aspect of the surface can influence significantly the local climate. This is because of the interaction of the angle of the sun's rays with the surface. Based on this concept, the easterly aspect of the study area faces direct sunlight during the hottest time of day before noon to noon, while the slope facing westerly aspect is exposed to sunlight during the afternoon. In this study, the aspect map is derived from the DEM using Spatial Analyst tool in ArcGIS software. The output raster map shows the compass direction of the aspect with ranges from 0^0 to 360^0, in which the value 0^0 is for true north and a 90^0 aspect is to the east, whereas 180^0 is to the south and so on. The visual interpretation of the aspect map reveals that the western parts have noticed with easterly and north-easterly aspect. Moreover, the northern hilly terrain and eastern parts have found with westerly and south-westerly aspect, this west facing slope surface has strong effect on weathering, drainage network flow and distribution of natural vegetation. Aspect map of Thuthapuzha river basin is shown in Fig. 4.7.

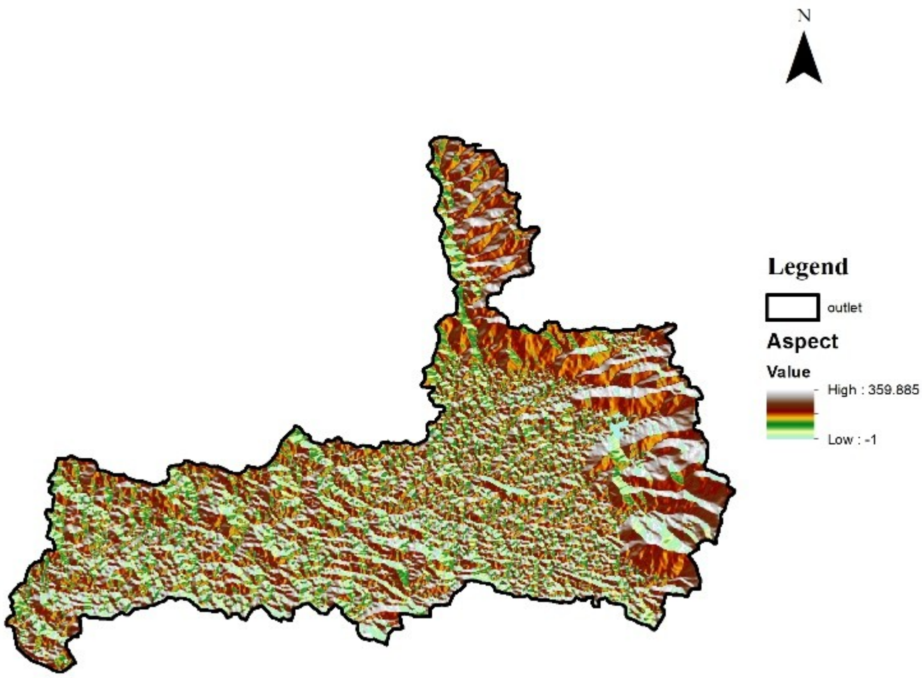


Fig. 4.7 Aspect map of Thuthapuzha river basin

4.1.4 Average annual rainfall

The morphometry of the sub-basin is highly influenced by the rainfall which induces surface runoff and overland flow depending on the slope condition. The area has available rainfall during both south-west monsoon (June–September) and north-east monsoon (October–December). The maximum rainfall occurs during the north-east monsoon (October and December) periods.

4.1.5 Hill-shade

Hill-shade represents the 3D representation of surface and it's just indication of mountain ridges and slopes. The map is generated up to azimuthal 315^0 and altitude from 0^0 to 90^0. In this study the Hill-shade is obtained maximum of 254^0. The Hill-shade of the Thuthapuzha river basin is shown in Fig 4.8.

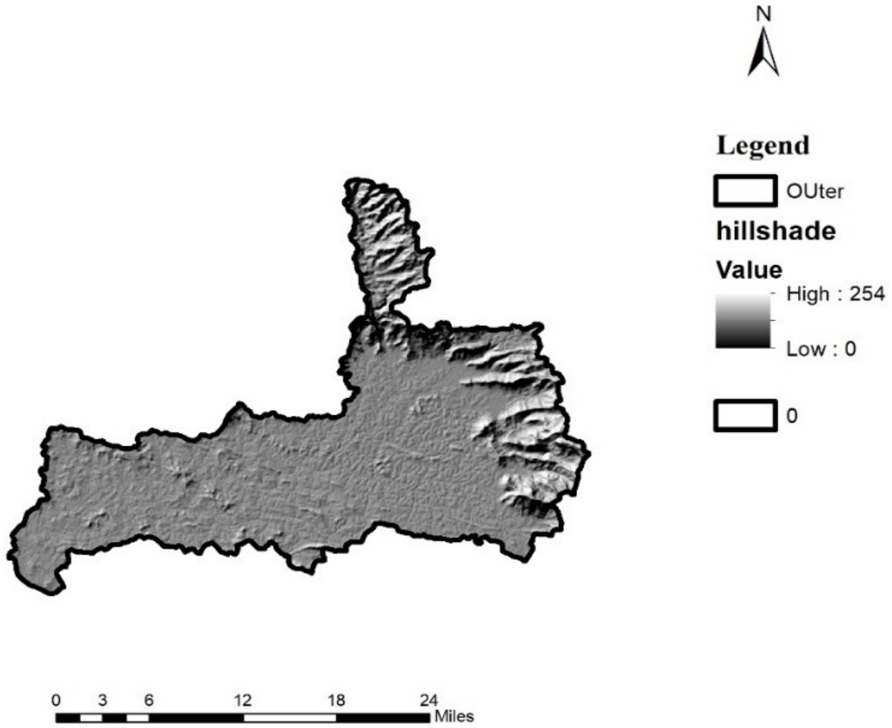


Fig. 4.8 Hill-shade map of the Thuthapuzha river basin

The parameters required for deriving geomorphological parameters are derived from morphometric parameters. The parameters are number of streams of order u (N_u), stream length of order u (S_L), area of the basin (A), perimeter of the basin (P), main channel length (L), maximum elevation (E_{max}) and minimum elevation (E_{min}) are used for computing geomorphological parameters.

4.2 GEOMORPHOLOGIC PARAMETERS OF THUTHAPUZHA RIVER BASIN

The geomorphological parameter of a basin or watershed are the parameter which represent the physical and morphological attributes those will contribute to the runoff. In this study 14 parameters are identified and derived using morphometric analysis. The entire river basin is divided into 19 Micro-watershed as shown in Fig. 4.9 and among the 19 Micro-watersheds number 9 and 11 there is no streams present in the area and the area is also less than 1 km2. So except from these two Micro-watershed, geomorphologic parameters are derived for 17 Micro-watersheds. Here also GIS software is used for deriving the parameters.

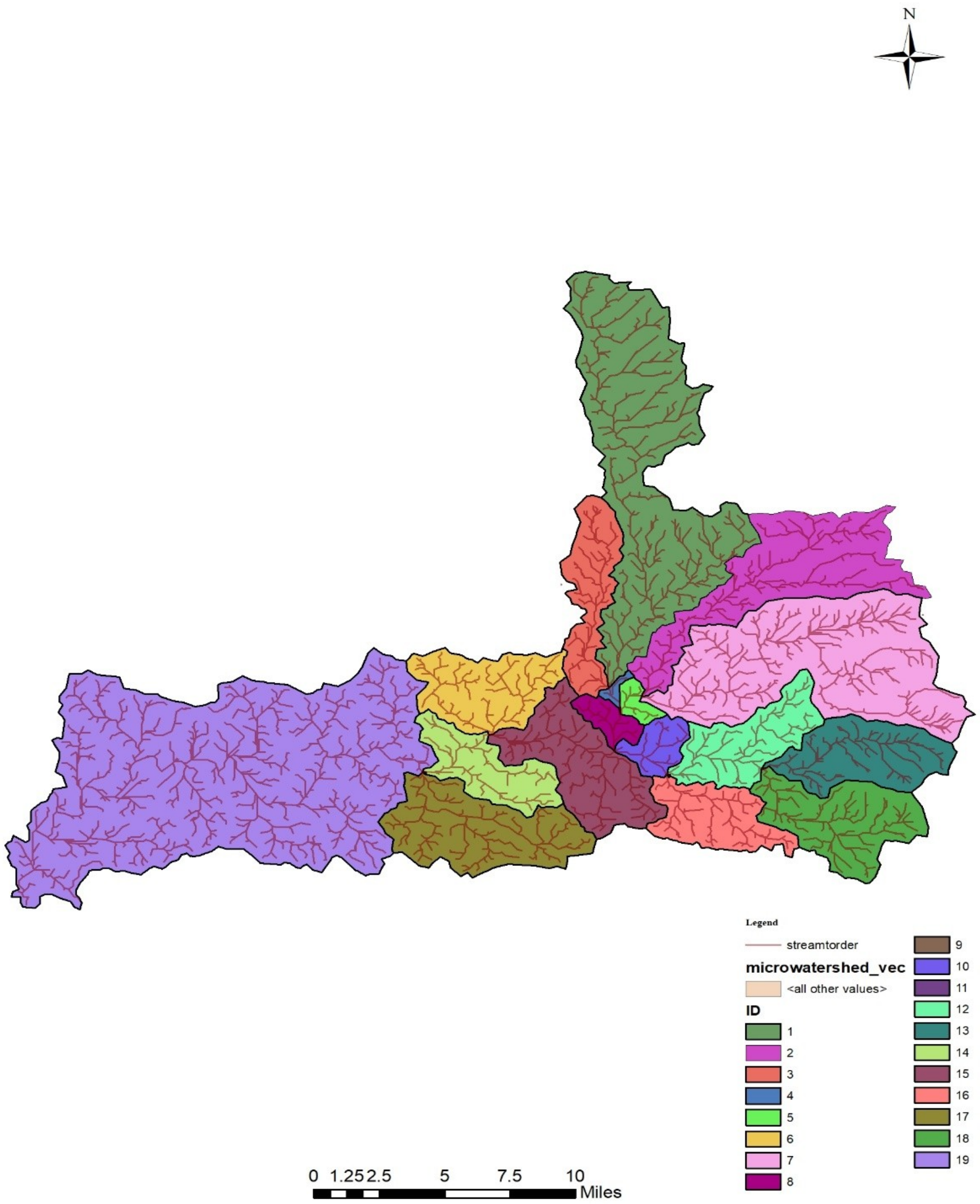


Fig. 4.9 Micro-watersheds map of the Thuthapuzha river basin

Microsoft excel 2013 version was used for doing calculation and making tables. The 14 parameters were identified and worked out for statistical analysis. All the parameters is computed performed under four aspects: linear, areal and relief parameters using defined mathematical equation. Linear parameters includes bifurcation ratio, elongation ratio, stream length ratio, stream frequency were measured to evaluate linear geomorphological parameters of the sub basin. In the areal aspect of analysis drainage density, drainage texture, infiltration number, length of overland flow length of overland flow, constant of channel maintenance were going to measure. In case of relief aspect basin relief, relief ratio, ruggedness number are derived

