QUANTITATIVE ANALYSIS OF MORPHOMETRIC PARAMETERS FOR UPPER PONNAIYAR BASIN USING ASTER GDEM

Suvish S

Student,Department of Remote sensing,Bharathidasan university,Tiruchirapalli-23

Abstract

This paper presents a detailed quantitative analysis of morphometric parameters crucial for understanding the characteristics and hydrological processes of the Upper Ponnaiyar Basin in Southern India. Leveraging Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) data, Geographic Information System (GIS) techniques are employed to extract parameters such as drainage density, stream frequency, basin shape, relief ratio, and slope characteristics. These parameters are essential for delineating watershed boundaries, assessing landforms, and analyzing hydrological behavior. The methodology involves preprocessing ASTER GDEM data, extracting relevant morphometric parameters, and conducting statistical analysis to derive meaningful insights. The study investigates the spatial distribution and variability of morphometric parameters across the basin, revealing significant variations indicative of diverse geological and geomorphological features. Regions with high drainage density, steep slopes, and irregular basin shapes are identified, with implications for water resource management, soil erosion control, and land use planning. This research contributes to understanding watershed dynamics in the Upper Ponnaiyar Basin and provides valuable information for sustainable land and water management practices. The findings lay a foundation for further studies on hydrological modeling, watershed management, and environmental conservation in the region.

Keywords:- Morphometric analysis, ASTER GDEM data, Geographic Information System (GIS) Watershed dynamics, Hydrological modelling

1. INTRODUCTION

Remote sensing and Geographic Information System (GIS) techniques have become indispensable tools in delineating, updating, and analyzing morphometric parameters of drainage basins. Understanding the characteristics of drainage basins is crucial for various hydrological investigations, including groundwater assessment and management. Physiographic characteristics such as size, shape, and slope of drainage areas, along with parameters like drainage density and tributary length, play a significant role in correlating hydrologic phenomena (Rastogi et al., 1976).

The integration of remote sensing data with conventional methods enables the delineation of ridgelines, characterization of basins, and identification of erosion-prone areas, facilitating water conservation strategies and infrastructure planning (Dutta et al., 2002). This study focuses on the morphometric analysis of the Upper Ponnaiyar Basin using Remote Sensing and GIS techniques, aiming to understand its hydrological behavior.

Land and water resources are vital for sustaining life on Earth, especially in the context of burgeoning population rates and unsustainable usage. Soil erosion, primarily driven by water resources, poses a significant threat to agricultural productivity and ecological sustainability (Panagos et al., 2018; Vanwalleghem et al., 2017). In India alone, soil erosion affects millions of hectares of land annually, leading to substantial soil loss and degradation (Bhattacharyya et al., 2015). This erosion not only affects agrarian productivity but also necessitates the conversion of forest and grassland into agricultural lands, further exacerbating environmental concerns (Borrelli et al., 2017; Gomiero, 2016).

To address soil erosion and ensure sustainable resource utilization, a thorough understanding of hydrological resources is essential. Quantitative analysis of watershed characteristics, facilitated by morphometric analysis, provides valuable insights into the lithology, drainage network, flood potential, and erosion susceptibility of a region (Banerjee et al., 2017).

Advancements in remote sensing and GIS technologies have revolutionized morphometric analysis, enabling detailed assessments of sub-watersheds using high-resolution Digital Elevation Model (DEM) data. Various morphometric parameters derived from DEMs aid in prioritizing watersheds for erosion control, groundwater management, and land use planning (Kumar et al., 2011; Farhan and Anaba, 2016).

