COMPARATIVE ASSESSMENT OF DIGITAL ELEVATION MODELS (DEMS) IN THE MORPHOMETRIC ANALYSIS OF BHARATHAPUZHA RIVER BASIN

BY

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DECLARATION

We here by declare that this project entitled "**Comparative Assessment of Digital Elevation Models (DEMs) in the Morphometric Analysis of Bharathapuzha River Basin**" is a bonafide record of project work done by us during the course of project and the report has not previously formed the basis for the award to us for any degree, diploma, associateship, fellowship or other similar title of any other university society.

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Place: Tavanur
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CERTIFICATE

Certified that this project report entitled "**Comparative Assessment of Digital Elevation Models (DEMs) in the Morphometric Analysis of Bharathapuzha River Basin**" is a record of project work done independently by **Mr**. **Akhil Prasad, Ms. Amritha Varsha P, Ms. Aparna T and Ms. Archa Lakshmi Sojan** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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SYMBOLS AND ABBREVIATION

^{o}	Degree
'	Minute
/	Per
m	Metre
km	Kilometer
Sq.km	Kilometer square
Appx.	Approximate
et al.	And Others
Fig.	Figure
GIS	Geographic Information System
MB	Megabyte
TIN	Triangular Irregular Network
DEM	Digital Elevation Model
SRTM	Shuttle Radar Topography Mission
ALOS	Advanced Land Observation Satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
EGM	Earth Gravitational Model
WGS	World Geodetic System
ISRO	Indian Space Research Organisation
NASA	National Aeronautics and Space Administration
SILC	Sensor Information Laboratory Corporation
lat	Latitude
long	Longitude
GE	Google Earth
RMSE	Root Mean Square Error
R^2	Coefficient of determination
ME	Mean error
STD	Standard deviation

CHAPTER I

INTRODUCTION

Bharathapuzha, the second largest river of Kerala which is one of the populous states in India, is catering to the needs of several millions of people. The river is currently facing tremendous pressure due to encroachments, sand and clay mining, and illegal diversion of water. Bharathapuzha takes its origin at an elevation of 1100 m above M.S.L from Anamalai hills and flows through the districts of Coimbatore, Palakkad, Malappuram and Thrissur and joins Arabian Sea near the Ponnani town, where it is known as Ponnanipuzha (Magesh *et al*., 2013). Its four main tributaries are, Gayatripuzha, Chitturpuzha, Kalpathypuzha and Thuthapuzha. The length of the river is 209km with a catchment area of 5988.56 Km^2 (Magesh *et al*., 2013) . The catchment area is spread over 11 taluks from the Western Ghats to the Arabian Sea. About 2/3rd of the drainage area of the basin lies in Kerala state and the balance in Tamil Nadu. The Bharathapuzha basin is bounded by Tirur and the Kadalundi basins on the north and the Kecheri river basin on the south. At present, 11 major irrigation projects are existing on various tributaries of the river in addition to a number of minor and lift irrigation schemes. Also, a number of studies and research activities are being carried out in Bharathapuzha river basin every year. For all these studies morphometric parameters are important indicators to understand the hydrological and morphological characteristics of the region.

Morphometric analysis is a quantitative measurement and mathematical analysis of landforms. For a river basin, it provides a quantitative description of the drainage system, which is an important aspect of the characterization of basins. It is important in any hydrological investigation like assessment of groundwater potential, groundwater management, basin management and environmental assessment. The main input data for morphometric processing are three layers of map i.e. watershed area map, drainage map and elevation map. Drainage map and elevation map can be derived from topography map. Recently, some researchers used DEM (Digital Elevation Models) data to extract drainage map, watershed area map and elevation map.

Digital Elevation Models (DEMs) are the most common and the simplest form of terrain representation in 3D. The satellite based DEMs can be assessed by comparing the elevation data generated from them with elevation data obtained from topographic maps. Digital Elevation Model (DEM) is a digital representation of terrain as a raster (a grid of squares) of the earth's surface that stores Earth’s elevation information (Al-husban, 2017.). DEMs represent a convenient way of storing elevation information and of making such information available to applications programs such as GIS. Most frequently the term is used to refer to a set of elevation data. Hence due to its expanding utilization and importance many national cartographic organizations are putting their efforts to generate DEMs of different characteristics. Remote sensing has the ability to cover a large area in a short time which leads remote sensing to be a very dominant tool in the modern-day geosciences. There are many applications of remote sensing techniques in various fields, such as natural disasters, mineral and groundwater exploration, environmental studies, land use, forest studies etc. (Lakshmi, S.E.,2017). DEMs are used often in geographic information systems. The DEM dataset is also referred as a primary (measured) DEM, whereas the Raster DEM is referred as secondary (computed) DEM (Patel, 2012). Existing satellite based DEMs still show large drawbacks with respect to consistency, availability, cost, degree of resolution, and coverage.

Nowadays, a large variety of DEMs are available to the public. These include SRTM DEM, CARTODEM, ASTER DEM etc. Due to differences in primary data acquisition technologies, processing techniques and fusion algorithms, these DEM products differ in trerms of spatial coverage, data resolution, quality and treatment of noise. It is important to examine their qualities and understand possible errors and other characteristics before attempting to extract different informations from these DEM products. Hence, this study aims to:

1. Carry out morphometric analysis of Bharathapuzha watershed using different DEMs.
2. Compare different DEM products based on elevation (using ArcGIS and Google Earth elevation data).

Review of literature

CHAPTER II

REVIEW OF LITERATURE

2.1 BHARATHAPUZHA RIVER BASIN

The Bharathapuzha river is the second longest West Flowing River that drains into the Arabian Sea in Kerala State. This basin is bounded in the East by the Cauvery basin, in the West by the Arabian Sea. The basin lies approximately between 10^0 26' and 11^0 13' North latitudes and 75^0 53' to 77^0 13' East longitudes. Its drainage area is 5988.56 sq.km spread over the two states namely Tamil Nadu and Kerala. The basin is elongated in shape and finds its outlet into the Arabian Sea. There are five Hydrological Observation Stations on this river maintained by CWC i.e at Kumbidi, Pulamanthole, Mankara, Pudur & Amabarampalayam.

The Total drainage area of the basin is 6,186 sq. km out of which nearly 71% lies in the Kerala State. The State wise distribution of the drainage area is given below:

1. Tamil Nadu - 1,786 sq km (29%)
2. Kerala - 4,400 sq km (71%)

The Bharathapuzha or Ponnani river as it is called in the lower reaches, rises in the Eastern slopes of Anamalai hills of the Western Ghats at an elevation of 2,250 m above MSL and flows in the North-Westerly direction in Pollachi taluk of Coimbatore district in Tamil Nadu State. On its 45th km. run from its origin, it is joined by a tributary namely, the Palar on its right bank. Traversing another 15 km Westward, it enters the Palghat district of Kerala State through the Palghat gap. At its 100th km run, it is jointed by the Kalpathipuzha on the right bank. Traversing another 109 km. in the Westward direction through Palghat and Malappuram districts, it finally discharges into the Arabian Sea near Ponnani town. The total length of the river from its origin to out fall is about 209 km and drains a total area of 5988.56 sq km. The upper reaches of the river is called as the Aliyar. When it enters Kerala, it is called as the Kannadipuzha till it meets the Kalpathipuzha. After confluence with the Kalpathipuzha, it is known as Bharathapuzha or Ponnani river. It is joined by the Gayathripuzha on the left bank and the Pulanthode on the right bank as it flows down to the Arabian Sea. It also receives a large number of small streams and rivulets.

The Gayathripuzha, the Kalpathipuzha and the Pulanthode, are the three important tributaries. All the three tributaries rise in the Western slopes of the different ranges of the Western Ghats and drains a major parts of the Palghat, Trichur and Malapuram districts.

The Bharathapuzha basin receives copious rainfall during the South West monsoon and it lies in the rain shed region of the Western Ghats. The rainfall varies from 2,000 to 2,800mm in the hilly region to 3,000mm in the coastal region. Since, the basin is located in tropical region, the temperature varies with the season.

At present there are 13 completed structures either reservoirs or weirs in the Bharathapuzha catchment out of which there are three important structures namely the Aliyar reservoir, Tirumurthi reservoir and Malampuzha reservoir.

The Bharathapuzha River is the cradle of civilization as well as the lifeline of people of Palakkad, Malappuramand Thrissur districts of Kerala state.The river is the life line water resource for more than 4.5 million people residing in five administrative districts, namely Malappuram, Trissur and Palakkad districts of Kerala, and Coimbatore and Thiruppur districts of Tamil Nadu. There are eleven dams and irrigation projects in the river basin catering 493,064 ha cultivations.

There are ten irrigation projects and several sub-surface dams in the river basin catering to 493064 ha cultivations(CWRDM, 2004 and Ravi *et al.*, 2004). In recent years,the river basin was found going through severe dearth of water and drought conditions.

2.1.1 Hydrological studies

Aiswarya *et al.* (2009) modelled the topography of Bharathapuzha river basin to study existing flow pattern using watershed simulation model and to suggest suitable intervention to improve the summer flow regime of river Bharathapuzha using z dem. A land use map was prepared from LISS III imagery of IRS P6 by supervised classification. Also, SWAT model was set up for Bharathapuzha river basin. This model predicted average river discharge , annualy and monthly with a fair degree of accuracy, which can be used for land and water management plans and decisions

Raj and Azeez (2009) examined the spatiotemporal variation in water quality and quantity of Bharathapuzha river basin using multivariate statistical analysis tools. The sub basins varied considerably in terms of river discharge ,elemental concentration as well as elemental load . It was found that basins that are more disturbed , monsoonal discharge was very advanced than the discharges in other seasons, while the slightly disturbed basin had stable level of discharge throughout the season. Changes in land use and the impact of dams are major reasons for the spatiotemporal variations in the surface water chemistry of the river.

Raj and Azeez (2009) investigated the rainfall trend using MannKendal's rank correlation statistics and wavelet analysis. The basin's annual rainfall, southwest monsoon, and pre-monsoon rainfall show a significant decrease in the later years of the study. The primary causes of variation are global climate and local environmental changes.

Jagadeesh (2014) studied to define trends in the annual and seasonal total rainfall over Bharathapuzha basin of Kerala using 33 years (1976–2008) of monthly rainfall data at four rain gauge stations (Eruthempathy, Mangalam dam, Thrithala, and Malampuzha dam). The method is based on the nonparametric Mann–Kendall test for the trend and the nonparametric Sen’s method for the magnitude of the trend. From Mann–Kendall analysis for annual rainfall and southwest monsoon rainfall, a positive trend was perceived for Eruthempathy and Malampuza dam stations. However, at all four stations considered, a negative trend was observed for the northeast monsoon rainfall, positive trend for non-monsoon rainfall and pre monsoon except at Eruthempathy. A alike trend observed from liner regression analysis, existed for annual and seasonal rainfall series estimated by Mann–Kendall Z statistics and Sen’s Slope method. Overall trend analysis for annual rainfall discloses stations in the north and east shows a growing trend and stations in the south and west a declining trend. Recent study will direct the future planning and management of water resources at Bharathapuzha river basin.