4.2.1 Drainage network parameters

The Drainage network aspect includes parameters which transport water and sediments through single outlet. The geomorphologic parameters are

a) Bifurcation ratio (B_r)

The bifurcation ratio was calculated from the ratio of number of streams (N_u) in a given order to the number of streams (N_{u+1}) in the next higher order and the value will varies from 0.66 to 2.78 for whole river basin with an average mean bifurcation ratio is 1.83. The higher ratio values have been calculated between the stream orders such as fourth and fifth order; second and third; first and second and the values are 2.78, 2.25 and 2.17 respectively. These lower values bifurcation ratio indicates that continuous runoff characteristics is structurally less disturbance hence runoff does not affected by geological condition. Bifurcation ratio for Micro-watersheds is ranges from 1.61 to 2.94 and also it was observed that highest bifurcation value is obtained (Micro-watershed 5 and Micro-watershed 13) in hill region which indicates runoff is affected by structurally. All Micro-watersheds with its bifurcation ratio is shown in Fig. 4.10.

a) Channel frequency/stream frequency (S_f)

Stream frequency is total number of stream segment of all orders per unit area. In the present study area, the stream frequency was obtained as 2.40 km/km^2. Lower value indicated stream frequency has fewer structural disturbances hence it caused a high rate of surface runoff and fast stream flow from the higher-order streams. This condition also prevailed in this area where a large amount of sediment has been eroded from the weathered rocky surface. Stream frequency for Micro-watersheds is ranges from 1.775 to 3.262 which indicated in all Micro-watersheds the number of streams per unit area is very low. All Micro-watersheds with its stream frequency is shown in Fig. 4.11.

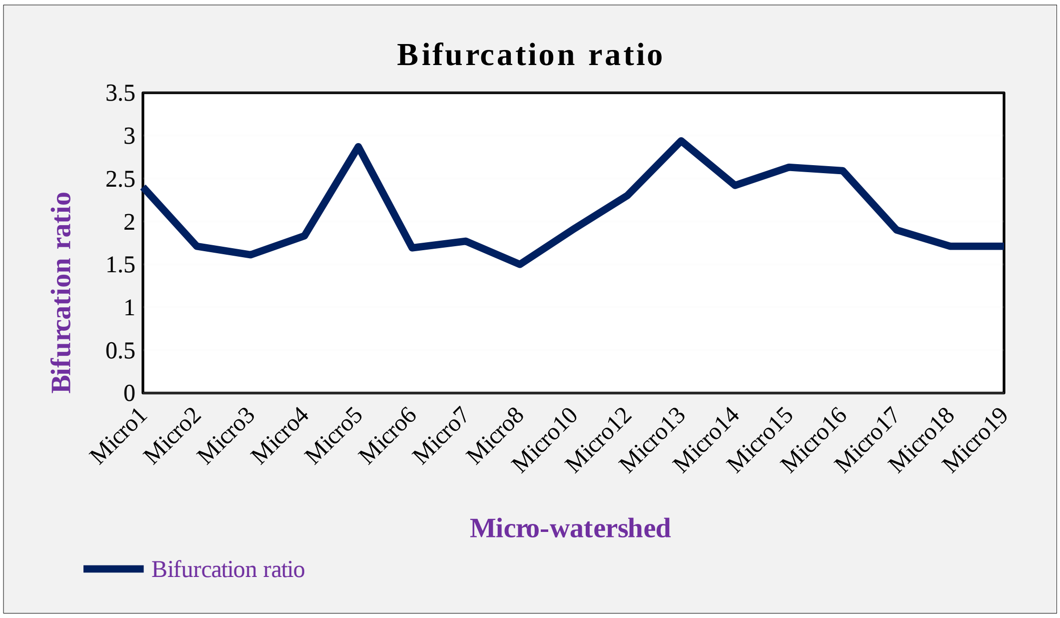


Fig. 4.10 Bifurcation ratio for all 17 Micro-watersheds in Thuthapuzha river basin

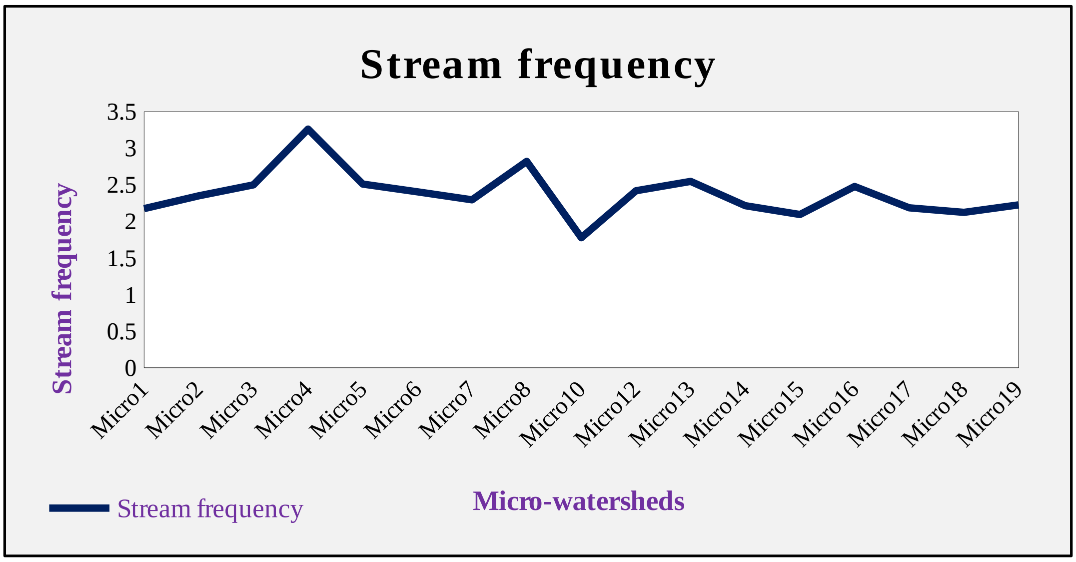


Fig. 4.11 Stream frequency for all 17 Micro-watersheds in Thuthapuzha river basin

4.2.2 Basin geometry

Basin geometry involves the parameters which describe the shape of the river basin and it is two dimensional. The parameters are

a) Elongation ratio (E_l)

Elongation ratio is an important parameter which describes the shape of a sub-basin area. The elongated length (main channel length) of the study area is 99.64 km and the computed elongated ratio is 0.176.This lower value has indicated that the sub-basin area is more elongated and it is characterized by low infiltration capacity along the river flow path hence runoff will be more with higher relief. Elongation ratio for Micro-watersheds ranges from 0.189 to 0.448. It is observed that elongation ratio lower in case hilly region (Micro-watershed 1, 2, 7, 3, 19) which indicates basin is more elongated. All Micro-watersheds with elongation ratio is shown in Fig. 4.12.

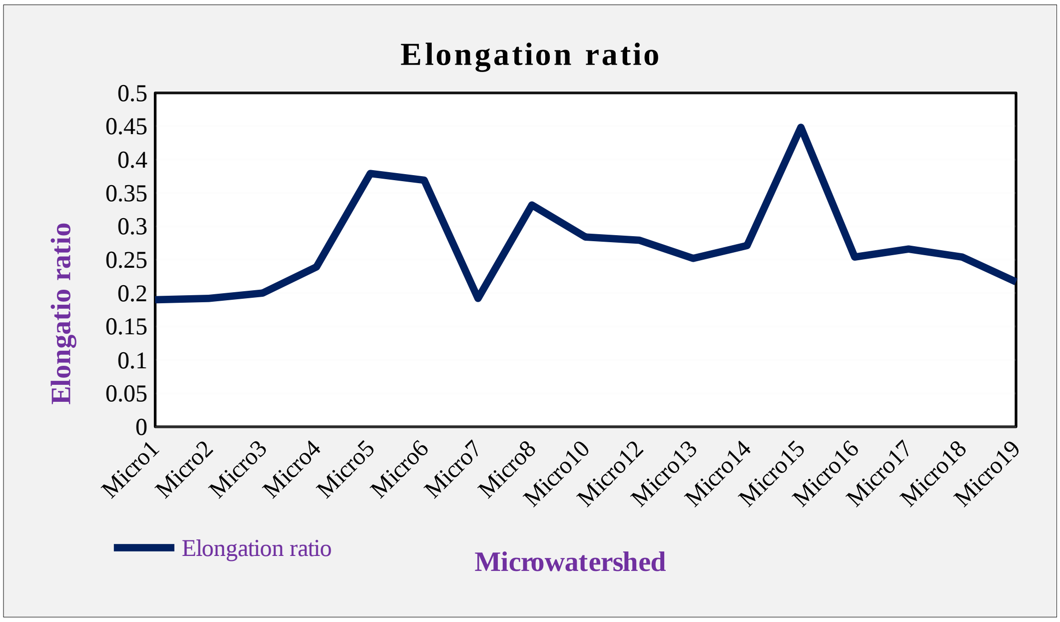


Fig 4.12 Elongation ratio for all 17 Micro-watersheds in Thuthapuzha river basin

b) Form factor (F)

Form factor is an important parameter to describe the shape of the catchment area. In this study area, the value of the form factor is measured as 0.10. The lower value indicated that the sub basin had more elongated shape in nature with the characteristics of flattened peak flow for a longer duration. Such elongated sub basins are highly vulnerable to flood flows than circular-shaped catchment area. Out of 17 Micro-watershed, the highest form factor is obtained from Micro-watershed 15 is about 0.62 which indicates moderate to high peak flow for short duration. Remaining all Micro-watersheds exhibited low form factor. Form factor for each Micro-watershed is given in Fig 4.13

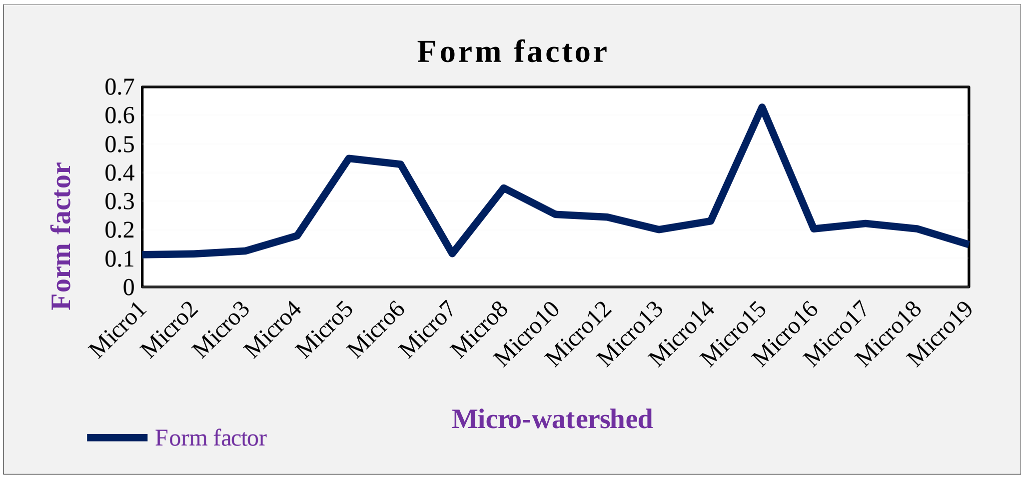


Fig. 4.13 Form factor for all 17 Micro-watersheds in Thuthapuzha river basin

c) Shape factor(S)

Similar to circulatory ratio, elongation ratio, form factor shape factor gives an idea about circular character of basin. Higher value of 9.87 indicates less circular more elongated which gives idea that basin is having shortest basin lag time. Shape factor for Micro-watersheds is ranges from 1.593 to 8.828. The lowest value is obtained from Micro-watershed 15 is about 1.593 which indicates circular, hence this are Micro-watershed gives moderate to high peak flow with short duration. The shape factor for all Micro-watersheds in Thuthapuzha river basin is shown in Fig. 4.14.