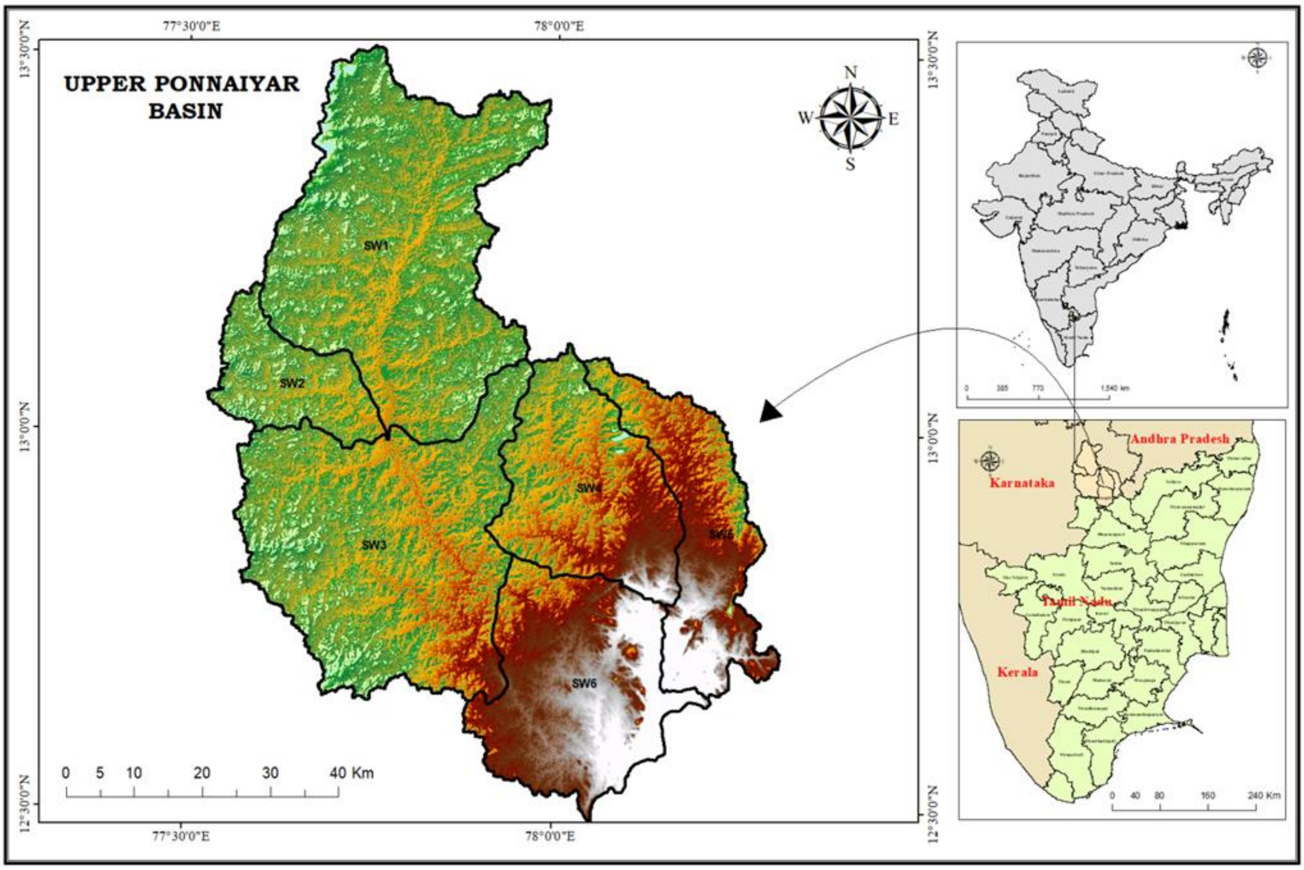
In this context, the current study focuses on the prioritization of the Upper Ponnaiyar Basin using morphometric indices extracted from ASTER Global Digital Elevation Model (GDEM). By utilizing high-resolution DEM data, this study aims to enhance the accuracy of morphometric evaluations, particularly in identifying erosion-sensitive sub-watersheds and formulating sustainable agricultural practices.

2. OBJECTIVE OF THIS STUDY

The main objective of this study was to perform morphometric analysis of Upper Ponnaiyar basin and find out their different characteristic with the help of various parameters like bifurcation ratio (R_b), mean stream length (R_l), drainage density (D_d), elongation ratio (R_e), circulatory factor (R_c), form factor (F_f) and RHO coefficient are calculated from the basic parameters. Relief-related parameters like basin relief, slope, relief ratio,and ruggedness number using the remote sensing and GIS techniques.

3. STUDY AREA

The Upper Ponnaiyar aquifer system is situated in the northwestern region of Tamil Nadu, India. The Ponnaiyar River basin, an interstate river, holds immense significance as one of the largest rivers in the state, often referred to as the 'Little Ganga of the South.' Throughout history, the river has sustained numerous civilizations in peninsular India and continues to serve as a vital water source for drinking, irrigation, and industrial purposes in the states of Karnataka, Tamil Nadu, and Pondicherry. The study area spans between latitudes 11°44'46" and 12°53' N and longitudes 77°46' and 78°53′ E. The Ponnaiyar River originates from the southeastern slopes of the Chennakesava Hills, northwest of Nandidurg in the Kolar district of Karnataka State, at an altitude of 1000m above mean sea level. Predominantly, the Ponnaiyar basin is composed of granite and gneiss rocks dating back to the Archean period. The granite formations are extensive and of high quality, with hornblende and feldspar being the chief components. Foliation is rare, though quartz is commonly found in the plains of the reserve forest. Additionally, scattered pockets of diamond granite are present in the Chitteri hills of Dharmapuri and Krishnagiri sub-divisions. Some areas also exhibit Charnockite rocks from the Archean period. Quaternary period deposits such as alluvium and sand-dunes can be observed in certain locations within the basin.



4. MATERIALS AND METHODS

The current study relies on the utilization of the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) dataset, which has been available for scientific and academic purposes since June 29, 2009 (USGS and Japan ASTER Program 2003; Sefercik 2012). This dataset, provided in GeoTIFF format (*.tiff files), offers geographic latitude/longitude coordinates and a 1 arc-second (30 m) grid of elevation postings, covering the entire planet surface with reference to the WGS84 geoid.