Manjula and Unnikrishnan (2019) studied the hydrochemical investigation of open well and river water samples of Thuthapuzha Sub-basin of Bharathapuzha, Kerala, was carried out to determine the spatial and temporal variations in the physico-chemical parameters. The suitability of water for drinking and irrigation purposes and the processes controlling the water chemistry were also examined. The study area experiences a humid tropical climate and heavy rainfall of ~ 3830 mm/year. Thirty-five open well and nine river water samples were placid during the pre-monsoon, monsoon and post-monsoon seasons. The chemical properties of the river water samples were controlled by alkaline earths and weak acids (CaHCO3 type). Even though bulk of the open well samples belonged to CaHCO3 type, few samples belonged to NaCl, mixed CaMgCl and mixed CaNaHCO3 water type. The groundwater and river water chemistry of the region was influenced by the chemistry of the host rock rather than precipitation and evaporation. Except pH and the total iron concentration, all other physico-chemical parameters of the open well samples of the study area were within the satisfactory limit of drinking purposes. The physico-chemical parameters of the entire river water samples were within the tolerable limit for drinking purpose. The entire open well and river water samples were suitable for irrigation purposes

Drissia and Anjali (2020) studied and gave a route for the evaluation of water scarcity in a river basin. The study area is the Bharathapuzha river basin in Kerala, India. The study has two steps (i) assessment of water scarcity using blue water scarcity indicator and (ii) analysis of influential factors. The magnitude and severity of water scarcity rise during January and February and reach maximum during March. The influential factors such as variation in change in demand, hydrological parameters, and the impact of land use change and engineering measures on stream flow are analysed. Among the findings are the increase in demand due to growth in industries and population, long-term reduction in annual and southwest monsoon, especially in water scarce regions. In addition, Soil Water Assessment Tool model has been carried out to find the impact of land use change and engineering measures.

2.2 MORPHOMETRIC ANALYSIS OF RIVER BASINS

Morphology is the study of forms or structures which is quantitative determination of landform. Morphometric analysis is the measurement and mathematical evaluation of the earth's surface, shape and dimension of its landform. Morphometric analysis is very useful in drainage basin evaluation, silt erosion control, flood frequency analysis, watershed prioritization, natural resources management & conservation. Hydrological behaviour depends on geomorphologic parameters which determines the variation in earth's surface from past to present. In many regions, most of the basins are either ungauged or difficult to access so study on geomorphology of basins become much more important (Deepak Khare *et.al* 2014). Geomorphological analysis provides quantitative description of the basin geometry to understand inequalities or slopes in rock hardness, it's structure control and geological history of drainage basin. Drainage basin is the fundamental hydrologic and geomorphic areal unit. Drainage line of any drainage basin area illustrates existing three-dimensional geometry of region but assists for understanding its evolution process (K.R. Praveen, 2014).

2.2.1 Importance in hydrological studies

Morphometric analysis provides quantitative expression of drainage basins, and is regarded as one important tool in hydric analysis providing simple and accurate measures to document the drainage systems. Morphometric analysis brings out the basic characters on the geometrical and mechanical aspects of the river basin which in turn would be helpful in understanding the hydrology, sediment characteristics and landscape evolution of basins. River basins are considered as an open system and the basic steps involved in morphometric analysis are defining, measuring and analysing the quantitative indices related to flow plane geometry and profile, and bed form of river basins. The morphometric analysis examines linear and areal aspects of the drainage networks.

Drainage basin/watershed analysis based on morphometric parameters is very important for watershed planning since it gives an idea about the basin characteristics regarding slope, topography, soil condition, runoff characteristics, surface water potential etc.

The morphometric analysis of watershed aids to know the aspects of linear, areal, and relief parameters.The various morphometric parameters include stream order, stream length, mean stream length, stream length ratio, bifurcation ratios, mean bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, form factor, circula-tory ratio and elongation ratio.

2.2.2 Data needed

The main input data for morphometric processing are three layers of map, i.e., watershed area map, drainage map, and elevation map. Drainage map and elevation map can be derived from topography map. Drainage map can be given or generated from topographic map. Recently some researchers used DEM (Digital Elevation Model) data to extract drainage map, watershed area map, and elevation map. Drainage map is extracted automatically by GIS (Geographic Information System) from DEM which is an essential input in defining the morphometric parameter values. DEM must be edited before generating elevation and stream map but no one mention about the editing of the derived stream map. Sometimes the resulted stream map contains errors which must be edited. Therefore, the stream map derived from DEM data should be checked.

P.P. Nikhilraj and P.A. Azeez (2012) studied morphometric information at subbasin level using GIS and Remote Sensing tools. LANDSAT imagery and ASTER DEM data were used for morphometric analysis and examination of slope and relief. This information can be utilised for conservation and sustainable management of Bharathapuzha basin

Magesh *et al.* (2013) studied the morphometric analysis of Bharathapuzha river basin using geoprocessing techniques in GIS. The study area was classified according to Strahler’s system of classification and various morphometric characters were analysed. This includes basin area, drainage density, slope, elongation ratio etc. from the study it was concluded that remote sensing data (SRTM DEM) coupled with geoprocessing techniques can be effectively used in the morphometric analysis, basin management and hydrological studies.

M. Dhanusree and G. Bhaskaran (2019) studied river basin morphometry namely the physical linear and areal parameters of Bharathapuzha river basin using

SRTM satellite data with the help of geospatial techniques and statistical formulas. The morphometric analysis was carried out by dividing the basin in to 9 watershed and it was noted that there is not much difference in morphometric values except in some watershed. Using these parameters watersheds were characterised by surface runoff and erosion. Hence this study was valuable for the erosion control and watershed management and water resource planning.

G. Thampi *et al.* (2019) examined land use/cover change in Bharathapuzha river basin in Kerala during the period 1990 to 2017 using LANDSAT series satellite images. The dynamics of land use/cover change were quantified and mapped using geospatial techniques. They used supervised maximum likelihood method and post classification technique for mapping and change detection respectively. The study subsequently revealed a drastic change in land use/cover during this period due to deforestation and urbanization. They also generated future land use /cover maps using Multi-Layer Perceptron Neural Network and Markov chain techniques.

Thomas. P. K *et al.* (2021) compiled data from GIS enabled morphometric studies on the rivers of Kerala state. They validated first and second Horton's laws and the correlation between morphometric parameters by statistical analysis of data. It was inferred GIS based morphometric analysis of drainage basins provides precise data to update digital Drainage Network atlas of Kerala.

2.3 Digital Elevation Model

A **digital elevation model** (**DEM**) is a digital representation of ground surface topography or terrain. It is also widely known as a **digital terrain model** (**DTM**). While the term can be used for any representation of terrain as GIS data, it is generally restricted to the use of a raster grid of elevation values. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps.

Several methods are available to create DEM :

a) Conversion of printed contour lines. The first method is conversion of printed contour lines and use it in raster or vector form. The elevation contours are "tagged" with elevations. Any other additional elevation data are created from the hydrography layer. Finally, an algorithm is used to interpolate elevations at every grid point from the contour data.

b) Photogrammetry: This can be done manually or automatically: i) Manually, an operator looks at a pair of stereo photos through a stereo plotter and must move two dots together until they appear to be one lying just at the surface of the ground ii) Automatically, an instrument calculates the parallax displacement of a large number of points.

Types of DEM: A DEM can be represented as a raster (a grid of squares, also known as a heightmap when representing elevation) or as a vector-based triangular irregular network (TIN). The TIN DEM dataset is also referred to as a primary (measured) DEM, whereas the Raster DEM is referred to as a secondary (computed) DEM. A 7.5-Minute DEM covers 30 x 30 meter data spacing.

2.3.1 Importance in hydrological studies

Hydrologic applications of the DEM include groundwater modelling, estimation of the volume of proposed reservoirs, determining landslide probability, flood prone area mapping etc.

DEM applications:

1) Estimating elevation

2) Estimating slope and aspect

3) Determining drainage networks

4) Determining the watershed

5) Terrain stability – Areas prone to avalanches are high slope areas with sparse vegetation, which is useful when planning a highway or residential subdivision.

6) Soil mapping – DEMs assist in mapping soils which is a function of elevation (as well as geology, time and climate).

7) To create a profile graph from digitized features of a surface.

2.3.2 Sources

SRTM (Shuttle Radar Topography Mission) is a good source of DEM data for almost anywhere in the world. The SRTM digital elevation data, produced by NASA originally, is a major breakthrough in digital mapping of the world, and provides a major advance in the accessibility of high-quality elevation data for large portions of the tropics and other areas of the developing world. This data is currently distributed free of charge by USGS. USGS DEMs are raster grids of elevation values that are arrayed in series of south-north profiles.

Indian Space Research Organisation provides all DEM data of India through its portal Bhuvan. Catrosat-1 and 2 provide all these sources.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a Japanese remote sensing instrument onboard the Terra satellite launched by NASA in 1999. The ASTER GDEM data products are created by the Sensor Information Laboratory Corporation (SILC) in Tokyo.

2.3.3. Studies using different DEMs

SRTM

Yang Liping *et al.* (2011) studied the principle, data set, void filling and accuracy of SRTM DEM with special emphasis on geology, geomorphology, water resources and hydrology, glaciology, evaluation of natural hazards and vegetation survey. In his study fruitful result have been achieved in all the field. However, little has been achieved in field such as urban characteristics. In some fields the applications are limited to certain factors. He concluded that SRTM data sets is unique worldwide topographic data set and is highly beneficial for many applications. Its application are limited when it comes to study of small scale or steep topographic features as well as the modelling of detailed drainage features.

R. Oleg *et al.* (2018) in his case study used Shuttle Radar Topography Mission (SRTM) 30m and SRTM 90m with Topographic DEM generated from ground topographic maps with a scale of 1:50,000 as a reference elevation to check the accuracy of those models by evaluation process at 625 CGPs. The aim of the study was approaching to a proper, accurate and economical scientific method for updating the topographic maps by evaluating the vertical accuracy of models. The study area lies between 31 to 31.5 E and 29.5 to 31.5 N. A number of (625) ground control points (GCPs) have been used in the evaluation process. From the statistical computations, it was obvious that SRTM 30m has the most discrimination of its performance in terms of the Standard deviation by ±5.53m compared with ±5.88 for SRTM 90m. SRTM 30m elevation data is featured a much greater absolute vertical accuracy than the value of ±16 m, which is published in the SRTM data specification. The analyses presented in the paper indicates that the absolute vertical accuracy of SRTM 1 arcsec data for datasets proven to 2.94 times higher than the value of ±16 m presented in the original SRTM requirement specification by using GCPs as a reference.