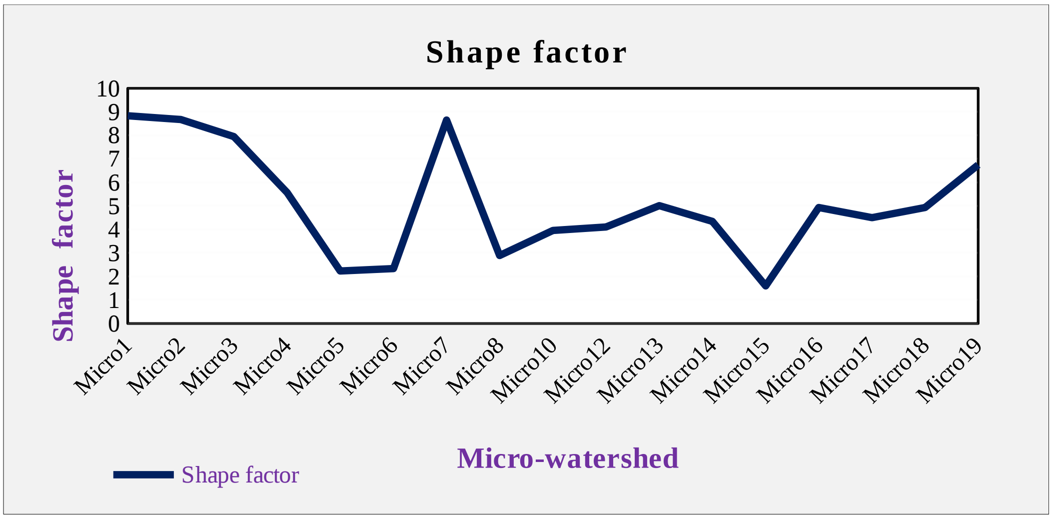


Fig. 4.14 Shape factor for all 17Micro-watersheds in Thuthapuzha river basin

d) Circulatory ratio (C_r)

The circulatory ratio represents the shape characteristics of the catchment area. The total areal extent of this sub basin is 1005 km2 and the perimeter is 240 km. In this study area, the circulatory ratio is computed as 0.219. This value indicates the river basin is elongated and young stage of tributaries. The circulatory ratio for micro-watershed ranges from 0.24 to 0.629. It is observed that almost all Micro-watersheds exhibits elongated area with young stage to mature stage of tributaries. All Micro-watersheds with their circular ratio is shown in Fig. 4.15

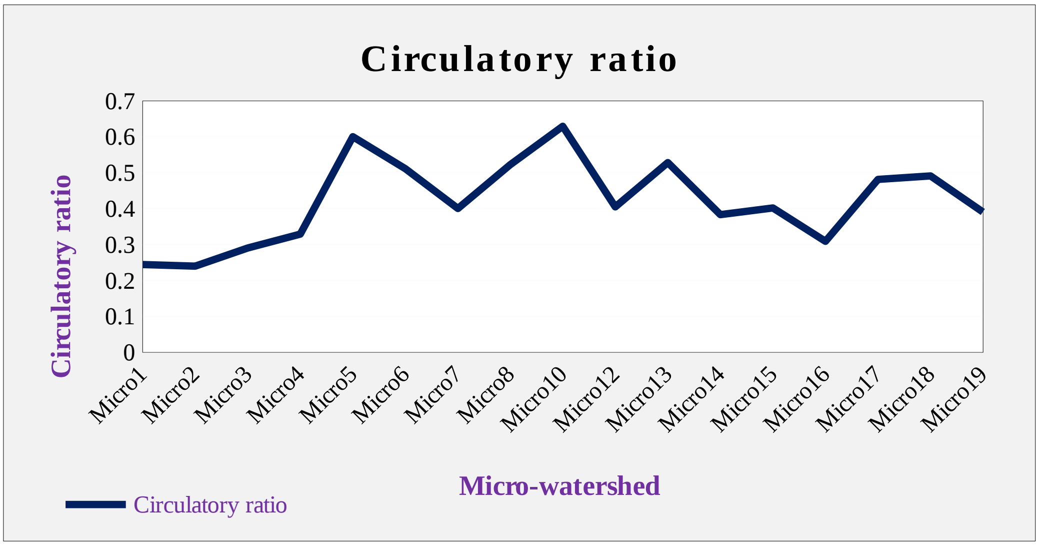


Fig. 4.15 Circulatory ratio for all 17 Micro-watersheds in Thuthapuzha river basin

4.2.3 Drainage parameters

Drainage texture analysis includes the basin frequency, density and intensity of the drainage characteristics

a) Drainage density (D_d)

Drainage density is a ratio of the total length of all streams per basin area and higher value indicates degree of the rainfall removal from the basin. The spatial variation of drainage density is demarcated in a raster map format using ArcGIS software and shown in Fig. 4.16. The average drainage density of Thuthupuzha River is obtained as 1.16 km/km^2. This moderate value indicates the availability of a large amount of precipitation on the slope terrain that results in moderate runoff and more surface drainage lines. Moreover, it is identified that the average value of drainage density and stream frequency value are nearly close; this reveals that the lengths of the streams are strongly controlled by slope and geological structures. Out of 17 Micro-watersheds the highest value is obtained from Micro-watershed 4 and lowest from Micro-watershed 5 which is about 1.19. The drainage density map of Thuthapuzha river basin is shown in fig 4.16. The drainage density for all Micro-watersheds in Thuthapuzha river basin is shown in Fig. 4.17.

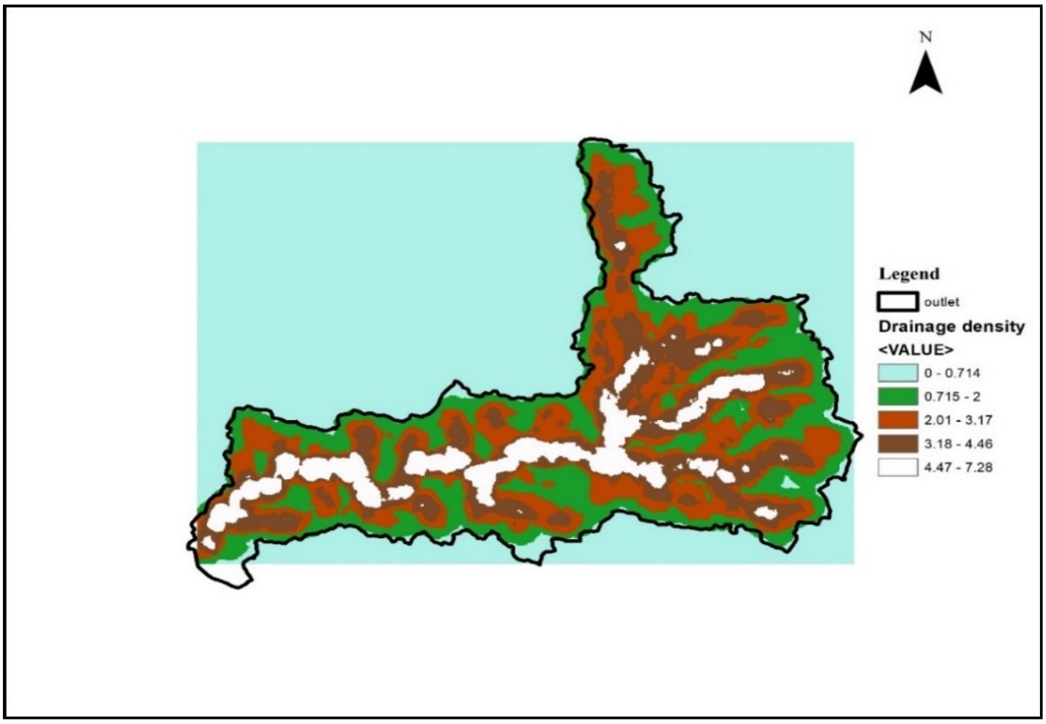


Fig. 4.16 Drainage density map of the Thuthapuzha river basin

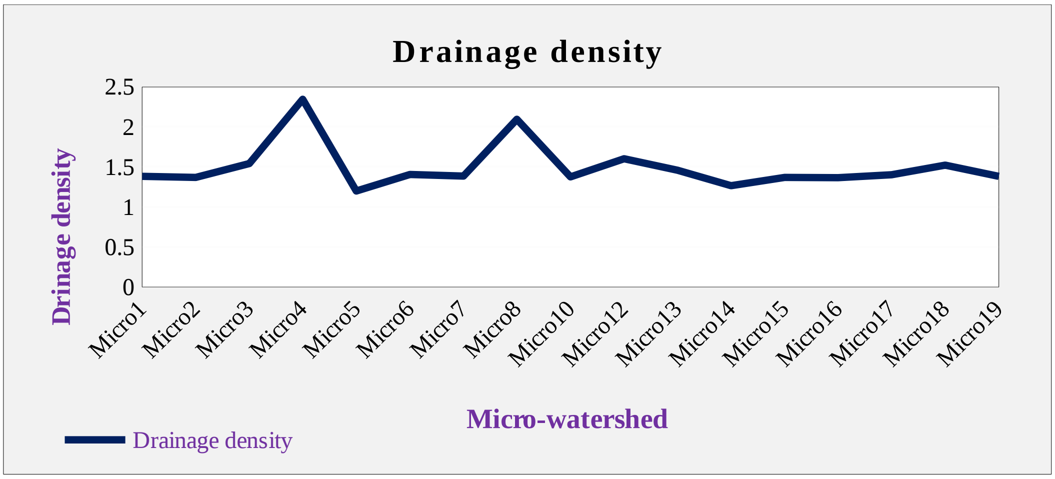


Fig. 4.17 Drainage density for all 17 Micro-watersheds in Thuthapuzha river basin

b) Drainage texture (D_t)

Drainage texture is an important parameter in the field of geomorphology which gives idea about intensity of drainage characteristics. It measures closeness of the stream spacing. In the present study the drainage texture is obtained as 10.05 for whole river basin which indicates that the river basin has very fine drainage texture. Out of 17 Micro-watersheds, maximum number of Micro-watersheds falls under the category of coarse texture where drainage texture value is varies from 2 to 4. In Micro-watershed 19 highest drainage texture is obtained which is about 6.589. All micro-watersheds with its drainage texture value is shown in Fig. 4.18

c) Infiltration number (I_n)

Infiltration number is the product of stream frequency and drainage density which gives idea about the infiltration characteristics of the basin. Higher value indicates higher runoff, lower infiltration and vice versa. In this study, the infiltration number obtained as 3.508 which indicates moderate infiltration. Out of 17 Micro-watershed, the highest infiltration number is obtained from the Micro-watershed 4 and Micro-watershed 8 *i.e.* 7.64 and 5.90 respectively. This value indicates moderate infiltration hence development of stream network is moderate. Infiltration number for all 17 Micro-watersheds is given in Fig. 4.19.