To begin with, Survey of India (SOI) toposheets were geometrically rectified and georeferenced using ground control points (GCPs) with Universal Transverse Mercator (UTM) projections and the World Geodetic System (WGS) 1984 UTM Zone 43 datum. Subsequently, these geocoded toposheets were mosaicked using ArcGIS 10.2 software.

The delineation of the basin's catchment area was carried out using ASTER GDEM and Survey of India topographical sheets through the spatial analyst tool of ArcGIS, focusing on the area of interest (AOI). The ASTER GDEM was instrumental in generating topographic maps, determining slopes, and delineating the drainage map of the basin, achieved through the hydrology toolset of ArcGIS 10.2. This extracted DEM facilitated the calculation of various morphometric parameters for the Upper Ponnaiyar basin and its sub-watersheds.

5. MORPHOMETRIC ANALYSIS OF THE BASIN

The morphometric analysis involves the assessment of various parameters, each providing valuable insights into the physical characteristics of the basin. Here, we delve into the interpretation of linear, relief, and aerial aspects of morphometry and the significance of the derived values within the study area.

I. Linear Aspects

Stream Order (Nu): Stream order delineates the hierarchical organization of streams within a basin, following Strahler's system, which is a modified version of Horton's system. The analysis revealed a stream order of 8th, with 51142 streams identified, predominantly exhibiting dendritic drainage patterns.

Stream Length (Lu)

Computed based on Horton's law, stream length serves as a crucial hydrological feature, reflecting surface runoff characteristics. The study area exhibited varying stream lengths across different orders, indicative of lithological variation and slope gradients.

Mean Stream Length (Lsm)

A characteristic property related to the drainage network, mean stream length was calculated by dividing the total stream length of each order by the number of streams. The values varied across stream orders, reflecting different drainage characteristics.

Stream Length Ratio (RL)

The ratio of mean stream length of a given order to that of the next lower order, RL values elucidate surface flow and discharge relationships, providing insights into slope gradients and topographic variations.

Bifurcation Ratio (Rb): Defined as the ratio of the number of stream segments of a given order to the number of segments of the next higher order, Rb serves as an index of relief and dissection. The study area exhibited varying Rb values, indicative of geological influences on drainage patterns.

II. Relief Aspects

Relief Ratio (Rh)

Expressed as the ratio of maximum relief to horizontal distance along the longest basin dimension, Rh signifies basin steepness and erosion intensity. The study area exhibited a moderate relief ratio of 5.94, indicating moderate slope gradients.

Relative Relief (Rbh)

Obtained through visual analysis of digital elevation models, relative relief indicates steep slope gradients within the study area, with elevations ranging from 479m to 1474m.

Ruggedness Number (Rn)

A product of maximum basin relief and drainage density, Rn values signify terrain ruggedness. The study area exhibited a ruggedness number of 2447.72, indicative of steep slopes and high relief.

III. Aerial Aspects

Drainage Density (Dd)

An essential indicator of landform scale, drainage density represents the average length of stream channels within a basin. With a value of 2.46 Km/Km2, the study area exhibited moderate drainage density, suggestive of permeable subsoil and vegetative cover.

Stream Frequency (Fs)

Expressed as the total number of stream segments of all orders per unit area, Fs values exhibited positive correlation with drainage density, indicating increased stream population with higher drainage density.

Texture Ratio (T)

Dependent on various natural factors, including climate, vegetation, and soil type, texture ratio represents the total number of stream segments per perimeter area. It offers insights into basin development and stage of maturity.

Form Factor (Ff)

Defined as the ratio of basin area to the square of basin length, Ff signifies flow intensity and basin shape. The study area exhibited an Ff value of 0.18, indicative of an elongated basin with lower peak flows of longer duration.

Circularity Ratio (Rc)

Rc, the ratio of basin area to the area of a circle with the same perimeter, reflects basin circularity. The study area exhibited an Rc value of 0.24, suggestive of low relief and less influence of structural disturbances on the drainage system.

Elongation Ratio (Re)

A measure of basin elongation, Re values indicate terrain shape and relief. With a Re value of 9.7, the study area displayed steep ground slopes and an elongated shape.

Length of Overland Flow (Lg)

Representing the length of water over the ground surface before channel concentration, Lg values inversely correlate with average channel slope, providing insights into hydrological and physiographic basin development. The study area exhibited an Lg value of 0.20.

5. RESULTS AND DISCUSSION

The morphometric analysis of the Upper Ponnaiyar basin provides valuable insights into its physical characteristics, hydrological behavior, and geomorphological processes. The derived parameters shed light on the basin's drainage patterns, relief features, and overall landscape morphology.