CARTODEM

Nadeem Ahmed *et al.* (2007) presented a paper which describes the evaluation of the Cartosat-1 stereo data, mainly through the generation and validation of DEM for moderately undulating and hilly areas. Photogrammetric techniques have been used for generation of DEM and Orthoimage for two cases i.e., 1) using RPCs (Rational Polynomial Coefficients) and 2) using RPCs along with ground control points. Root Mean Square Error (RMSE) in elevation values for the moderately undulating (Dehradun) and hilly area (Shimla), are found to be 4.38 and 3.69m respectively.

O S Srivasthava *et al.* (2014) conducted morphometric analysis of Semi Urban Watershed, trans Yamuna River Basin, Allahabad using Cartosat DEM data and GIS. GIS based approach facilitates analysis of different morphometric parameters and to explore the relationship between the drainage morphometric and properties of landforms, soils and eroded lands. Different landforms were identified in the watershed based on CartoSAT-1 DEM data with 30m spatial resolution, and GIS software. The study concluded that CartoSAT-1 (DEM) data, coupled with GIS techniques, prove to be a competent tool in morphometric analysis.

Surabhi Bhatt and Ahmed S A (2014) evaluated basin characteristics from the morphometric parameters that helps in understanding flooding in the main Krishna River. The advanced technologies, such as Remote sensing and Geographic

Information System (GIS), were used for extraction of drainage networks using Cartosat Digital Elevation Model (DEM) for the Upper Krishna basin, to evaluate the morphometric analysis. The morphometric analysis for the ten major potential flood prone river catchments of the basin revealed that, the river catchments such as Krishna, Koyna, Yerla having the greater tendency to peak discharge in a short period of time to the main Krishna River because of high relief ratio (Rh), high ruggedness number and less time of concentration (Tc). The Don catchment having the highest drainage density (Dd), stream frequency, mean bifurcation ratio and infiltration number causes greater runoff influence on the main Krishna River. The study indicates that systematic analysis of morphometric parameters derived from Cartosat DEM using GIS provide useful information about catchment characteristics with respect to floods management.

Agarwal Ankit *et al.* (2020) proposed a novel method to increase the vertical precision of CARTOSAT 10 m DEM by blending it with publicly available SRTM (Shuttle Radar Topography Mission) DEM using machine learning methods. Machine learning methods such as Genetic Programming (GP) and Artificial Neural Networks (ANN) are applied to the SRTM-1 DEM and the CARTOSAT DEM in India to generate DEM of improved vertical accuracy. Quantifiable results show that proposed approach improve the vertical accuracy, considering the reference as Ground control Points (GCPs) elevation from Differential Global Positioning System (DGPS) survey data. Significant improvements of 47 and 35% in RMSE are offered by generated DEMs compared to the SRTM-1 and CARTOSAT respectively

ASTER

S R Hosseinzadeh (2011) in his paper showed the quality and accuracy of drainage network analysis resulted from ASTER DEMs. Hydrology toolsets in the ArcGIS package was used to extract drainage networks from a grid DEM for cheshmehkhan catchment in the north-eastern of Iran. Extracted networks compared with the one derived from aerial photographs and high-resolution satellite Images as real ground. Results showed both the DEMs and current GIS algorithms have basic imperfections. However, drainage morphometry analysis based on extracted rivers from DEM are similar of natural network in the raster format and for whole catchment area but there are many large differences when vector datasets are used for analysing separate land features. They found that the best threshold values for Extraction of rivers from ASTER DEMS were 25 cells for head waters in the mountain areas, 50-100 for pediments, 100-250 for Alluvial fans and 500 for plain domains. Hence it is concluded that automated river extraction from DEMs can be improved by dividing the basin into geomorphological units and using a different threshold in each unit. The best method for river extraction can be using the high resolution of aerial photograph and satellite images.

Pareta Kuldeep *et al.* (2011) studied the morphometric characteristics of Karawan watershed in Dhasan basin, Madhya Pradesh using ASTER (DEM) and geographical information system (GIS). Watershed boundary, flow accumulation, flow direction, flow length, stream ordering have been prepared using ArcHydro Tool; and contour, slope, aspect, hillshade have been prepared using Surface Tool in ArcGIS10 software, and ASTER (DEM). Different thematic maps i.e., drainage density, slope, relief, superimposed profile, and longitudinal profiles have been prepared by using ArcGIS software. Authors have computed more than 85 morphometric parameters of all aspects. Based on all morphometric parameter analysis, they found that the erosional development of the area by the streams has progressed well beyond maturity and that lithology has had an influence in the drainage development.

P.K. Deshpande *et al.* (2013) carried out flood level mapping of Koyana river basin along with the ASTER GDEM based layers derived in ILWIS software developed by ITC, Netherlands. ASTER GDEM in GeoTIFF format with geographic lat/long coordinates and a 1 arc second (approximately 30 m) grid were used. Here the efforts were made to derive GIS layers like extracted contour, drainage, various slope maps for the slope analysis, flow direction map and flow accumulation map. It was observed that ASTER GDEM is an effective tool for many applications and has potential benefits in planning against flood disaster management and mitigation. ASTER GDEM was having the accuracy level higher than the DEM generated from the topographic map, and emerging as a very effective tool for a planning engineer for the decision making at strategic levels especially in the areas of watershed management, hazard zonation mapping and its vulnerability assessment, infrastructural development planning etc.

2.4 Comparison of different DEMs – A hydrological perspective

Jeffrey *et al.* (2005) conducted a study for the generation of DEM ideal for difficult terrain investigations by comparing accuracy of ASTER/SRTM DEM with DEMs derived from contour maps. For selected peaks in high mountains of diverse climatic regions (Andes, Hindu Kush, Tien Shan) digital elevation models (DEMs) have been generated from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data using PCI Geomatica 8.1/8.2 software. Artifacts in the ASTER DEM were eliminated using data from the Space Shuttle Radar Topography Mapping mission (SRTM). Geomorphic analyses were undertaken using the software ArcInfo, ArcView and SAGA. The SRTM DEM shows correct elevations in all altitudes, elevations in the ASTER DEM are slightly low in higher altitudes and south-exposed aspects. Both DEMs are useful for an interpretation of the macro- and mesorelief. The DEM scale sets limits for the level in analysis detail. Results shows that SRTM DEMs offer more precise elevations whereas ASTER DEMs offer more geomorphologic details.

P. Jacobs *et al.*(2008) compared the advantages and limitations of Shuttle Radar Topography Mission (SRTM) DEMs, derived from radar interferometry, and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEMs, derived from digital photogrammetry. The ready-to-be-used SRTM dataset is of great interest for morphological studies of volcanic terrains. The combination of topographic data with multi-spectral information, the repeated data acquisition over volcanic regions allowing analysis of morphological changes at active volcanoes, the low cost, and the high spatial resolution are advantages of ASTER data in comparison with SRTM. The practical use of ASTER DEMs in characterizing volcano morphology and modelling volcano hazard is however limited by the small-scale artefacts produced by matching errors.

Christoph *et al.*(2009) examines the application and quality of digital elevation models (SRTM and ASTER DEMs), high resolution satellite imagery (Quickbird) and GIS techniques for the detection and mapping of karst landforms (mainly enclosed depressions) at different scales in the Ida Mountains of Central Crete. . The findings of the studies proved that an integrated approach based on SRTM, ASTER and Quickbird data is of great value for computerized karst mapping on larger units with meso- to macroC. As demonstrated by the results, DEMs like SRTM or ASTER and their derivatives have a limited precision as they were not able to capture small to medium-sized karst depressions. Hence they concluded that increasing level of detail of DEMs and satellite imagery would bring along enhanced possibilities, future work may consider integrating more environmental parameters, using better DEMs and improving the automation of the mapping process.

Eko Kustiyanto *et al*. (2011) assessed the thematic information content using subwatershed boundaries mapped using advanced spaceborne thermal emission and reflection (ASTER) global digital elevation model (GDEM), shuttle radar topography mission (SRTM) DEM and a topographic map (Topo-DEM), and verifies the absolute elevation accuracy by the use of a real-time kinematic differential global positioning system (RTK-DGPS) survey. Subwatershed boundaries extracted from the three different DEMs exhibit a high degree of congruency especially in upstream areas. In these areas, SRTM exhibits lower root mean square errors (RMSEs) than the ASTER GDEM. The discrepancies were larger at lower altitudes. The vertical accuracy assessment using the RTK-DGPS data showed strong correlation with the three DEMs at some stations but the accuracy varied from one area to another. The ASTER GDEM and SRTM had lower accuracy than the Topo-DEM due to the influence of artefacts as shown by their total average RMSE (4.42, 3.30 and 3.13 m, respectively). The average RMSE values also indicate that SRTM is comparatively more accurate than ASTER GDEM.

R.Rejani *et al*. (2014) made an attempt to develop a spatial runoff estimation model for Budhabalanga River basin using GIS coupled with SCS-CN method. SRTM 90 m and ASTER 30 m DEM data was used for generating the basin map, drainage network, slope map etc and evaluated the feasibility of ASTER and SRTM DEMs for delineating the river basins of Kerala. SRTM DEM was found to be performing better for delineating river basins and watersheds.

Mariusz Sojka *et al.*(2016) tested four digital elevation models (LiDAR-, Airborne-, ASTER- and SRTM-DEM) to define polder retention capacities. The vertical accuracy of available ASTER- and SRTM-DEMs is insufficient to calculate the polder volume and model the transformation of flood waves in river systems. The spatial accuracy of the ASTER and SRTM models is insufficient due to their lack of good reproduction of levee embankments in order to determine the polder boundary. These models may, however, become useful for certain cartographic studies.

Subbu Lakshmi. E1 & Kiran Yarrakula (2016) compared the accuracy of digital elevation model (DEM) from high resolution Cartosat-1 stereo data with elevation values from SRTM (shuttle radar topography) DEM, Survey of India toposheet (SOI) and Google Earth. It was observed that, an elevation value of Cartosat-1 DEM was better than SRTM, and Google Earth. The Cartosat-1 DEM provided good and satisfactory information on topographic related analyses especially in flat terrain region. Moreover, SRTM-DEM provided good elevation in hilly region. For this study, DGPS elevation values were not used due to high cost and unavailability. This study is useful for environmental mapping tasks like avalanche hazard mapping, 3D perspective terrain visualization, landform studies and topographic maps updating.

Elkhrachy Ismail (2017) made a study for the evaluation of the quality of DEMs acquired by SRTM ver.3 and ASTER ver.2. The reference levels produced from GPS elevations, and the topographic map was used to assess the vertical accuracy of SRTM and ASTAR DEMs in Najran city, Saudi Arabia. The 30 m SRTM elevation data featured a much greater absolute vertical accuracy. Analyses presented in this paper indicated that the absolute vertical accuracy of SRTM ver3 datasets proven to be two to three times higher than the value of ±16 m presented in the original SRTM requirement specification by using GPS elevation as a reference.