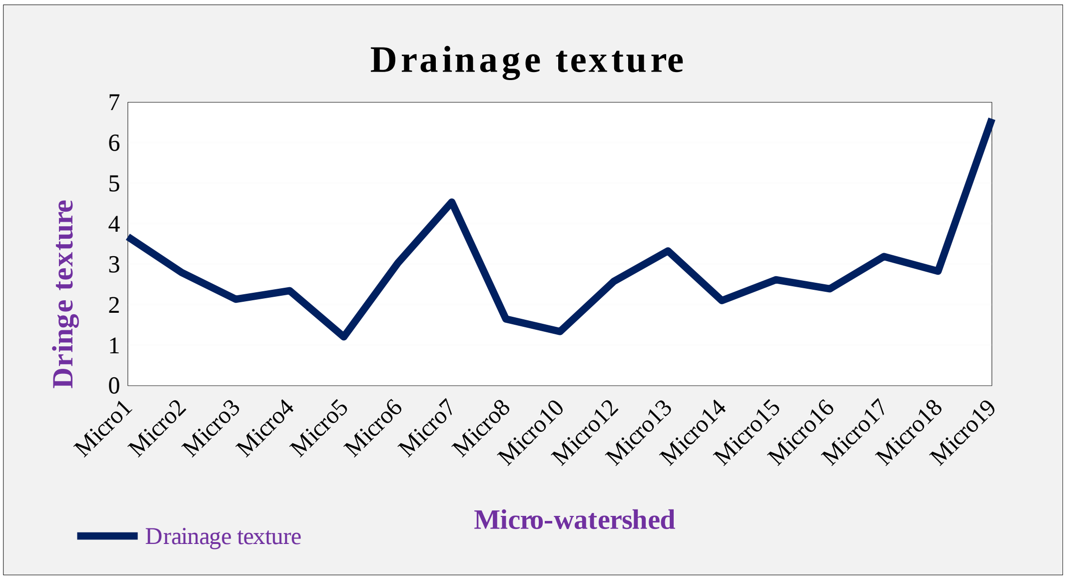


Fig. 4.18 Drainage texture for different Micro-watersheds in Thuthapuzha river basin

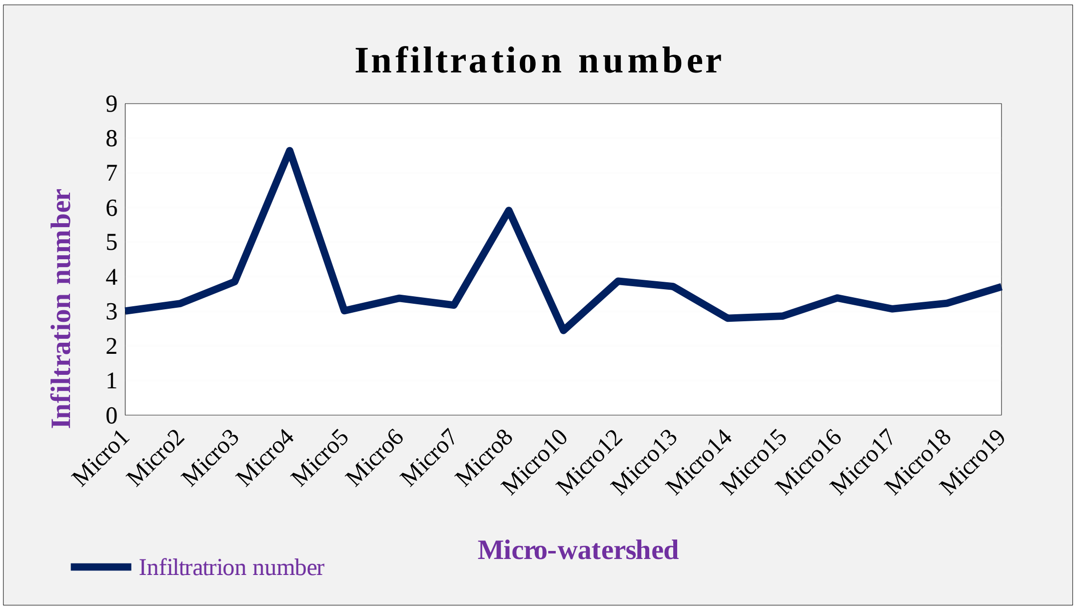


Fig. 4.19 Infiltration number for all 17 different Micro-watersheds in Thuthapuzha river basin

d) Length of overland flow (L_f)

The length of overland flow is defined as the length of flow path projected to the horizontal of the non-channel flow from a point on the adjacent stream channel. The length of overland flow is mostly influenced by both hydrologic and physiographic structures of the area. In the study area, the computed overland flow value is 0.342. This lower value indicates that Thuthupuzha river basin is under stream erosion is more dominant than sheet erosion. Out of 17 Micro-watersheds, only Micro-watershed 5 has moderate stream erosion with length of overland of 0.417. Remaining all Micro-watersheds are comes under more channel erosion. Length of overland flow for all Micro-watersheds is given in Fig. 4.20.

e) Constant of channel maintenance (C_c)

It is inverse function of drainage density which gives idea about number of km2 required to develop stream of 1 km. The computed obtained value of constant of channel maintenance for river basin is 0.684 and value indicates 0.684 unit area required to sustain unit length of stream in the basin with least erodibility. Out of 17 Micro-watershed, Micro-watershed 4 and Micro-watershed 8 gives constant of channel maintenance of 0.427 and 0.478 respectively which indicates low erodible area whereas remaining all Micro-watershed falls under least erodibility. The constant of channel maintenance for all Micro-watersheds is given in Fig. 4.21

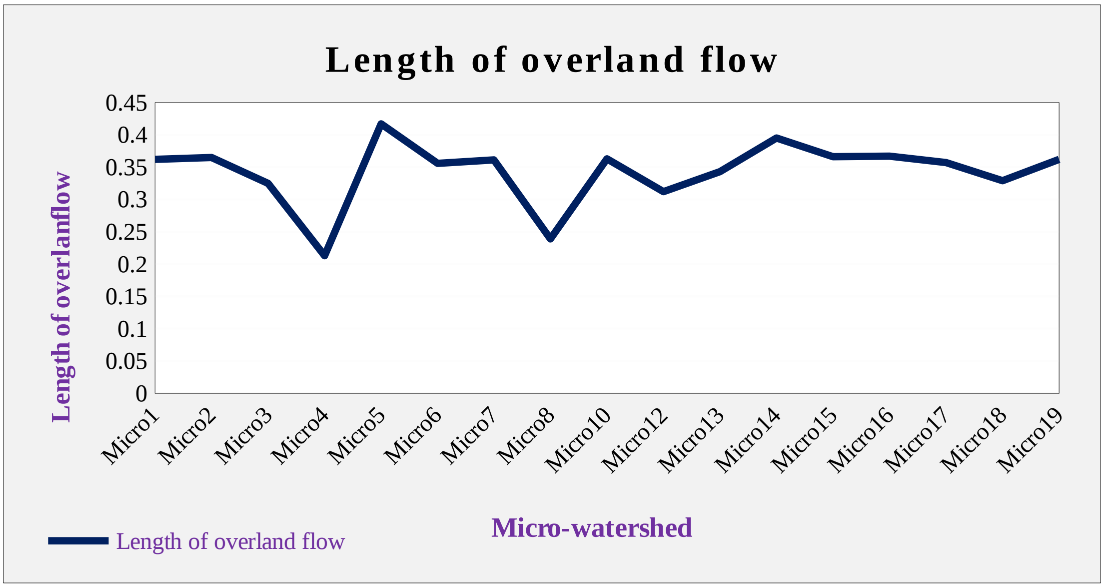


Fig. 4.20 length of overland flow for all Micro-watersheds in Thuthapuzha river basin

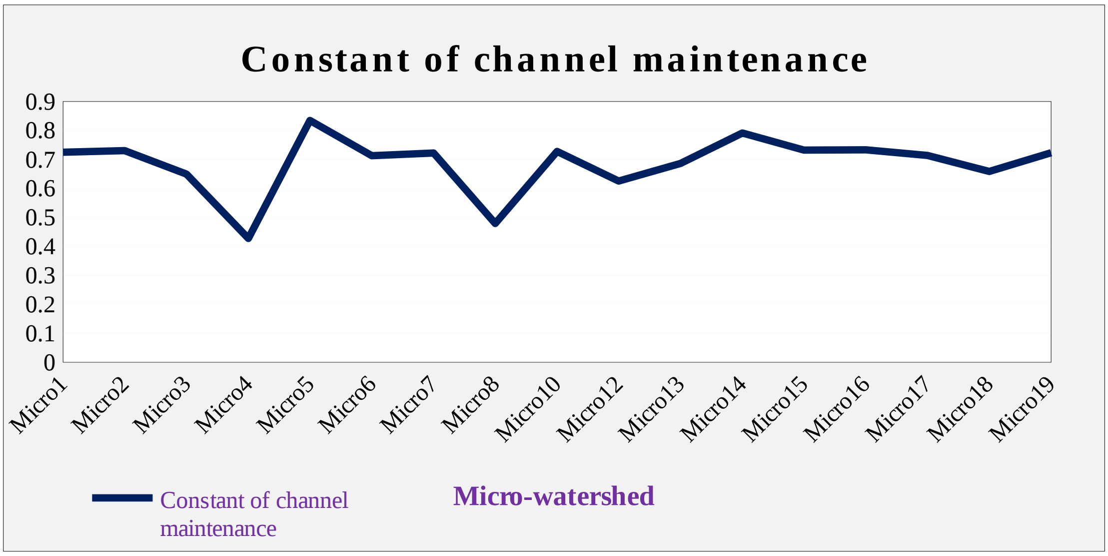


Fig. 4.21 Constant of channel maintenance for all 17 Micro-watersheds in Thuthapuzha river basin

4.2.4 Relief aspect

Drainage network, basin geometry are one and two dimension parameters but in case of relief parameters, it is the three dimension parameters. By measuring the elevation of each stream segment to the point where it joins the higher order stream and dividing the total by the number of streams of that order, it is possible to obtain the average elevation(vertical fall). The parameters involving relief aspect are

a) Basin relief (R_b)

The relief of the sub-basin area varies at different reference points (peak of the hilly terrain) in the northern and eastern part. The maximum relief (basin relief) of the area is 2.330 km. the computed higher value of basin relief indicates lesser time for flow accumulation hence runoff will be more. Fig. 4.22 gives basin relief in all Micro-watershed which indicates variation is more in case of relief parameters.