Linear Aspects: The delineation of stream orders and assessment of stream lengths reveal the hierarchical organization of the basin's drainage network. The predominance of first and second-order streams indicates active erosion processes and the efficient conveyance of runoff. The observed dendritic drainage pattern suggests homogeneity in lithological composition and minimal structural control, consistent with previous studies (Strahler, 2002).

Relief Aspects: The calculated relief parameters, including relief ratio, relative relief, and ruggedness number, underscore the basin's topographic variability and erosional dynamics. The moderate relief ratio and ruggedness number indicate terrain ruggedness and steep slope gradients, likely influenced by geological structures and tectonic activity. These findings corroborate previous research highlighting the region's complex geomorphological history and active erosion processes (Schumm, 1956).

Method of Calculating Morphometric Parameters of Drainage Basin			
	Morphometric Parameters	**Methods**	**References**
Linear	Stream order (U)	Hierarchical order	Strahler,1964
	Stream length (Lu)	Length of the stream	Hortan, 1945
	Mean stream length (Lsm)	Lsm = Lu/Nu where, Lu=Stream length of order 'U', Nu=Total number of stream segments of order 'U'	Hortan, 1945
	Stream length ratio (RL)	RL=Lu/Lu-l; where Lu=Total stream length of order 'U', Lu- I=Stream length of next lower order.	Hortan, 1945
	Bifurcation ratio (Rb)	Rb = Nu/ Nu+l; where, Nu=Total number of stream segment of order'u'; Nu+l=Number of segment of next higher order	Schumn,1956
Relief	Basin relief (Bh)	Vertical distance between the lowest and highest points of watershed.	Schumn,1956
	Relief ratio (Rh)	Rh=Bh/Lb; Where, Bh=Basin relief;Lb=Basin length	Schumn,1956
	Ruggedness number(Rn)	Rn=Bh ×Dd where,Bh=Basin relief,Dd=Draianage density	Schumn,1956
Areal	Drainage density (Dd)	Dd - L/A where, L=Total length of streams;A=Area of watershed	Hortan, 1945
	Stream frequency (Fs)	Fs = N/A where, N=Total number of streams: A=Area of watershed	Hortan, 1945
	Texture ratio (T)	T = N1/P where,NI=Total number of first order streams: P=Perimeter of watershed	Hortan, 1945
	Form factor (Rf)	Rf=A/(Lb) 2;where, A=Area of watershed, Lb=Basin length	Hortan, 1945
	Circulatory ratio (Rc)	Rc=4zA/P2 ;where, A=Area of watershed, x=3.14, P=Perimeter of watershed	Miller,1953
	Elongation ratio (Re)	Re V(Au/∏)/Lb Where, A=Area of basin, Lb=Basin length	Schumn,1956
	Length of overland flow (Lg)	Lg=1/2Dd ;Where, Dd=Drainage density	Hortan, 1945
	Constant channel maintenance(C)	Lof=1/Dd Where, Drainage density	Hortan, 1945

Aerial Aspects: The analysis of aerial parameters, such as drainage density, stream frequency, and form factor, provides insights into basin-scale hydrological processes and landform development. The moderate drainage density and stream frequency suggest efficient channelization of runoff and moderate landform dissection. The elongated basin shape, indicated by the form factor, implies prolonged flow paths and lower peak flows, contributing to sediment transport and fluvial dynamics (Horton, 1945).

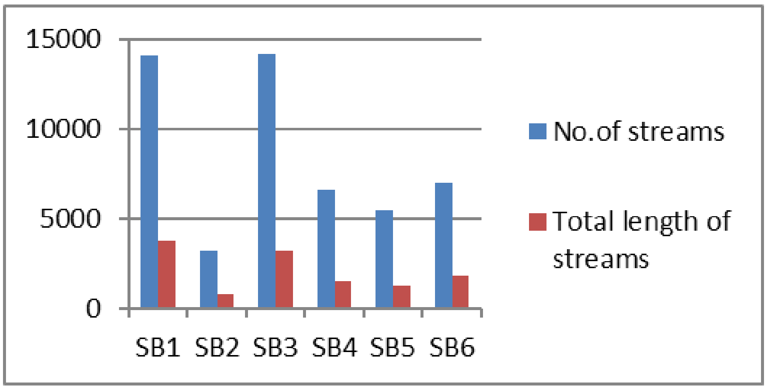
Overall, the morphometric analysis underscores the interplay between geological, hydrological, and geomorphological processes shaping the Upper Ponnaiyar basin. The observed patterns reflect a dynamic landscape characterized by active erosion, efficient drainage network development, and complex topographic variability. These findings have implications for water resource management, land-use planning, and environmental conservation efforts in the region, highlighting the need for sustainable practices to mitigate the impacts of natural hazards and anthropogenic activities on basin dynamics.