P. JulioMiranda *et al.* (2018) in his study evaluated the feasibility of DEMs derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the Shuttle Radar Topography Mission (SRTM) for lahar modelling on Popocatépetl Volcano, Mexico. Two GIS-based models are used for lahar modelling, LAHARZ and a flow-routing-based debris-flow model (modified single-flow direction model, MSF). Flow-path prediction is found to be more reliable with SRTM data, though with a coarser spatial resolution. Lahar modelling with the ASTER DEM results in a more finely spaced predicted inundation area but does not add any significant information in comparison with the SRTM DEM. Both types of DEMs basically have been found feasible for application with the mass-flow models LAHARZ and MSF. Because of the global coverage of this type of remote-sensing data, the conclusion that both SRTM and ASTER-derived DEMs are feasible for lahar modelling opens a wide field of application in volcanic-hazards studies.

M. Rajasekhar *et al.* (2018) compared the lineaments from the Cartosat, ASTER and SRTM of Digital Elevation Model (DEM) of different spatial resolutions, in the software ArcGIS 10.4. The extracted lineaments result showed that ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM gives the lowest number of lineaments reflects Cartosat and SRTM (Shuttle Radar Topography Mission) DEM shows a medium number of lineaments. Cartosat DEM is most appropriate for extraction of contours precisely rather than ASTER and SRTM. This study revealed that the Cartosat DEM data is best to use extraction of lineaments in the Indian provinces, offers at most comprehensive geological structural info amongst all the data sets. The extracted lineaments lengths and densities were determined by the statistical method. Based on the data generated lineament density and rose diagram. Cartosat DEM data were the best suited for studying very small areas as through geological and structural information can be mined by using this data.

Materials and methods

CHAPTER III

MATERIALS AND METHODS

3.1 STUDY AREA

The study area was selected as Bharathapuzha river basin which lies between 10º15’ to 10º40’ North latitudes and 76º00’ to 76º35’ East longitudes and it covers Malappuram, Thrissur and Palakkad districts of Kerala, and Coimbatore district in Tamil Nadu, India. It originates from the Western Ghats at an altitude of about 1100 m

above mean sea level, fed by its four main tributaries namely Kalpathypuzha, Gayathripuzha, Thootha and Chitturpuzha, which drain through highly varied geological and geomorphologic regions of Kerala.

3.2 DEMS USED IN THE STUDY

The reference used in the study is google earth data. This data was downloaded from google earth pro software installed in the system.

Random number of points were selected in google earth (within Bharathapuzha river basin) and a KML file was created. The elevation data of these points were collected and converted into shape file using GPSVisualizer (https://www.gpsvisualizer.com). The same shapefile of points was then opened in ArcGIS software and elevation data in different DEMs were obtained using ‘add surface information’ tool.

3.2.1 Google Earth

Google Earth is a computer program that renders a 3D representation of Earth based primarily on satellite imagery. The program maps the Earth by superimposing satellite images, aerial photography, and GIS data onto a 3D globe, allowing to see cities and landscapes from various angles

The different DEMs used in the study include:

Table 3.2.1different DEMS used in the study

Sl.no	DEM	Source	Resolution	Date of issue
1	SRTM	https://earthexplorer.usgs.gov/	90m	19/4/2022
2	CARTODEM	https://bhuvan.nrsc.gov.in/home/index.php	30m	19/4/2022
3	ASTER	https://www.earthdata.nasa.gov/news/new-aster-gdem	30m	7/5/2022
4	ALOS	https://doi.org/10.5069/G94M92HB	30m	20/3/2022
5	GTOPO	https://earthexplorer.usgs.gov/	900m appx. 1km	7/5/2022

3.2.2 SRTM

The **Shuttle Radar Topography Mission** (**SRTM**) is an international research effort that obtained digital elevation models on a near-global scale from 56 °S to 60 °N,[2] to generate the most complete high-resolution digital topographic database of Earth to date. The elevation models are arranged into tiles, each covering one degree of latitude and one degree of longitude, named according to their south western corners. It follows that "n45e006" stretches from 45°N 6°E to 46°N 7°E and "s45w006" from 45°S 6°W to 44°S 5°W. The resolution of the cells of the source data is one arc second, but 1" (approx. 30 meter) data have only been released over United States territory; for the rest of the world, only three arc second data (approx. 90 meter) are available. [3] Each one arc second tile has 3,601 rows, each consisting of 3,601 16-bit bigendian cells. The dimensions of the three arc second tiles are 1201 x 1201.

The elevation models derived from the SRTM data are used in Geographic Information Systems. They can be downloaded freely over the Internet, and their file format (.hgt) is supported by several software developments.

The Shuttle Radar Topography Mission is an international project spearheaded by the U.S. National Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA).

Product Specifications

Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Vertical Units	Meters
Spatial Resolution	1 arc-second for global coverage (~30 meters)
	3 arc-seconds for global coverage (~90 meters)
Raster Size	1 degree tiles
C-band Wavelength	5.6 cm

3.2.3 CARTODEM

CartoDEM is generated using Augmented Stereo Strip Triangulation (ASST) - indigenously developed software by Space Application Centre, ISRO. The seamless CartoDEM generation is an automatic process and makes use of limited Ground Control Points (GCPs) in long stereo strip pairs using dense feature matching, Triangulated Irregular Network (TIN) modelling and automatic long strip mosaicking. The generated DEM and ortho images of each Cartosat-1 segment are cut into tiles of 7.5’x7.5’ extents. The entire Indian region is covered by approximately 500 Cartosat-1 segments with a total number of around 20,000 tile pairs. Every tile is subjected to quality verification process through panning and 2.5D draped visualization to identify and demarcate distortions in Quality Verification (QV) system for further improvement. The automatic generation of DEM has inherent problems like water-body irregularities, hill-top distortions, plain-area sinks and residual mosaics; and these are corrected in the Tile Editing (TE) system. Qualified CartoDEM tiles are formatted and archived systematically in database Dissemination System (DS).

Parameters	Specifications
Image Format	Geo-Tiff
Data Type (DEM)	Signed short (2 bytes)
Data Type (Ortho-image)	Unsigned short (2 bytes)
Datum (planimetric and height)	WGS84
Projection	Geographic
Ortho Image Resolution	1/12 arc sec ~ 2.5 m
Posting	1/3 arc sec ~ 10 m
DEM type	Digital Surface Model
Absolute accuracy (Planimetric)	15m (CEP 90)
Absolute accuracy (Vertical)	8 m (LE 90)
Relative accuracy (Vertical)	> 5 m (LE 90)
Ellipsoidal height Units	Meters
Tile Extents (Size)	7.5’x7.5’
Generating Agency	NRSC / ISRO
Copyright	NRSC / ISRO

3.2.4 ASTER DEM

The Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) Version 3 (ASTGTM) provides a global digital elevation model (DEM) of land areas on Earth at a spatial resolution of 1 arc second (approximately 30-meter horizontal posting at the equator).

The development of the ASTER GDEM data products is a collaborative effort between National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI). The ASTER GDEM data products are created by the Sensor Information Laboratory Corporation (SILC) in Tokyo.

The ASTER GDEM Version 3 data product was created from the automated processing of the entire ASTER Level 1A archive of scenes acquired between March 1, 2000, and November 30, 2013. Stereo correlation was used to produce over one million individual scene-based ASTER DEMs, to which cloud masking was applied. All cloud screened DEMs and non-cloud screened DEMs were stacked. Residual bad values and outliers were removed. In areas with limited data stacking, several existing reference DEMs were used to supplement ASTER data to correct for residual anomalies. Selected data were averaged to create final pixel values before partitioning the data into 1° by 1° tiles with a one-pixel overlap. To correct elevation values of water body surfaces, the ASTER Global Water Bodies Database (ASTWBD) Version 1 data product was also generated.

The geographic coverage of the ASTER GDEM extends from 83° North to 83° South. Each tile is distributed in Cloud Optimized GeoTIFF (COG) format through NASA Earthdata Search and in standard GeoTIFF format through the LP DAAC Data Pool. Data are projected on the 1984 World Geodetic System (WGS84)/1996 Earth Gravitational Model (EGM96) geoid. Each of the 22,912 tiles in the collection contain at least 0.01% land area.

Provided in the ASTER GDEM product are layers for DEM and number of scenes (NUM). The NUM layer indicates the number of scenes that were processed for each pixel and the source of the data.

While the ASTER GDEM Version 3 data products offer substantial improvements over Version 2, users are advised that the products still may contain anomalies and artifacts that will reduce its usability for certain applications.

Characteristic	Description
Collection	Terra ASTER
DOI	10.5067/ASTER/ASTGTM.003
File Size	~25 MB
Temporal Resolution	Multi-Year
Temporal Extent	2000-03-01 to 2013-11-30
Spatial Extent	Global
Coordinate System	Geographic Latitude and Longitude
Datum	WGS84/EGM96
File Format	GeoTIFF
Geographic Dimensions	1 degree lat x 1 degree lon
Number of Science Dataset (SDS) Layers	2
Columns/Rows	3601 x 3601
Pixel Size	30 m

3.2.5 ALOS

The ALOS Global Digital Surface Model (AW3D30) is a global dataset generated from images collected using the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) aboard the Advanced Land Observing Satellite (ALOS) from 2006 to 2011. As described by the Japan Aerospace Exploration Agency: The Japan Aerospace Exploration Agency (JAXA) releases the global digital surface model (DSM) dataset with a horizontal resolution of approx. 30-meter mesh (1 arcsec) free of charge. The dataset has been compiled with images acquired by the Advanced Land

Observing Satellite "DAICHI" (ALOS). The dataset is published based on the DSM dataset (5-meter mesh version) of the "World 3D Topographic Data", which is the most precise global-scale elevation data at this time, and its elevation precision is also at a world-leading level as a 30-meter mesh version. This dataset is expected to be useful for scientific research, education, as well as the private service sector that uses geospatial information.

Raster Resolution : 30 meter

Coordinate System:

Horizontal: WGS 1984 [EPSG: 4326]

Vertical: WGS84 (EGM96 GEOID)

Units : meter

3.2.6 GTOPO

GTOPO30 is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometre). GTOPO30 was derived from several raster and vector sources of topographic information. For easier distribution, GTOPO30 has been divided into tiles which can be selected from the map. GTOPO30, completed in late 1996, was developed over a three year period through a collaborative effort led by staff at the U.S. Geological Survey's Center for Earth Resources Observation and Science (EROS). The following organizations participated by contributing funding or source data: the National Aeronautics and Space Administration (NASA), the United Nations Environment Programme/Global Resource Information Database (UNEP/GRID), the U.S. Agency for International Development (USAID), the Instituto Nacional de Estadistica Geografica e Informatica (INEGI) of Mexico, the Geographical Survey Institute (GSI) of Japan, Manaaki Whenua Landcare Research of New Zealand, and the Scientific Committee on Antarctic Research (SCAR).