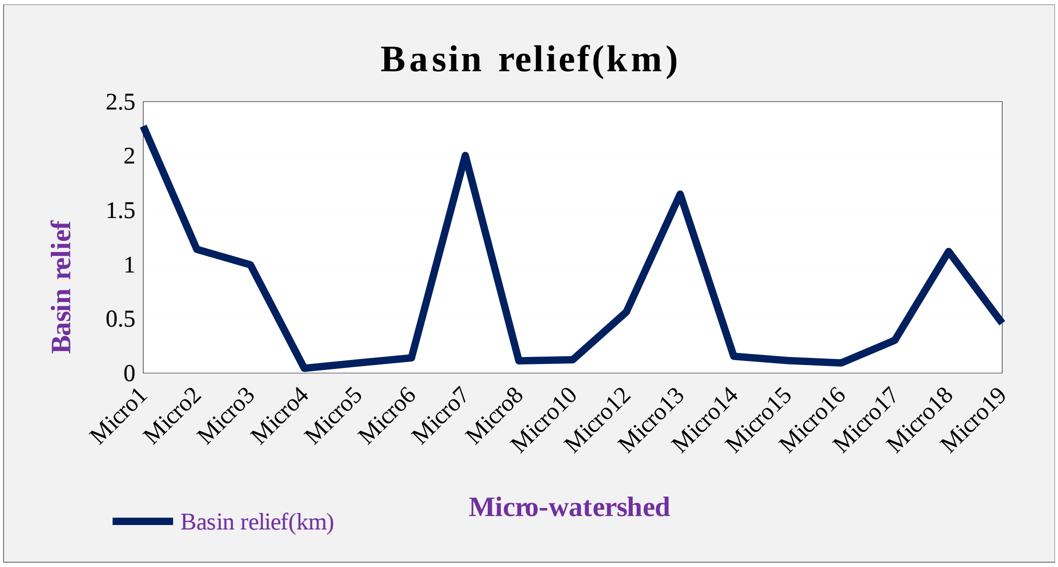


Fig. 4.22 Basin relief for all 17 Micro-watersheds in Thuthapuzha river basin

b) Relief ratio (R_r)

Relief ratio describes as the overall steepness of the river basin and this is a main indicator of the intensity of erosion process operating on the slope of the basin. Higher value indicates that area is located in hilly region, whereas lower value indicates basin is located in valley region. In this study area, the relief ratio is computed as 0.023 and this lowest value of ratio indicates moderate relief and gentle slope. It is observed that relief ratio is higher in place where Hill-shades with highest relief ratio of 0.14 and lower in case Micro-watershed 16 which is about 0.008. Relief ratio of all the Micro-watersheds is shown in Fig. 4.23.

b) Ruggedness number (R_n)

Ruggedness is the product of basin relief and drainage density and its value obtained as 3.404 which is higher. This value indicates higher stream velocity because the relief parameters are higher which implies the Thuthapuzha river basin having high prone to soil erosion. The ruggedness value is ranges from 0.112 to 3.14 in case of 17 Micro-watershed. It is observed that highest ruggedness number is obtained from Micro-watershed which are present in Hill-shades. All Micro-watershed with its ruggedness number is shown in Fig. 4.24.

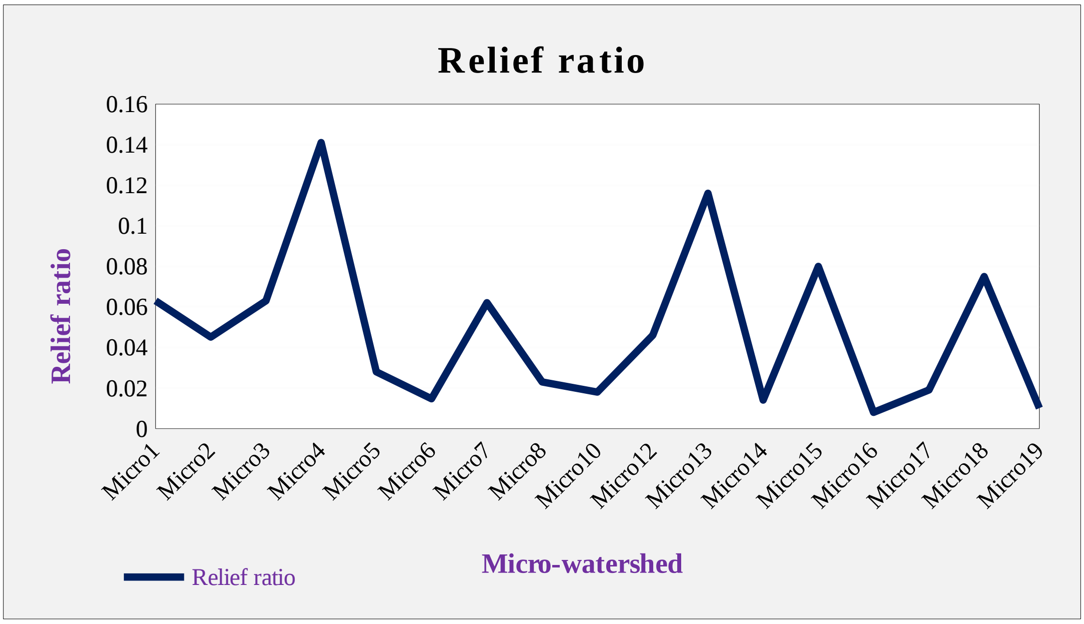


Fig. 4.23 Relief ratio for all 17 Micro-watersheds in Thuthapuzha river basin

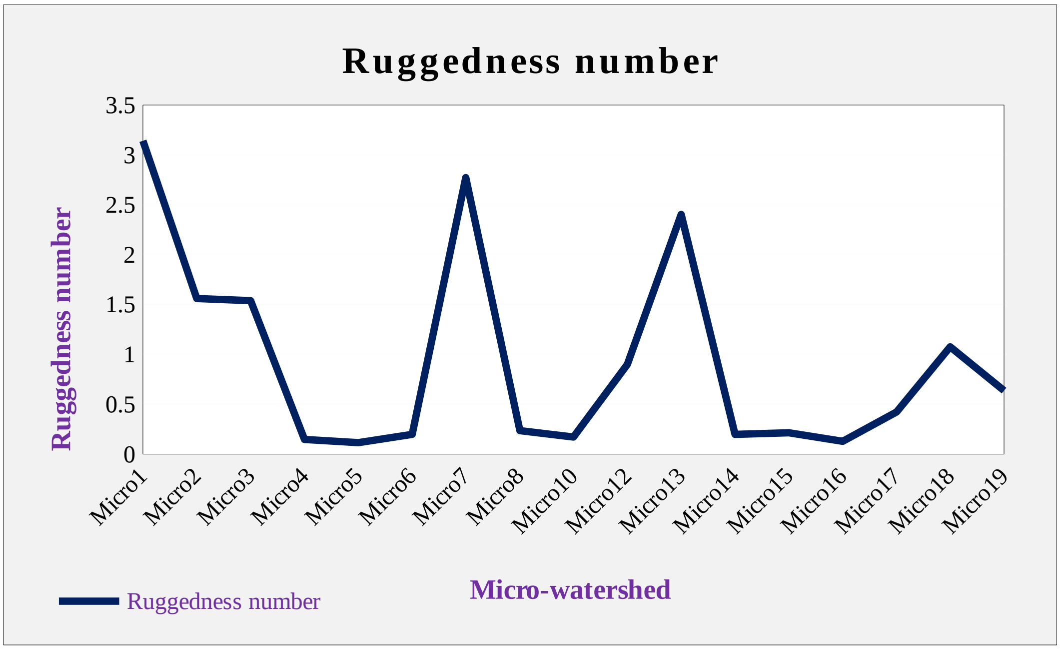


Fig. 4.24 Ruggedness number for all 17 Micro-watersheds in Thuthapuzha river basin

4.4 Identification of influential geomorphological parameters on runoff

Geomorphologic parameters influences of the sub-basin landscape. The morphometry characteristics of this study area such as stream order, stream length, stream network etc. are mainly influenced by its local topographical surfaces and geological formation. So statistical methods are applied for the identification of influential parameters. The entire river basin is divided into 17 sub-basins and from all these sub basin, geomorphologic parameters are derived. All 14 parameters are identified and worked out for statistical analysis.

Finding influential parameter from large number of data can be done by applying multivariate analysis especially factor analysis is used for this purpose. Since the data in these case is geomorphological parameters having 14 parameters from 17 Micro-watersheds, the first step is to make these parameters into tables in Microsoft excel and this table is imported into the Minitab worksheet and finally subjected to factor analysis. The results from factor analysis can be interpreted with the correlation matrix, scree plot, Eigen values, variance and factor score. The interpretation is discussed below.

4.4.1 Interpretation of Scree plot

Scree plot also plotted to find the number of factors for the analysis. The plot of Eigen values versus number of factors shows that select the factors. From this graph the bent is obtained at number of factors is at three. The Eigen values is also greater than one. So the number of factor to be selected for the factor analysis is three and it is shown in Fig. 4.25.