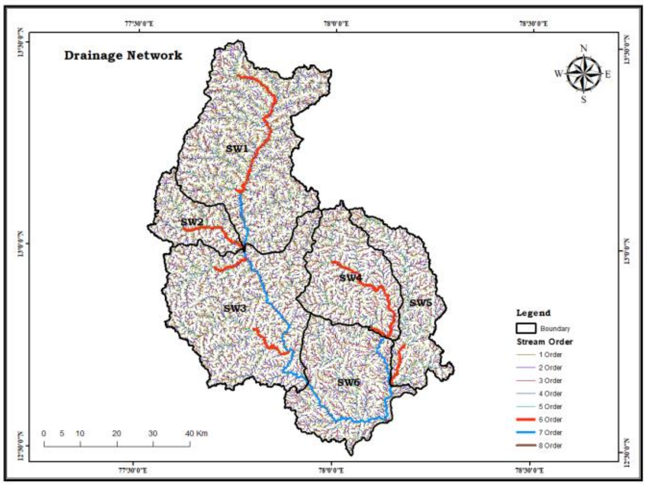
Moreover, the comparison of morphometric parameters with regional and global datasets can enhance our understanding of landscape evolution processes and inform predictive modeling efforts for future hydrological scenarios. Further research integrating field-based observations, remote sensing data, and numerical modeling techniques will be instrumental in unraveling the intricacies of basin-scale dynamics and advancing our knowledge of landscape processes in a changing environment.

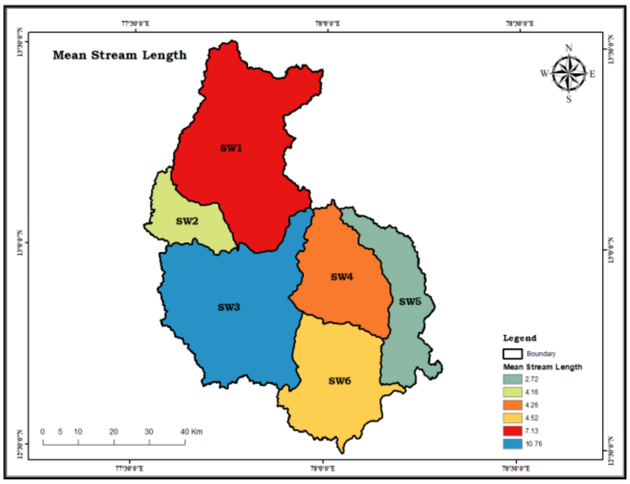
Result of Morphometric Analysis

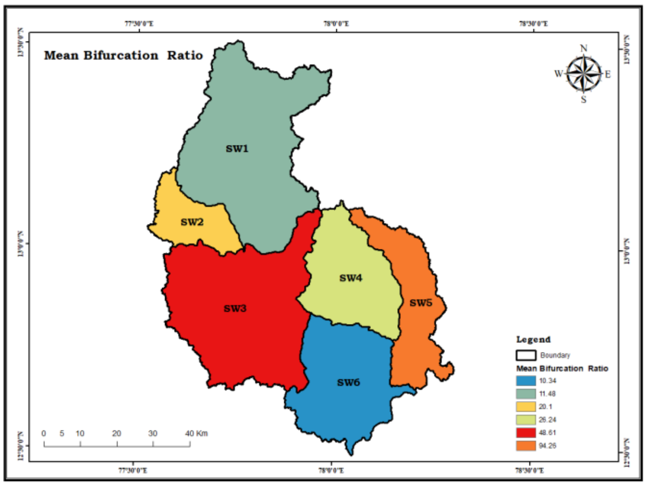
Parameters	**SB1**	**SB2**	**SB3**	**SB4**	**SB5**	**SB6**
Linear						
Mean Bifurcation Ratio	11.48208	*20.0997*	*48.6065*	26.23632	94.26192	*10.3403*
Mean Stream Length	7.129501	*4.15926*	*10.7626*	4.258192	2.718945	*4.51525*
Stream Length Ratio	0.469822	0.720448	0.711318	0.630461	0.609972	*157.785*
Areal						
Drainage Density	*2.63919*	*2.51458*	*2.39367*	2.353	2.313	*2.34323*
Stream Frequency	*9.78586*	*10.3461*	10.463	10.040	9.885	*8.9181*
Form Factor	*0.21613*	*0.26604*	*0.21781*	*0.2403*	0.246	0.235
Length of overland flow	*0.18945*	*0.19884*	0.209	0.213	0.216	*0.21338*
Infiltration number	*12.8306*	*13.3255*	*13.2829*	*12.845*	*12.660*	*11.7092*
Drainage Texture	*58.3066*	30.479	62.169	*53.3811*	30.593	45.705
Relief						
Relief Ratio	*7.56695*	3.504632	*3.44566*	*9.92828*	*12.1986*	*7.62505*
Ruggedness Number	1628.38	301.75	651.078	1223.503	1332.28	1035.71