Projection : GEOGRAPHIC

Datum : WGS84

Zunits : METERS

Spheroid : WGS84

3.3 INTERFACE USED

ArcGIS is a family of client software, server software, and online geographic information system (GIS) services developed and maintained by Esri. ArcGIS was first released in 1999 and originally was released as ARC/INFO, a command line based GIS system for manipulating data. ARC/INFO was later merged into ArcGIS Desktop, which was eventually superseded by ArcGIS Pro in 2015. ArcGIS Pro works in 2D and 3D for cartography and visualization, and includes Artificial Intelligence (AI).

Table 3.3.1ArcGis version history

Version	**Year**	**Version**	**Year**	**Version**	**Year**
8.0	1999-12-27	10.0	2010-06-29	10.5.1	2017-06-29
8.0.1	2000-01-13	10.1	2012-06-11	10.6	2018-01-17
8.1	2001-05-01	10.2	2013-07-30	10.6.1	2018-07-16
8.2	2002-05-10	10.2.1	2014-01-07	10.7	2019-03-21
8.3	2003-02-10	10.2.2	2014-04-15	10.7.1	2019-06-27
9.0	2004-05-11	10.3	2014-12-10	10.8	2020-02-20
9.1	2005-05-25	10.3.1	2015-05-13	10.8.1	2020-07
9.2	2006-11-14	10.4	2016-02-18	10.9	2021-05-06
9.3	2008-06-25	10.4.1	2016-05-31		
9.3.1	2009-04-28	10.5	2016-12-15		

The version used in this study is ArcGIS 10.4.

3.4 MORPHOMETRIC ANALYSIS OF BHARATHAPUZHA RIVER BASIN – STEPS

3.4.1 Mosaicking

A mosaic is a combination or merge of two or more images. Tiles corresponding to the study area were downloaded from official data source. The tiles were then converted into a single raster data set using the mosaic tool in ArcGIS 10.4.

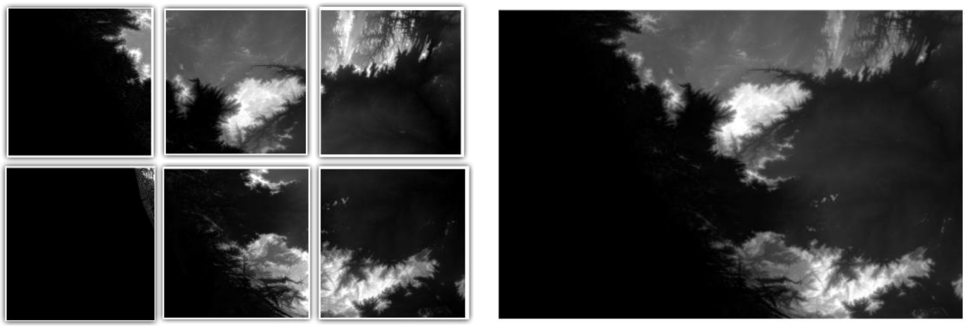

Fig 3.1

Mosaicking of CartoDEM

3.4.2 Extraction of river basin

The final image obtained after mosaicking was filled using the fill tool from spatial analyst tool box. Using this filled image as input the flow direction data was obtained. This was done by using the flow direction tool from hydrology tool. Flow accumulation data was then generated. For getting better streamlines the flow accumulation layer was modified by changing symbology into classified and changing the number of classes into 2. Later the range of the class values were changed to obtain the best result. Then the Bharathapuzha river basin was extracted.

3.4.3 Extraction of stream network

Using the flow accumulation as input another raster data was generated by using raster calculator tool. The final stream network of the watershed was extracted using the stream order and stream to feature using the ArcGIS.

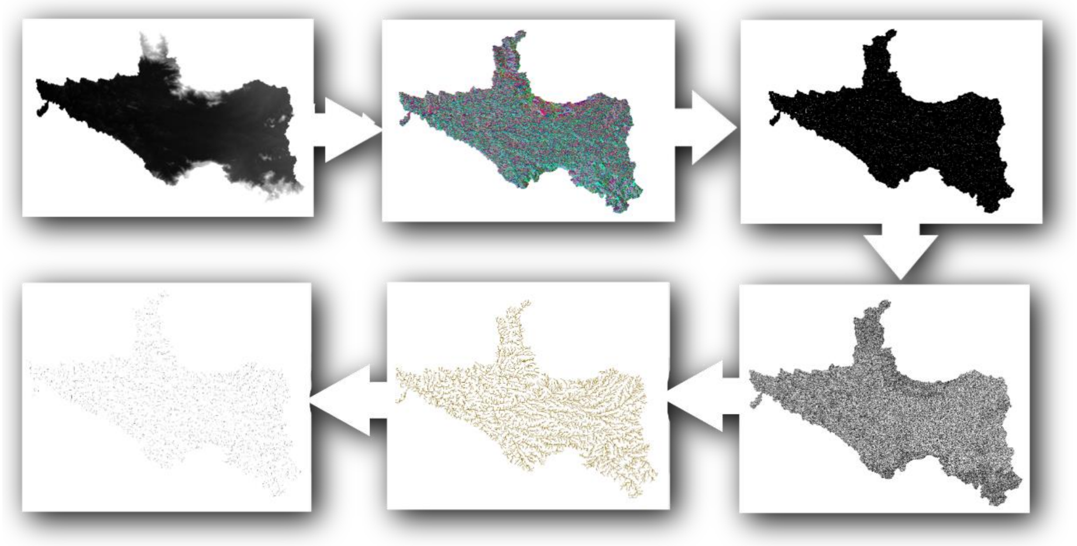

Fig 3.2 Extraction of drainage network from CARTODEM

To compare the DEMs, a fraction of 0.01% flow accumulation area was taken and various parameters like stream number, stream order, stream length, stream length ratio, bifurcation ratio, basin length, basin area, elongation ratio, length of overland flow, drainage density, stream frequency and form factor have been analysed using the standard mathematical formulae.

Table 3.4.3 Morphometric parameters

Sl no	Parameters	Formulae
1	Stream Order (U)	Hierarchical rank
2	Number of streams (N_u)	
3	Stream length (L_u)	Length of the stream
4	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$
5	Stream length ratio (RL)	$RL = L_u/(L_{u-1})$
6	Bifurcation ratio (Rb)	$Rb = Nu/(N_{u+1})$
7	Mean bifurcation ratio (Rbm)	Rbm = average of bifurcation ratios of all order
8	Drainage density (Dd)	Dd = Lu/A, A is the area of basin
9	Drainage texture (T)	T = Dd x Fs
10	Stream frequency (Fs)	$Fs = N_u/A$
11	Elongation ratio (Re)	$Re=D/L=1.128 \sqrt{(A/L)}$
12	Form factor (Ff)	$Ff = A/L^2$
13	Length of overland flow (Lg)	Lg = 1/(2xDd)

3.5 COMPARING DEM USING ELEVATION

Inorder to compare DEMs on elevation point of view, random number of points were selected in google earth (within Bharathapuzha river basin) and elevation data of these points were collected. Correspondingly, elevation data in different DEMs were obtained using ‘add surface information’ tool.

Mean error, Standard Deviation, R^2 value and RMSE values were then calculated

$$\mathrm{STD} = \sqrt{\frac{\sum_{i=i}^{n} (x_i - y_i - \mathrm{ME})^2}{n-1}},$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=0}^{n} (x_i - y_i)^2}{n}},$$

$$R^2 = \frac{[\sum_{i=0}^{n} (x_i - \overline{x}) \times (\mathrm{y}_i - \overline{\mathrm{y}})]^2}{\sum_{i=0}^{n} (x_i - \overline{x})^2 \times \sum_{i=0}^{n} (\mathrm{y}_i - \overline{\mathrm{y}})^2},$$

$$\mathrm{ME} = \frac{\sum_{i=1}^{n} (x_i - y_i)}{n},$$

Results and Discussions

CHAPTER IV

RESULTS AND DISCUSSION

4.1 MORPHOMETRIC ANALYSIS OF BHARATHAPUZHA RIVER BASIN

After the extraction of stream network from different DEMS, the morphometric parameters of the Bharathapuzha river basin was calculated using the equations.

Table 4.1.1 Result of morphometric analysis

parameters	SRTM	ASTER	CARTODEM	GTOPO	ALOS
stream order	7	7	7	6	7
NUMBER OF STREAMS					
1st order	1907	2551	2874	1515	2907
2nd order	352	482	536	197	534
3rd order	92	130	128	54	118
4th order	19	30	29	12	30
5th order	6	8	8	3	10
6th order	2	2	2	1	4
7th order	1	1	1		1
TOTAL	**2379**	**3204**	**3578**	**1782**	**3604**

STREAM LENGTH (Km)					
1st order	2861.775	3140.251	2992.589	3629.305	2867.341
2nd order	1245.158	1440.353	1420.662	830.767	1353.608
3rd order	668.976	793.714	721.05	379.599	710.746
4th order	314.138	351.216	411.48	166.276	348.516
5th order	126.398	181.156	233.608	172.852	114.706
6th order	177.557	93.38	73.296	50.099	182.989
7th order	75.783	150.212	74.553	nill	95.628
TOTAL LENGTH	**5469.785**	**6150.282**	**5927.238**	**5228.898**	**5673.534**
Stream length ratio	0.613	0.682	0.575	0.491	0.656
Mean bifurcation ratio	3.709	3.847	3.931	4.568	3.901

Area (km2)	5689.87	6257.09	6127.69	5980.56	5988.50
Drainage density(km/km2)	0.91337233	1.027005156	0.989760143	0.873147802	0.947395367
Basin length(km)	145.900	149.600	143.081	142.807	142.807
Stream frequency(/km2)	0.397257438	0.535020105	0.597472514	0.297567362	0.601814126
Form factor	0.293645543	0.293645543	0.293645543	0.293645543	0.293645543
Length of over flow	0.547421882	0.486852473	0.505172898	0.572640736	0.527762767

4.1.1 Stream order

Stream ordering is a widely applied method for stream classification in a river basin. Stream ordering is defined as a measure of the position of a stream in the hierarchy of tributaries (Leopold et al. 1964) and the streams of Bharathapuzha river basin have been demarcated according to the Strahler's system of stream ordering. The stream order and total number of stream segments in each order are shown in the table. The basin has been designated as a seventh-order basin in all the DEMS except GTOPO, where the stream order is only six.

4.1.2 Stream number (Nu)

With the help of GIS, the number of streams of different orders and the total number of streams in the basin are counted independently. Generally, the number of streams gradually decreases as the stream order increases; the variation in order and size of tributary basins is largely depends on physiographic and structural condition of the region. On comparing the total number of streams ALOS had the maximum (*ie* 3604) followed by CARTODEM (3578), ASTER (3204), SRTM (2379) and GTOPO showed the minimum (*ie* 1782) number of streams. Also maximum frequency is observed in the first-order streams in all the DEMs.