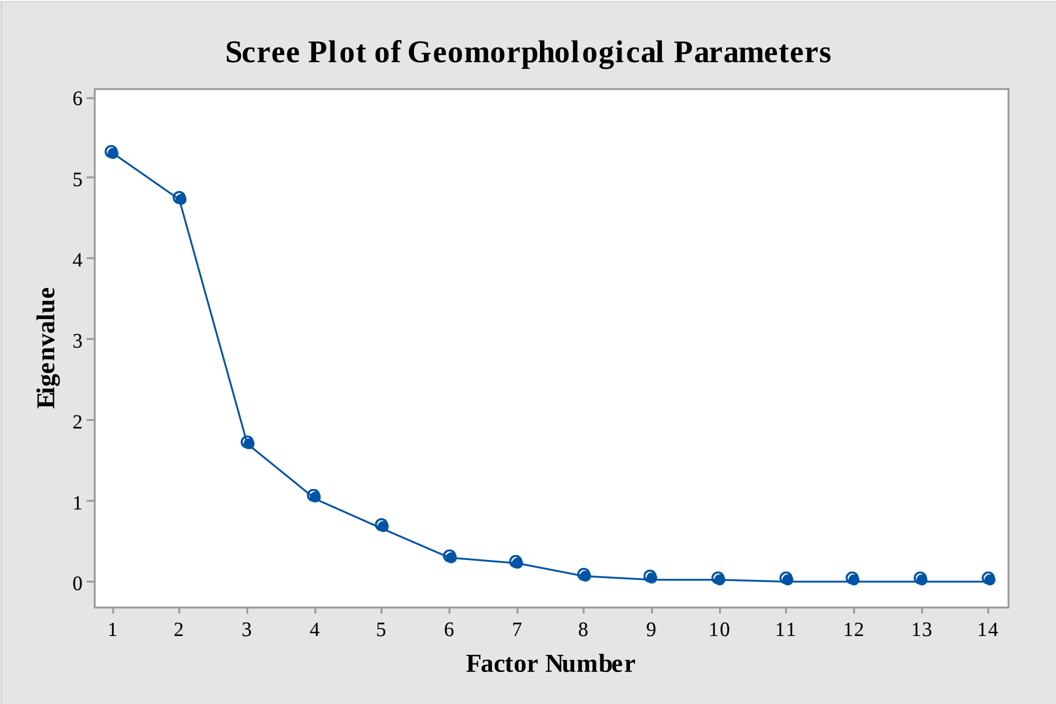


Fig. 4.25 Scree plot of Geomorphological parameters

4.4.2 Interpretation of factor loadings

Loadings are nothing but correlation of the variables with the factor. Loadings are main factor to identify the variables not related to other variables. The interpretation of factor loadings can be discussed under two condition *viz.* unrotated factor loadings and rotated factor loadings. Both can be easily differentiated by observing the graphs.

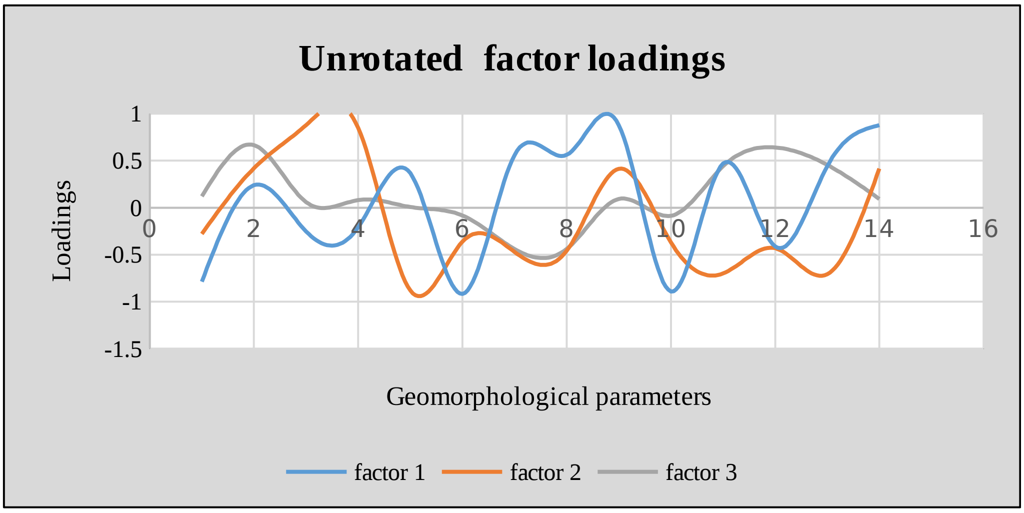


Fig 4.26 Unrotated factor loadings for three all factors

The graph loadings in unrotated is obtained to understand the distribution of the variables within the factor. In the Fig. 4.26 we can observe most of the variables are loaded at one factor (factor 1) and more variables meets at same loadings in different factor (loadings at -0.5, 0, -0.1). In this condition, interpretation of loadings is difficult. For avoiding this, the loadings are rotated in order to distribute the variables and pattern of loadings can easier to interpret the results.

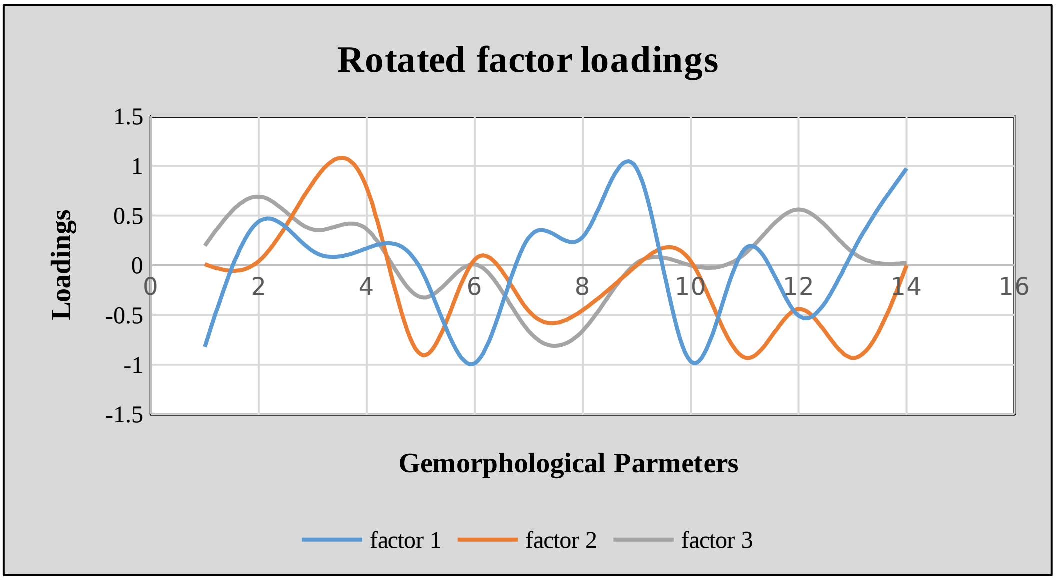


Fig. 4.27 Rotated factor loadings for all three factors

The rotated factor loadings is obtained by the rotating the PCA. In this study, Varimax method is used for factor rotation. In the Fig. 4.27, we can observe the distribution of variables in different factors and also distribution pattern also changed. The interpretation of loadings in this case easy compare to unrotated loadings. Rotation doesn’t change the results of PCA but the pattern of loadings can easier to interpret the results

Factor loadings are used to indicate up to what extent the factor can explain the variance and it is given by correlation coefficient which ranges from -1 to 1. The value -1 to nearer to this gives negative relationship (less influencing), whereas the +1 or nearer value indicates the positive relationship (more influencing). The closer to zero gives the lesser relationship. The factor loadings from each factor with variables are discussed in both positive and negative significant variables.

a) Factor 1

In this factor the highest positive correlation coefficient is obtained from length of overland flow and constant of channel maintenance. Both of the variables are having correlation coefficient of 0.974. This value indicates two variables exhibits more relationship (influencing) with factor. In case of negative correlation parameters, the highest relationship is obtained from drainage density having correlation coefficient of -0.987. The remaining negative correlation parameters are infiltration number and stream frequency. Both variables having coefficient of -0.968 and -0.822 respectively. Results obtained from both positive and negative correlation variables (length of overland flow, constant of channel maintenance, drainage density, infiltration number and stream frequency) exhibits the characteristics of the runoff. Hence runoff characteristics are more influencing in Thuthapuzha river basin and this factor named as runoff factor.

b) Factor 2

In this factor the highest positive correlation coefficient is obtained from elongation ratio having correlation coefficient of 0.831. Form factor also exhibits positive correlation with factor 2 having correlation coefficients 0.78. In case of negative correlation parameters, the highest relationship from ruggedness number having correlation coefficient of -0.933. The other less influential (negative correlation) parameters are basin relief and shape factor. Both variables having coefficient of -0.929 and -0.897 respectively. From the above results from both positive and negative correlation variables, the parameters elongation and shape factor exhibits shape characteristic of the basin. Hence shape characteristics are more influencing in Thuthapuzha river basin after the runoff factor.

c) Factor 3

In this factor the highest positive correlation coefficient is obtained from bifurcation ratio having correlation coefficient of 0.692. Drainage texture and circulatoryratio exhibits negative correlation with factor having correlation coefficient of -0.662 and -0.625 respectively. From all these variables, correlation coefficient less than 0.6 in both case of positive and negative influential parameters hence factor 3 variables are having less influence parameters.

Factor 1 and 2 are more influencing, hence the loading plot also drawn between first two factors and it is shown in Fig. 4.28.

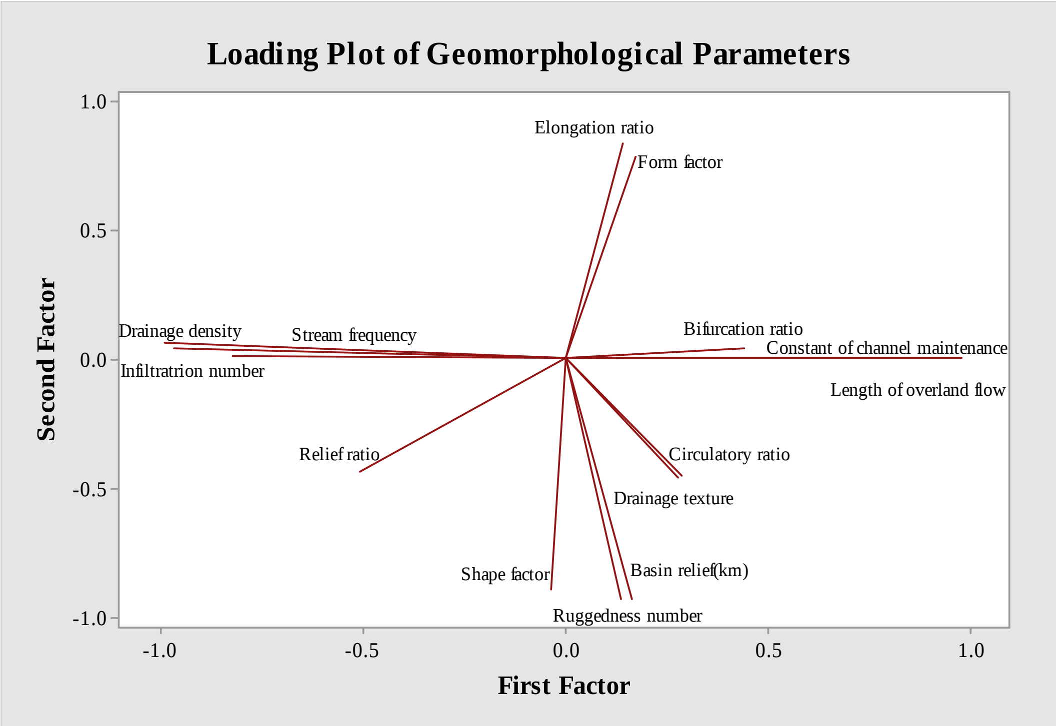


Fig. 4.28 Loading plot of geomorphological parameters

From the graph form factor, bifurcation ratio exhibits positive influence in first factor but less in factor. Drainage texture, circulatory ratio, exhibits less influences with both factors. Relief ratio exhibits negative influences in both factors but correlation coefficient is less. Stream frequency exhibits more exhibits more relationship in first factor but it is in factor 2

4.4.1 Interpretation of variance

The variance also derived through factor analysis to check the variability among the factors. Out of four factors runoff factor (factor 1) exhibits the variance of 5.192. This shows that factor 1 exhibits more variability and gives comparatively good result. The other factors 2 and 3 gives the variance of 4.416 and 2.101 respectively. Total variance explained by all three factors is 11.247.