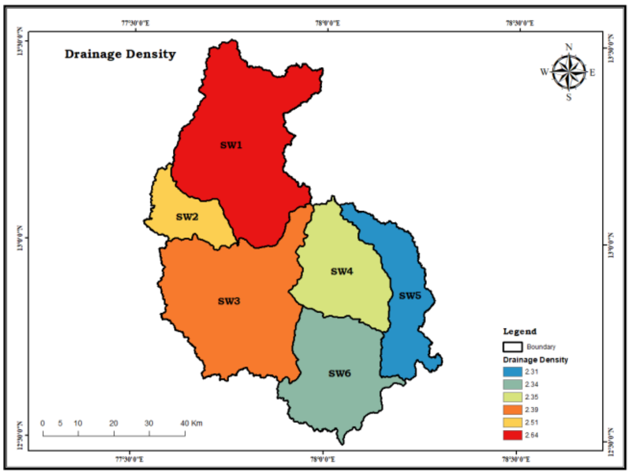
The chart shows that the variations in number of streams and total length of streams for one watershed and another.

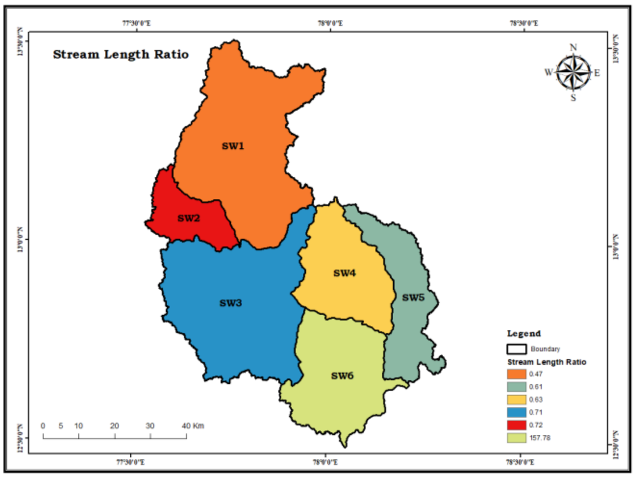


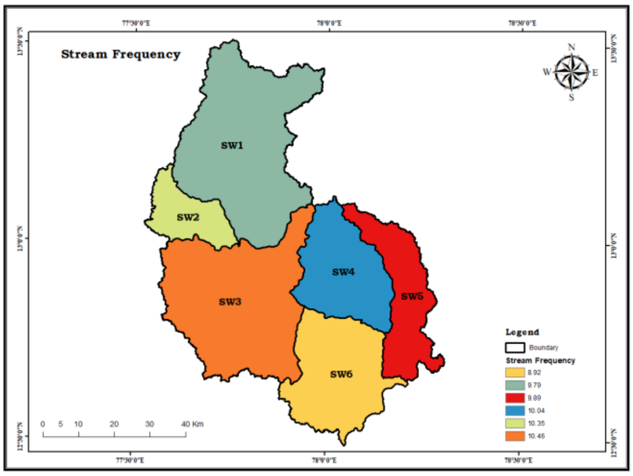

Drainage Network
SW1
SW2
SW3
SW4
SW5
SW6
Legend
Boundary
Stream Order
1 Order
2 Order
3 Order
4 Order
5 Order
6 Order
7 Order
8 Order
0 5 10 20 30 40 Km

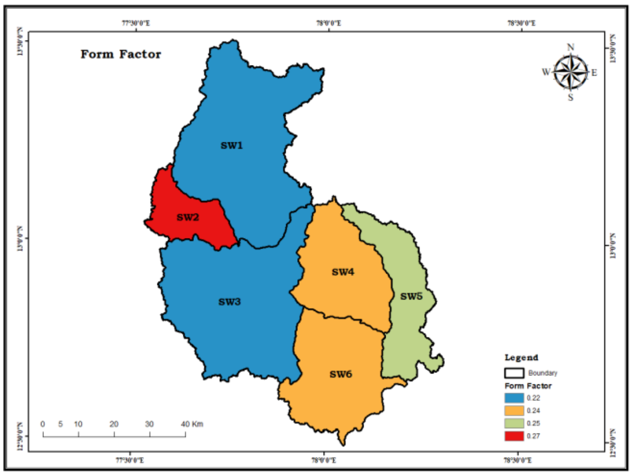

Mean Stream Length
SW1
SW2
SW3
SW4
SW5
SW6
Legend
Boundary
Mean Stream Length
2.72
4.16
4.26
4.52
7.13
10.76
0 5 10 20 30 40 Km