4.1.3 Stream length

The stream length is measured from mouth of the river to the drainage divide near the source. 'Lu' has been computed on the basis of Horton's law of stream length, which states that geometrical similarity is maintained in the basins of increasing orders. The total length of stream segments is the maximum in first-order streams and decreases with an increase in the stream order.

We know that, the length of trunk order stream in Bharathapuzha basin is 95 km (Magesh *et al.,* 2013). ALOS was the only DEM which validated this statement by showing a length of 95.628 km. While SRTM and CARTODEM shown comparable values of 75.783 km and 74.553 km respectively ASTER showed a higher value of 150.212 km. On considering the total length of the first order streams ASTER exhibited best value of 3140.251 km even though GTOPO showed the highest of 3629.305 km, SRTM and CARTODEM showed a comparable 2861.775 km and 2992.589 km respectively.

4.1.4 Stream length ratio (RI)

Stream length ratio (Rl) is the ratio between the lengths of streams in a given order to the total length of streams in the next lower order (Horton 1932). ASTER and ALOS had the highest stream length ratio of 0.682 and 0.656 respectively whereas GTOPO had the lowest value of 0.491.

4.1.5 Bifurcation ratio (Rb)

The term ‘bifurcation ratio (Rb)’ was introduced by Horton in 1932. Rb is related to the branching pattern of a drainage network and is defined as the ratio of the number of streams of any given order to the number of streams in the next higher order in a drainage basin. It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin. Rb shows a small range of variation for different regions or for different environments except those where the powerful geological control dominates. The analysis showed that Rb is not same for all orders. Considering the mean bifurcation ratio, the value ranges between 3.0 and 5.0 for all the DEMs. Low Rb value indicates poor structural disturbance and the drainage patterns have not been distorted (Strahler, 1964), whereas the high Rb value indicates high structural complexity and low permeability of the terrain. Bharathapuzha river basin has less structural disturbances and so the mean bifurcation ratio would also be less (Magesh *et al*, 2013). In this aspect, only GTOPO showed the poor result.

4.1.6 Basin length (Lb)

The basin length (Lb) is the longest length of the basin from the headwaters to the point of confluence. Here the basin length varies from 140 to 150 km for all the DEMs.

4.1.7 Drainage density (Dd)

Drainage density (Dd) is one of the important indicators of the landform element and provides a numerical measurement of landscape dissection and runoff potential. Dd is defined as the total stream length in a given basin to the total area of the basin. A low drainage density indicates permeable sub-surface strata and has a characteristic feature of coarse drainage, which generally shows values less than 5.0. On analysis, only GTOPO gave value less than 0.9 (0.873km/km^2). Among other DEMs, ASTER showed the highest value of 1.027km/km^2.

4.1.8 Stream frequency (Fs)

According to Horton (1945), stream frequency (Fs) is defined as the ratio of the total number of stream segments of all the orders in the basin to the total area of the basin. ‘Fs’ is an index of the various stages of landscape evolution. The stream frequency for the Bharathapuzha basin is 0.74 (Magesh *et al*, 2013). The stream frequency value (0.656) given by ALOS is in agreement with this statement. While all other DEMs shower lower values than ALOS. It is to be noted that GTOPO showed the poorest value of 0.297 among all.

4.1.9 Form factor (Ff)

Form factor (Ff) is the ratio of the basin area and square of the basin length. Since we had used the same shapefile for extracting boundary of the basin, the form factor was calculated as 0.293 for all the DEMs. This lower value indicates that Bharathapuzha basin is an elongated basin with lower peak flows of longer duration.

4.1.10 Length of overland flow (Lg)

Length of the overland flow (Lg) is the length of water over the ground before it gets concentrated into definite stream channels. ‘Lg’ can be defined as the mean horizontal length of flow path from the divide to the stream in a first-order basin and is a measure of stream spacing and degree of dissection and is approximately one-half the reciprocal of the drainage density. The high Lg value indicates the rainwater had to travel relatively longer distance before getting concentrated into stream channels (Chitra et al. 2011). However, low Lg values indicate that the rainwater will enter the stream quickly.

The values of Lg ranges between 0.486 (ASTER) and 0.572 (GTOPO). SRTM, CARTODEM and ALOS showed values of 0.547, 0.505 and 0.528 respectively.

4.2 INFERENCE FROM MORPHOMETRIC ANALYSIS

From the morphometric analysis, it is evident that ALOS performed better followed by ASTER DEM. SRTM and CARTODEM gave almost comparable results in all the morphometric parameters. The analysis also showed that GTOPO is inefficient in finding out the morphometric characteristics of watershed.

4.3 STATISTICAL ANALYSIS

To check the validity of inferences from the morphometric analysis, the DEMs were analysed statistically using Google Earth elevation data as reference.

The elevation data of 2620 points are shown table 4.1.

Table 4.1 Statistical analysis

FID	Lat	Long	Elevation	ASTER	CARTODEM	SRTM	ALOS	GTOPO
1	75.9106	10.7875	0	0	-91	0	0	1
2	75.9232	10.7853	0	0	-89.0008	0	2	1
3	75.9333	10.7895	0	0	-91.5857	0	3.51404	1
4	75.9365	10.7946	0.658	0.626652	-89.7601	0.052221	3.979795	1
5	75.9408	10.7968	0.502	8.127392	-90	-1.15945	1.962342	1
6	75.9483	10.8041	0.052	5.065473	-89.8558	-1.80493	3.189853	3.285365
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
2617	76.5428	11.0439	390.442	388.8477	297.3716	379.9849	399.411	2214.193
2618	76.5484	11.0432	544.023	535.7984	461.0752	545.0491	552.0241	2152.58
2619	76.5554	11.0422	557.866	554.3901	470.1015	556.7154	559.0938	2143.836
2620	76.5582	11.0418	544.798	536.6639	456.8782	544.2854	543.6658	2156.874

Table 4.2 Table of error calculation

FID	GE	ASTER	CARTODEM	SRTM	ALOS	GTOPO
1	0	0	91	0	0	-1
2	0	0	89.00082	0	-2	-1
3	0	0	91.58569	0	-3.51404	-1
4	0	0.031348	90.41812	0.605779	-3.3218	-0.342
5	0	-7.62539	90.502	1.66145	-1.46034	-0.498
6	0	-5.01347	89.90784	1.856933	-3.13785	-3.23337
	..	..	..	..	..	..
	..	..	..	..	..	..
2617	0	1.594298	93.0704	10.45708	-8.96897	-1823.75
2618	0	8.224593	82.94776	-1.02614	-8.00115	-1608.56
2619	0	3.475926	87.76447	1.150587	-1.22783	-1585.97
2620	0	8.134146	87.91978	0.512587	1.132175	-1612.08

Table 4.3 Table of mean error, standard deviation and root mean square error

	GE	**Aster**	**Cartosat**	**SRTM**	**ALOS**	**GTOPO**
Mean error	0	4.9632	NA	7.010392	-0.22134	-4.80245
Standard deviation error	0	9.161051	NA	100.7451	5.645846	624.215
Root mean square error	0	10.41759	97.61864	100.9695	5.649107	624.1146

The R^2 values were calculated for each DEM with Google Earth.