4.4.1 Interpretation of % variance

The % variance ranges from 0 to 1(0% to 100%). Minimum 60% of variance can be determined through factor analysis. In this study the % variance explained by all factors is about 0.839(83.9%). Among all these factors, first factor (runoff) factor exhibits % variance of 0.371. Remaining factors exhibits %variance of 0.3.18 and 0.150 respectively. This values shows that runoff factors exhibits more % variance compare to all other factors.

4.4.1 Interpretation of factor score

It is the rank wise order of the variables within the factor in other words the important variable in each factor is given by factor score. The larger the value of variable, more important corresponding variable and that variable is used as independent variables in regression analysis. From the factor analysis, the highest factor score is obtained from length of overland flow having factor score 0.190. Remaining parameters having factor score are elongation ratio, form factor having factor score of 0.165 and 0.152 respectively and these parameters are used as independent variables in regression analysis.

4.5 MULTIPLE REGRESSION

A regression analysis describes the statistical relationships between a given dependent variable and one or more independent variables and regression analysis can also evaluates relationship between the variables. In this study, the runoff is taken as dependent variables and rainfall, constant of channel maintenance, length of overland flow and elongation ratio as independent variables. The interpretation of results from multiple regression analysis as discussed below.

4.5.1 Interpretation of p-value

To determine relationship between the dependent and independent variables in the model is statistically significant, compare the p-value for the variable to your significance level. In this study, p-value obtained which is less than α which indicates the relationship between geomorphological parameter and rainfall with runoff is statistically significant.

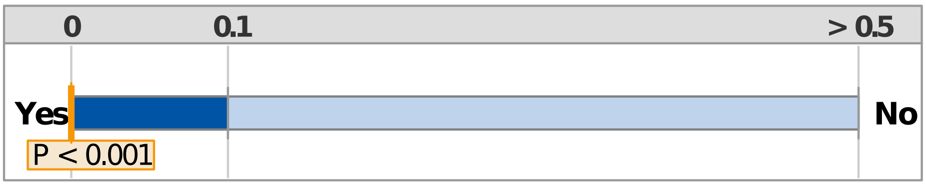


Fig 4.29 P-value of multiple regression in Minitab

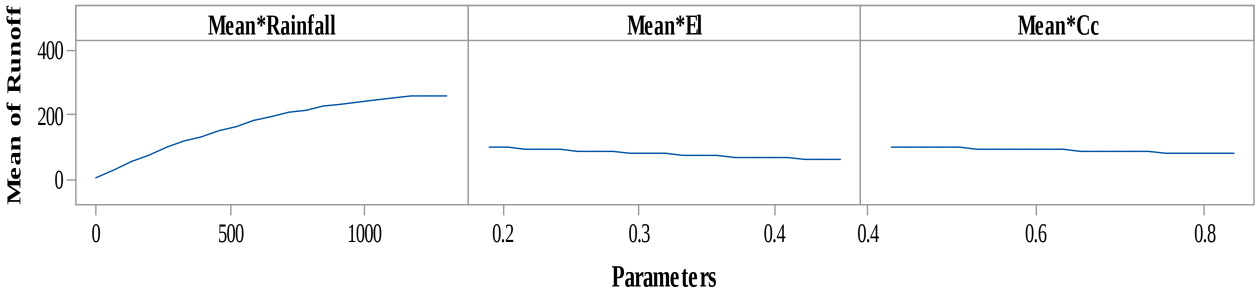
4.5.2 Interpretation of R^2

R^2 determines how well the model fits the data, examine the goodness-of-fit statistics in the model summary table. In this study the R^2 obtained as 97.85% which indicates 97.85% of variation of runoff can be explained by this regression model. Hence the model fits very well and this equation can be used for estimating the runoff for specified values of rainfall and geomorphological parameters.

4.5.3. Interpretation of interaction plots for runoff

Interaction plots helps in how runoff changes when two independent variables are changed. In this study, the interaction between the elongation ratios, constant of channel maintenance, rainfall with runoff are shown. Among these, increase in constant of channel maintenance, elongation ratio reveals that slight decrease in runoff. In case of interaction between rainfall and runoff, rainfall increases can cause increase in the runoff.

Fig 4.30 Interaction between rainfall, elongation ratio, constant of channel maintenance with runoff



4.5.4 Interpretation of residuals plot

Residuals is the difference between observed value and corresponding fitted value. The plot of residual versus observation order shows that residuals falls near centre line which indicates residuals may be correlated but not independent.

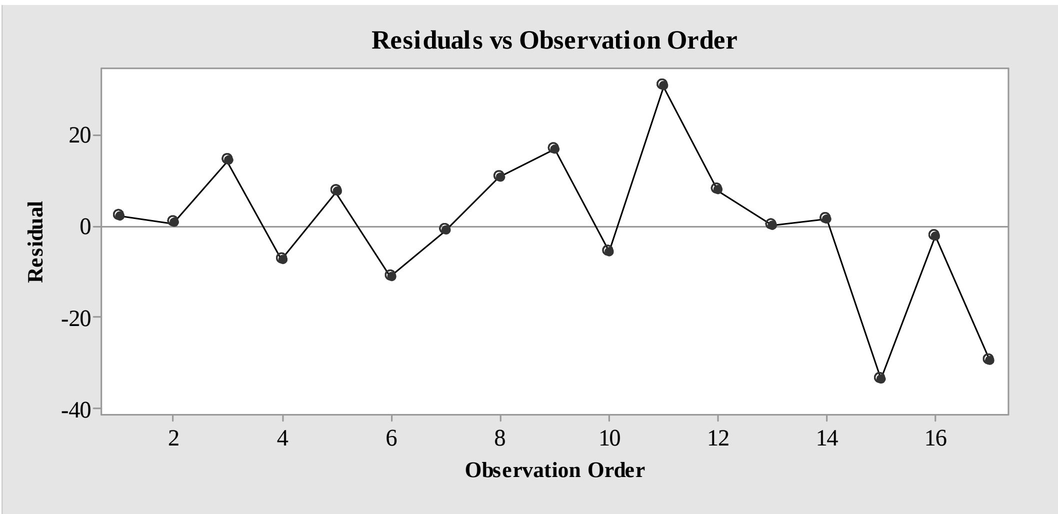


Fig 4.31 Graph of residual versus observation order

4.5.5 Model building report

Model building report shows how variables are built in regression model, and which variables are contribute more to runoff. The model are built in four steps

Step 1: Add rainfall to the model, then the R^2 adjusted is about 82% with significant p-value

Step 2: Add constant of channel maintenance and elongation ratio to the model. The p-values will change from 0.519 to 0.305 in constant of channel maintenance. In case of elongation ratio, the p value is changing from 0.653 to 0.142. Both the variables adding to the model reveals that model goes towards significantly with increasing in R^2.

Step 3: % R^2 are increased by adding rainfall*elongation ratio which implies 50 % change in p-value.

Step 4: Finally $(\text{Rainfall})^2$ is added to model which leads to maximum response from the model.

All these steps with increase in R^2 are shown in Fig. 4.32.

Fig. 4.34 shows contribution of runoff by each independent variables. From this Fig., rainfall contributes to runoff about 95 % of predicted runoff, remaining R^2 value comes with constant of channel maintenance and elongation ratio. In this Fig. length of overland and constant of channel maintenance exhibits same correlation with runoff. Hence out of these two variables, one variables can use in this model.

The final model equation is given by

$$Runoff = -589 + 804\,X_4 + 2344\,X_2 + 0.756\,X_1 - 0.000144\,(X_1)^2 - 3188\,X_2 X_4 - 1.381\,X_1 X_2$$

Where X_1 is Rainfall (mm), X_2 is elongation ratio, X_3 is Length of overland flow, X_4 is constant of channel maintenance, and Runoff is in m^3/sec