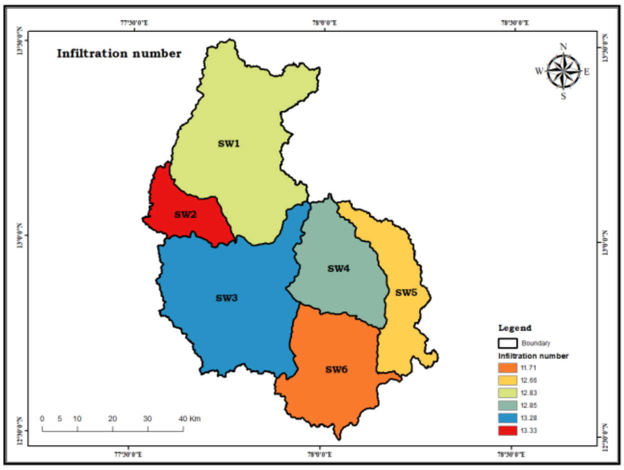

Mean Bifurcation Ratio
SW1
SW2
SW3
SW4
SW5
SW6
Legend
Boundary
Mean Bifurcation Ratio
10.34
11.48
20.1
26.24
48.61
94.26
0 5 10 20 30 40 Km

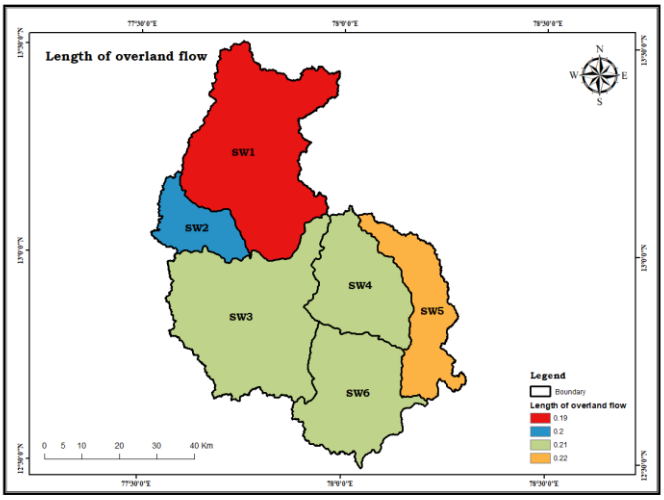

Drainage Density
SW1
SW2
SW3
SW4
SW5
SW6
Legend
Boundary
Drainage Density
2.31
2.34
2.35
2.39
2.51
2.64
0 5 10 20 30 40 Km

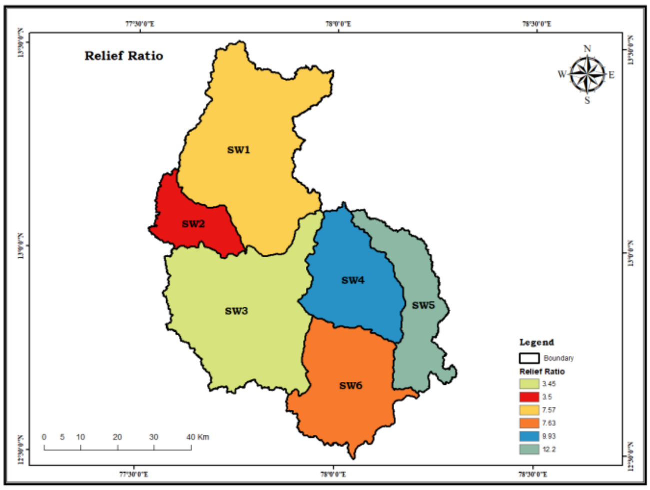

Stream Length Ratio
SW1
SW2
SW3
SW4
SW5
SW6
Legend
Boundary
Stream Length Ratio
0.47
0.61
0.63
0.71
0.72
157.78
0 5 10 20 30 40 Km

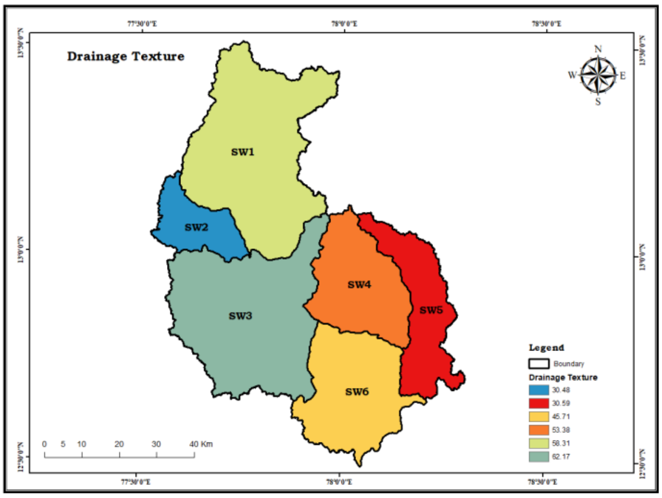

Stream Frequency
SW1
SW2
SW3
SW4
SW5
SW6
Legend
Boundary
Stream Frequency
8.92
9.79
9.89
10.04
10.35
10.46
0 5 10 20 30 40 Km