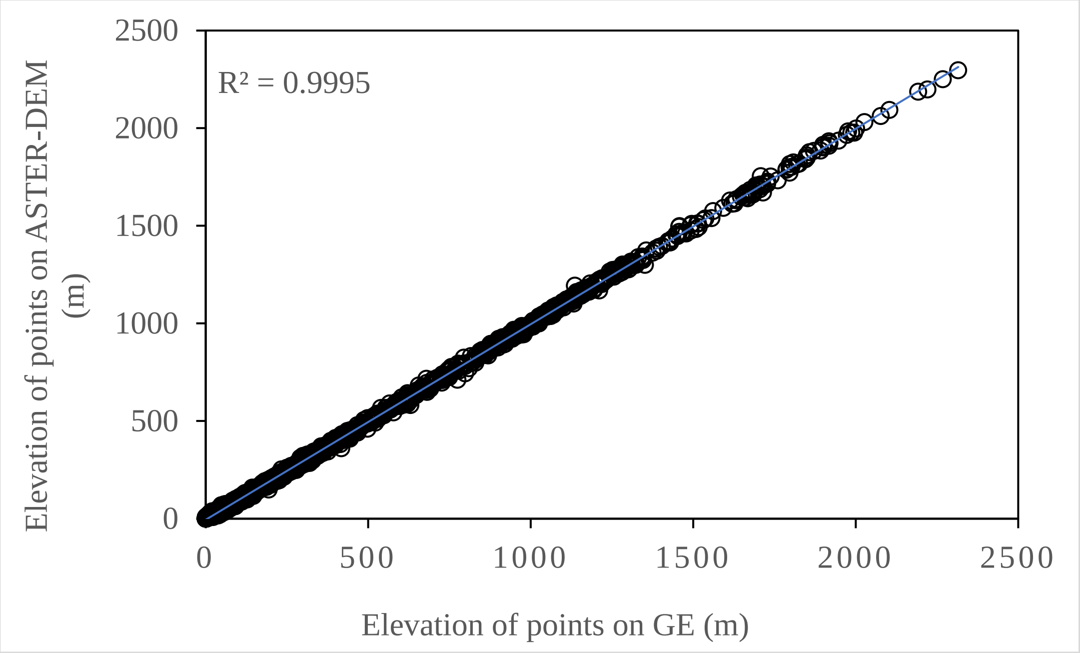

Fig 4.1 Scatter plot of elevation: Google Earth Vs ASTER

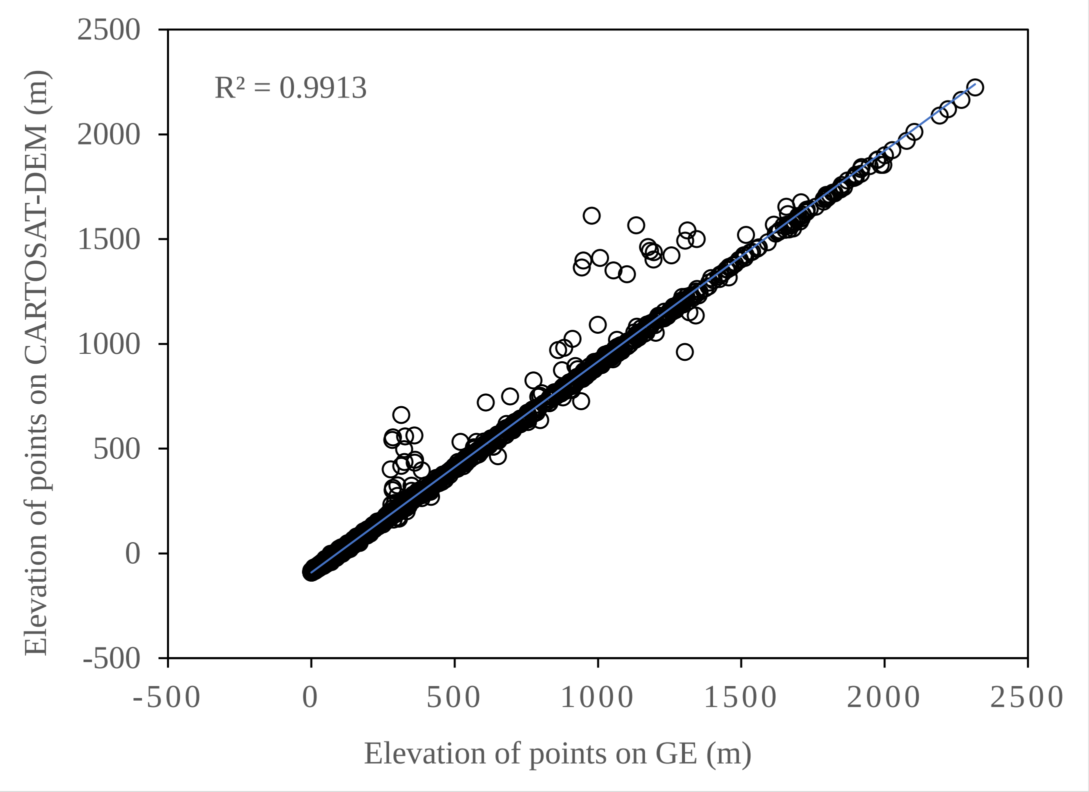

Fig 4.2 Scatter plot of elevation: Google Earth Vs CARTODEM

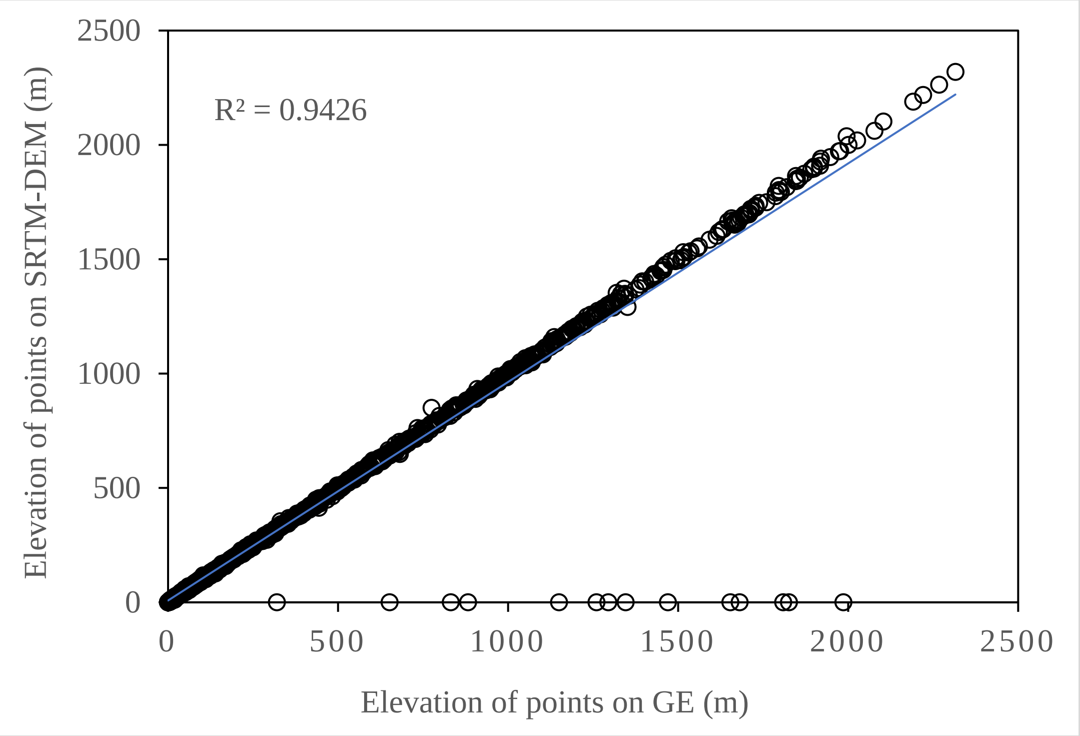

Fig 4.3 Scatter plot of elevation: Google Earth Vs SRTM

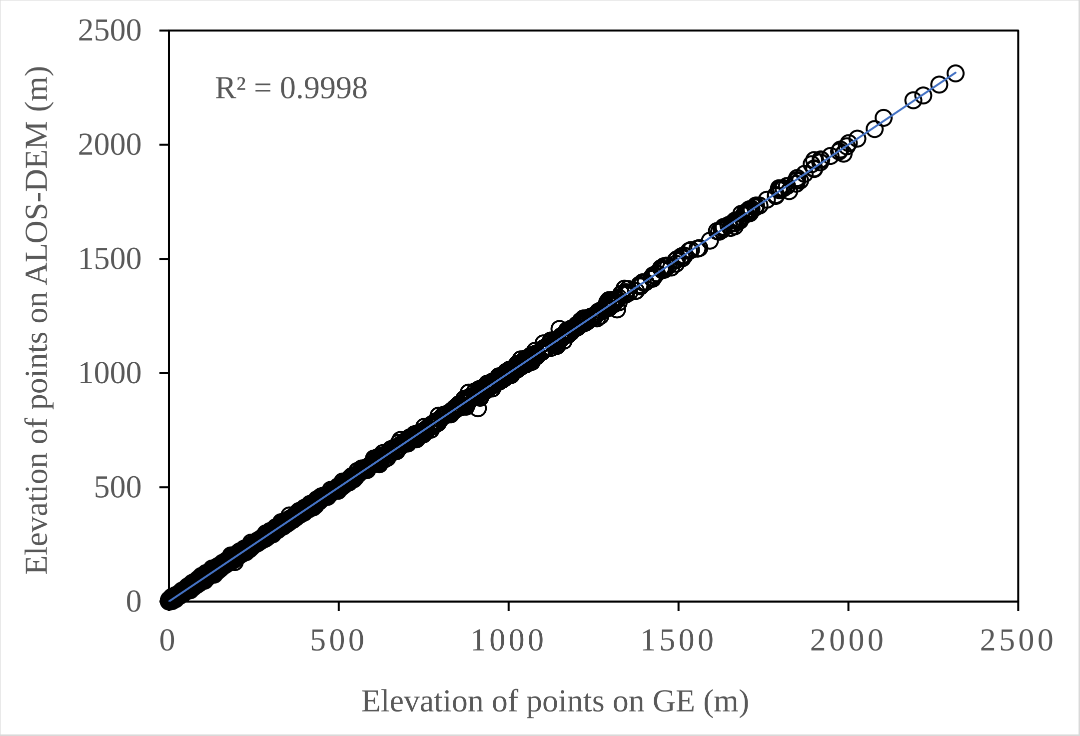

Fig 4.4 Scatter plot of elevation: Google Earth Vs ALOS

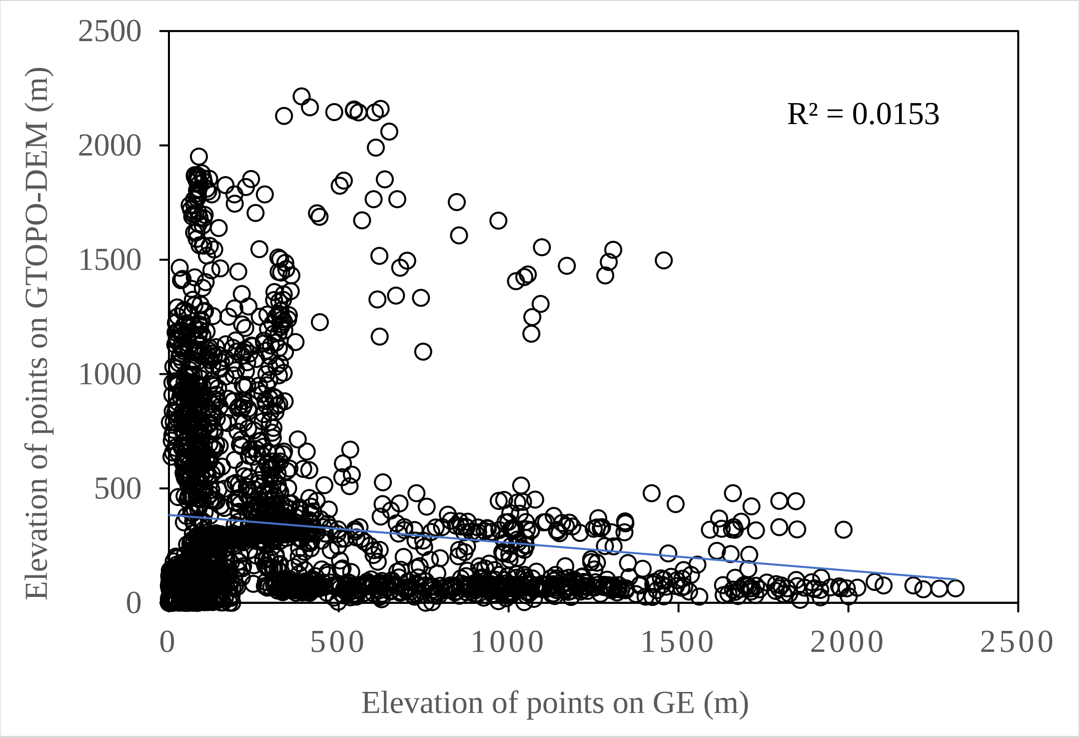

Fig 4.5 Scatter plot of elevation: Google Earth Vs GTOPO

On analysing R^2 values, ALOS and ASTER showed excellent coefficient of determination. Also, GTOPO showed poor R^2 value. i.e., elevation data of GTOPO and Google Earth is not comparable. This analysis supports the inference made from morphometric analysis.

All the points in ALOS and ASTER follows the trend of 1:1 line whereas SRTM and CARTODEM does not. In case of GTOPO, the points are literally scattered.

R^2 values of each DEM Vs Google Earth in 11 elevation classes were plotted as shown.