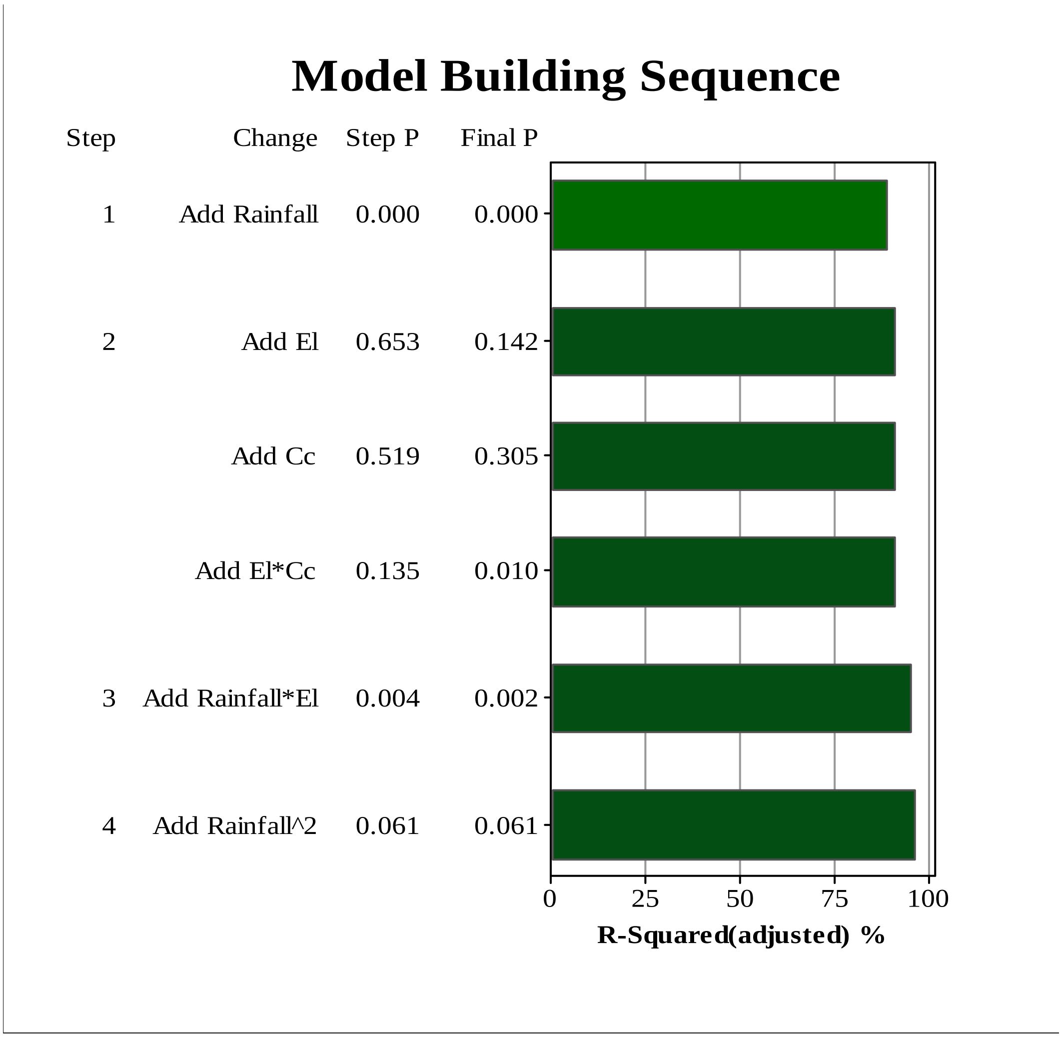


Fig. 4.32 Model building report for runoff in Minitab

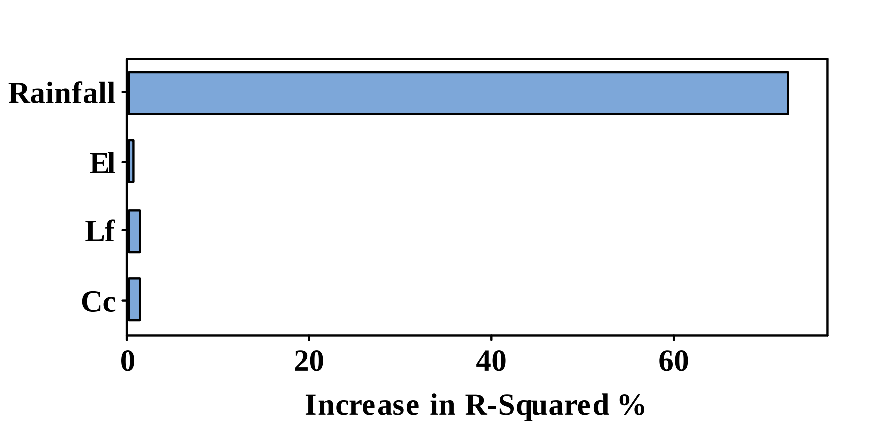


Fig. 4.33 Contribution of runoff by each independent variables

4.5.6 Prediction report

This report shows that solution are obtained to get target value. The optimal values of constant of channel maintenance, elongation ratio and rainfall are 0.834, 0.1899 and 1307.7 respectively. The predicted runoff obtained from this optimal solution is 420.521 which describe the 95% occurrence.

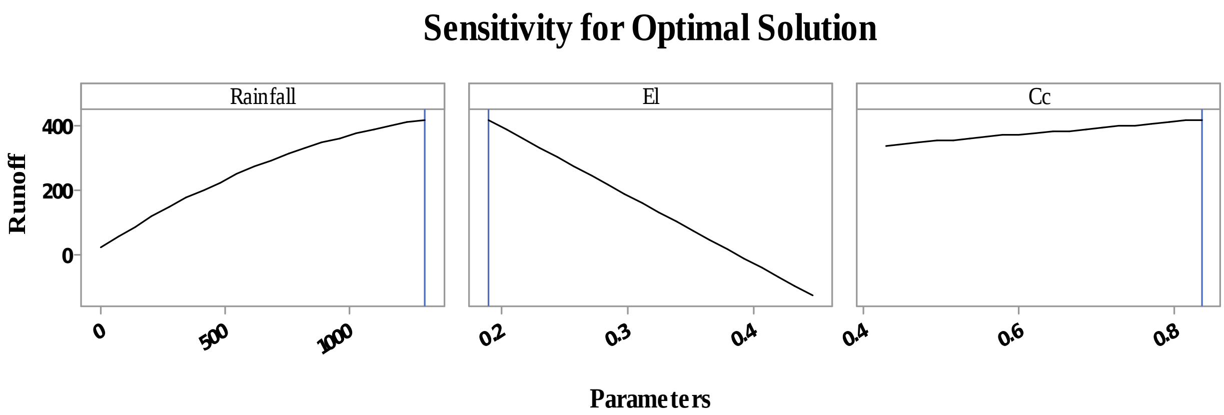


Fig. 4.34 Sensitivity analysis in Minitab

Sensitivity for optimal solution also obtained for how much runoff changes when independent variables changes. From the Fig. 4.35 it shows that with increase in constant of channel maintenance slight increase in runoff. In case of elongation ratio runoff decreases with increase in elongation ratio and also increase in rainfall, runoff also increases.

The five optimal solution also derived using this model and all these shown in Table 4.3.

Table 4.3 Optimal solution for runoff estimation

X_1	X_2	X_4	Predicted Y
1307.5	0.722	0.192	396.24
483	0.478	0.332	177.199
619	0.727	0.284	172.396
728.4	0.712	0.369	113.227
297.4	0.625	0.279	108.532

CHAPTER V

SUMMARY AND CONCLUSION

The geomorphologic parameters of the Thuthapuzha river basin were derived by morphometric analysis using GIS. GIS is an efficient tool in hydro-geomorphological analysis, as it deals with spatial data like DEM. The morphometric parameters like number of streams, stream order, their length, area of the basin, perimeter, and main channel length etc. were derived using GIS. The geomorphological parameters and processes associated with geomorphology gives better understanding of the hydrological processes within the basin.

The interaction between the long-time hydrologic and geological processes, determines stream characteristics, landform, basin area, perimeter, and other morphometric parameters. It is observed that the Thuthapuzha river basin has a dendritic type of drainage network and the basin is also having much difference in the relief. It is noticed that the first order stream network has a greater number of stream segments than the second, third, fourth, fifth order streams. In the case of sixth order streams, the number of streams is higher than the fifth order streams which indicates that bifurcation ratio is less than one. This obviously reveals that the highest stream orders originate nears to Hill-shade having long main channel length and this make the shape of the basin elongated. The shape of basin is described by shape parameters such as form factor, shape factor, circulatory ratio, and elongation ratio. The Thuthapuzha river basin has an elongated shape as indicated by all these parameters. Circulatory ratio obtained has low value which reveals that the basin is elongated and also suggest that lower order streams are at young stage. Because the basin is elongated, shape factor exhibits the characteristics of a flattened peak flow for longer duration and indicates that the basin is highly vulnerable to flood flows. The elongation ratio reveals that the basin is more elongated in Hill-shade. The low infiltration number gives more runoff along the flow path. The infiltration number also reveals low to moderate infiltration in different parts of Thuthapuzha river basin, which leads to high to moderate runoff. Drainage network parameters like low bifurcation ratio reveals that the basin is having less relationship between stream order and the mean bifurcation ratio which again indicates that the basin has less disturbance by the geological structures. Hence stream segments is mainly determined by external forces like the surface runoff which cause to erode the surface. Lower stream frequency reveals that the basin has less structural disturbances as a result of high surface runoff and fast stream flow influenced in the present study area. It is observed that the drainage density and stream frequency are nearly close to each other which reveals that the length of streams are strongly controlled by the slope and geological structure. Drainage texture show that the intensity of the stream network is finer indicating that the surface runoff is maximum and erosion is intense.

Since bifurcation ratio, and stream frequency describes the erosion characteristics, the lower value of the length of overland flow in the study area reveals that the stream erosion is more dominant in the basin than sheet erosion. Hence stream bank erosion control measures have to be taken up for preventing erosion. With respect to the constant of channel maintenance parameter, the basin exhibits areas of moderate to low erodibility. The high basin relief indicates that the basin has lesser time for flow accumulation. But the relief ratio reveals that overall steepness of the basin show moderate relief and gentle slope. From the ruggedness number it is observed that stream has higher velocity because of relief. Hence the Thuthapuzha river basin is highly prone to soil erosion.

The total percentage variance explained by all the factors in factor analysis is relatively high. The factor analysis is a good approach for finding significant parameters. Among the percentage variance explained by each factor, the runoff factor exhibits more percentage variance. The high correlation coefficient between runoff and geomorphological parameters are more significant. The positive correlation values on runoff factor are length of overland flow, and constant of channel maintenance whereas the drainage density exhibits less significance. All these parameters indirectly indicate that runoff factor is controlled by these groups of variables.

The results of factor analysis show that the form factor, elongation ratio, and circulatory ratio, exhibit shape characteristics which are more important after considering the runoff factor. The present study is useful in eliminating the relatively insignificant parameters and arranging the remaining significant factors into clearly distinguish groups. The results show the significance of factor analysis in hydrologic response studies and also the results from the factor analysis can be used for prioritizing the watershed.

Variables with large value of factor score in factor analysis is used as independent variables in regression analysis. Hence, the length of overland flow, constant of channel maintenance, elongation ratio and rainfall are used as the independent variables for estimating the runoff. The R^2 obtained through regression analysis is high and is also statistically significant which indicates the regression equation gives good fit. The results from regression analysis reveals that the constant of channel maintenance has positive impact on runoff whereas elongation ratio has negative impact on runoff. The drainage density of the basin has to increase to get a lower constant of channel maintenance. The regression equation can be used for finding missing river discharge time series values for hydrologic design of structures.

CHAPTER VI

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INFLUENCE OF GEOMORPHOLOGY ON RUNOFF CHARACTERISTICS OF A CATCHMENT

By

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ABSTRACT OF THESIS

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ABSTRACT

Morphometric analysis for deriving the geomorphological parameters of the Thuthapuzha river basin was performed using GIS platform. GIS is proven to be an efficient tool for hydro-geomorphological studies. The geomorphological parameters and the processes associated with geomorphology gives a better understanding of the hydrological processes within the basin. The derived Geomorphological parameters for Thuthapuzha river basin show a dendritic type of drainage network with elongated basin. As the Thuthapuzha river basin exhibits higher stream velocity, the basin is highly prone to soil erosion and the stream erosion is more predominant than sheet erosion.

The total percentage variance explained by all the factors is about 83.9%, when the factor analysis which is a good approach for finding the significant parameters is conducted. Among the percentage variance explained by each factor, the runoff factor exhibits the highest percentage variance of about 37%. The highest correlation coefficient is obtained between runoff and the length of overland flow, and the constant of channel maintenance which are more significant. Factor analysis shows that the form factor, elongation ratio, and circulatory ratio, exhibits shape characteristics which are more important after the runoff factor.

Factor analysis eliminates the insignificant parameters which may be discarded in the regression model with least loss of accuracy. The variables with large values of factor score from the factor analysis is considered as the independent variables in the regression analysis. The length of overland flow, constant of channel maintenance, elongation ratio and rainfall are used as the independent variables for estimating the runoff. R^2 obtained through the regression analysis is 97.85%, a statistically significant value indicating the goodness of fit for the regression equation. Regression analysis revealed that the constant of channel maintenance has a positive impact on the runoff whereas the elongation ratio revealed a negative impact on the runoff. The regression analysis show that the rainfall exhibit more contribution to the runoff, as expected.