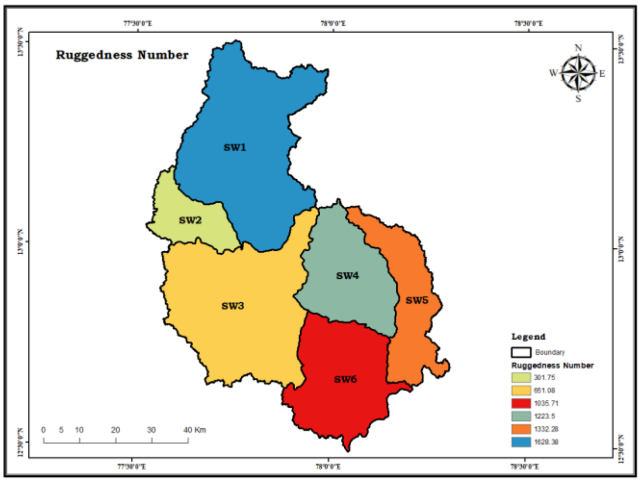

Form Factor
SW1
SW2
SW3
SW4
SW5
SW6
Legend
Boundary
Form Factor
0.22
0.24
0.25
0.27
0 5 10 20 30 40 Km


Infiltration number
SW1
SW2
SW3
SW4
SW5
SW6
Legend
Boundary
Infiltration number
11.71
12.66
12.83
12.85
13.28
13.33
0 5 10 20 30 40 Km









6. CONCLUSION

GIS and Remote sensing techniques have proved to be accurate and efficient tool in drainage delineation and their updation. Bifurcation ratio, length ratio and stream order of basin indicates that the basin is eighth order basin with dendritic type of drainage pattern with homogeneous nature. Relief ratio, is one such quantitative technique which is useful in analysing the soil erosion vulnerability of the watersheds. Thus, the present study demonstrates the effective use ASTER GDEM for prioritisation of Upper Ponnaiyar basin based on morphometric indices to identify the vulnerability of soil erosion which affects the agricultural productivity of the lands and ecological sustainability.The formula used for evaluating morphometric parameter are are tabulated and the results of this morphometric analysis of upper Ponnaiyar basin is also tabulated.Results of morphometric analysis shows that sub watersheds SB3 & SB4 are possibly having high erosion & control measures are required in these watersheds to preserve the land from further erosions.

7. REFERENCES:

1. Rastogi, T., K. V. N. R. Rao, and H. N. Siddiqui. "Some Aspects of Morphometric and Basin Analysis of the River Mahi System, Western India." Geografiska Annaler. Series A. Physical Geography 58, no. 2 (1976): 123-36.

2. Dutta, Subhas, R. P. Singh, and S. K. Srivastava. "Remote Sensing in Hydrogeological Exploration." Journal of the Indian Society of Remote Sensing 30, no. 3 (2002): 143-63.
3. Panagos, Panos, Pasquale Borrelli, Jean Poesen, Christina Alewell, Luca Lugato, Tiago Wollny, and Cristiano Ballabio. "The New Assessment of Soil Loss by Water Erosion in Europe." Environmental Science & Policy 54 (2015): 438-47.
4. Borrelli, Pasquale, David A. Robinson, Panos Panagos, Christine Lugato, Katrin Meusburger, Emanuele Modugno, Chris J. M. Van Oost, and Cristiano Ballabio. "An Assessment of the Global Impact of 21st Century Land Use Change on Soil Erosion." Nature Communications 8 (2017): 2013.
5. Kumar, Prashant, D. Kumar, and K. K. Sharma. "Quantitative Morphometric Analysis of a Watershed of the Betwa River, India Using ASTER (DEM) Data and GIS." Journal of the Geological Society of India 78, no. 1 (2011): 63-75.
6. Farhan, Yahya Saleh, and Mustafa F. Anaba. "Morphometric Analysis of The Central Part of The Jordan Rift Valley Using Geographic Information System (GIS)." Arabian Journal of Geosciences 9, no. 7 (2016): 1-11.
7. Sefercik, U. G. (2012). ASTER Global Digital Elevation Model Version 2 - Summary of Validation Results. NASA Technical Report.
8. Horton, R. E. (1932). Drainage basin characteristics. Transactions of the American Geophysical Union, 13(1), 350-361.
9. Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin, 67(5), 597-646.
10. Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In Handbook of applied hydrology (pp. 39-76). McGraw-Hill.
11. Melton, M. A. (1957). An analysis of the relations among elements of climate, surface properties, and geomorphology. US Government Printing Office.
12. Miller, V. C. (1953). A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Columbia University.
13. Schideggar, A. E. (1970). Morphometric analysis of drainage basins in Little Washoe County, Nevada. Geological Society of America Bulletin, 81(1), 51-64.
14. Gottschalk, L. C. (1964). Morphometry of drainage basins. In Quantitative geomorphology of drainage basins and channel networks (pp. 89-100). Geological Society of America.
15. Nag, S. K. (1998). Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. Journal of the Indian Society of Remote Sensing, 26(1), 69-76.