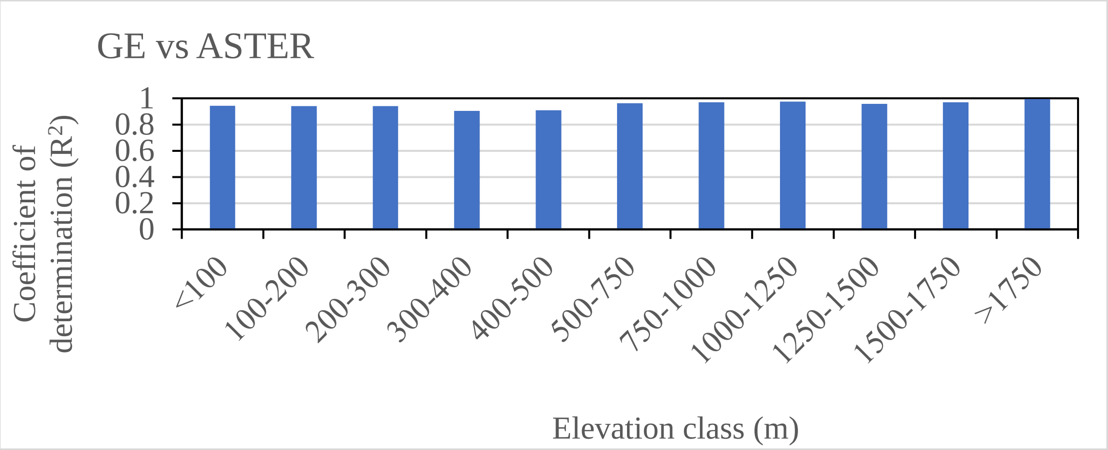

Fig 4.6 Coefficient of determination: Google Earth VS ASTER

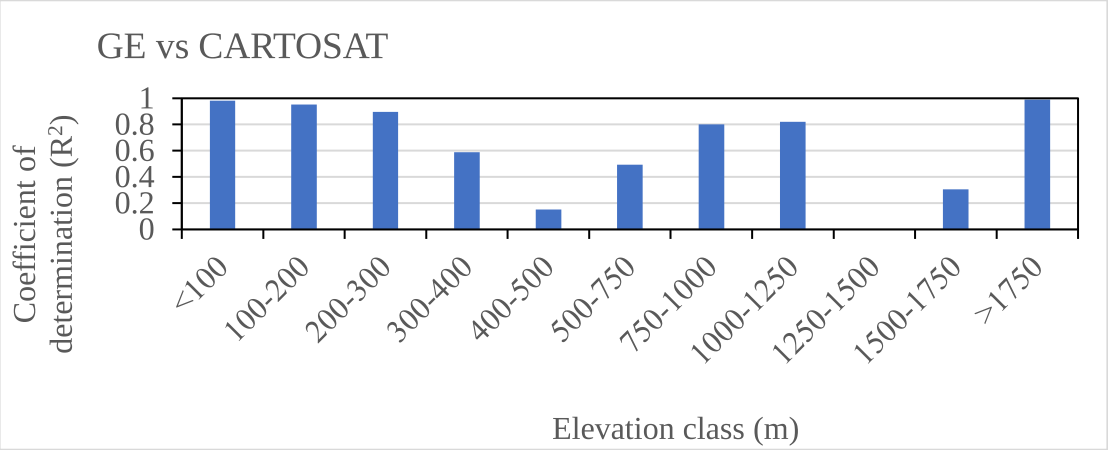

Fig 4.7 Coefficient of determination: Google Earth VS CARTODEM

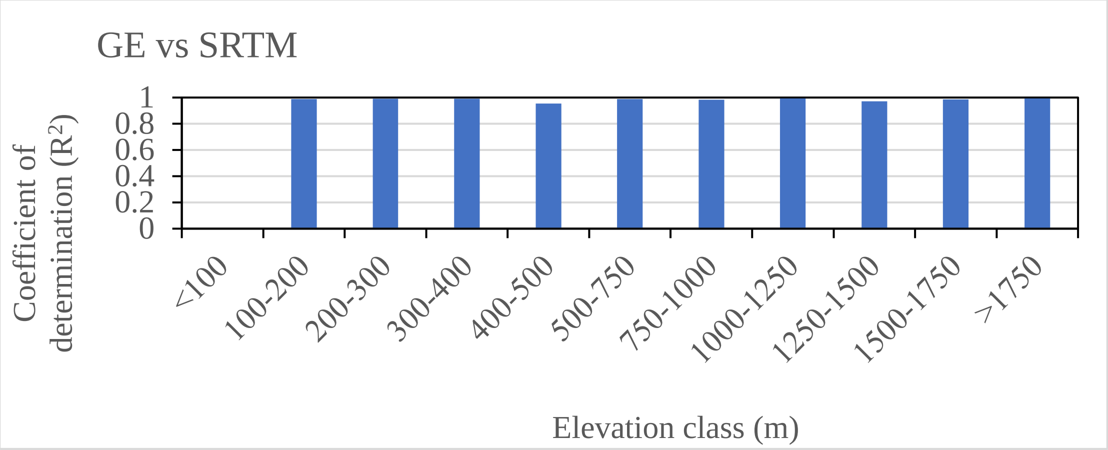

Fig 4.8 Coefficient of determination: Google Earth VS SRTM

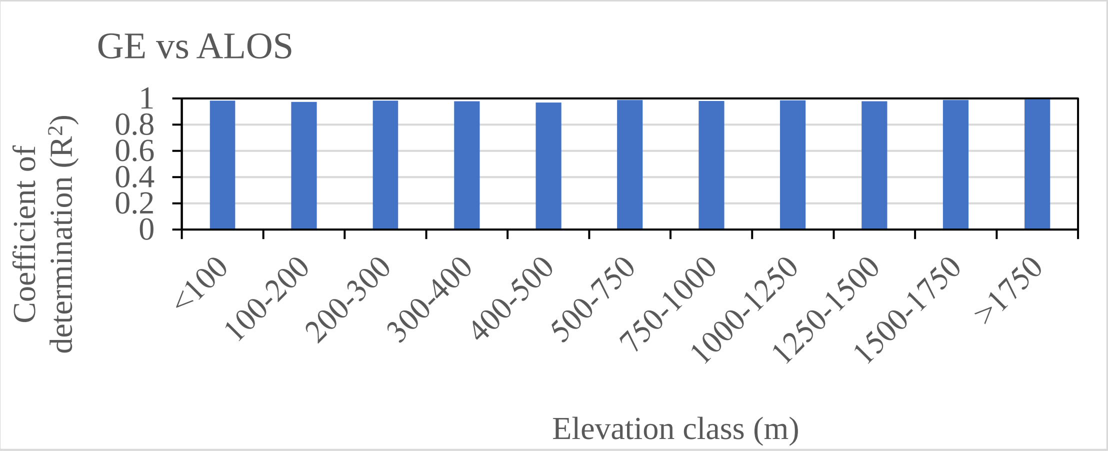

Fig 4.9 Coefficient of determination: Google Earth VS ALOS

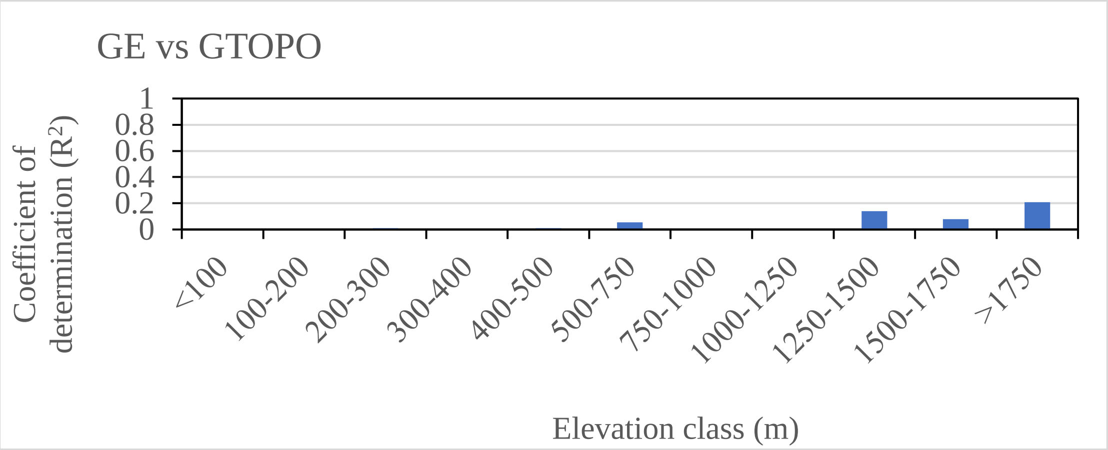

Fig 4.10 Coefficient of determination: Google Earth VS GTOPO

In ALOS, it was observed that the R^2 values are near to 1 in all elevation classes. The ASTER DEM showed excellent coefficient of determination (0.9-1) in all classes. Similar results were shown by SRTM except for elevation class <100m. In the case of CARTODEM, R^2 values varies greatly across the classes with maximum values at lower (<300 m) and higher elevation (>1750 m). GTOPO displayed negligible R^2 values in all eleven classes.

Summary and conclusions

CHAPTER V

SUMMARY AND CONCLUSIONS

Several studies are taking place with geospatial technologies on watershed morphometric and hydrologic analysis. The main input data for all these analyses is the DEM and hence, the accuracy and quality of the DEM is very important for these kinds of studies. At the same time, information on the accuracy of the various DEM products available in the public domain are highly insufficient.

Hence this study has been taken up to check the suitability of some of the commonly available DEMs to perform the morphometric analysis of large basin. Catchment area of Bharathapuzha river basin has been selected for the study. DEMs used in this study for comparison are ASTER, SRTM, CARTODEM, GTOPO and ALOS. Among the five DEMs, the first three are very commonly used ones and the fourth and fifth ones are less popular in hydrological studies plausibly due to their late enty to the public domain. The results of the study revealed that ALOS can effectively be used in the studies of Bharathapuzha river basin along with ASTER DEM. As per the observations made in the study SRTM and CARTODEM didn’t perform well. GTOPO which is having the least resolution among all showed the poorest results as expected.

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COMPARATIVE ASSESSMENT OF DIGITAL ELEVATION MODELS (DEMS) IN THE MORPHOMETRIC ANALYSIS OF BHARATHAPUZHA RIVER BASIN

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ABSTRACT OF THE THESIS

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ABSTRACT

A study on comparative assessment of Digital Elevation Models (DEMs) in the morphometric analysis of Bharathapuzha river basin was done in Kelappaji College of Agricultural Engineering and Technology, Tavanur. The objective of the study was to statistically analyse the suitability of different DEMs in the morphometric studies of watershed.

Five different DEMs were selected for the study i.e. GTOPO, ASTER DEM, CARTODEM, ALOS and SRTM DEM. The aerial and linear morphometric parameters of study watershed was found out using each of these DEMs and the results were compared. Then statistical analysis was done, in the elevation point of view, using Google Earth as reference.

It was observed that ALOS and ASTER DEM performed better in morphometric analysis when compared to other DEMs. This observation was validated in the statistical analysis with ALOS and ASTER having the least error among all. On the other hand GTOPO was found to have the maximum error.

The results clearly showed that ALOS and ASTER DEM are more effective for the morphometric studies of river basin. SRTM DEM could be recommended for higher elevation points (>100 km) and CARTODEM for both lowest (<300 km) and highest elevation (>1750 km) areas.