Bulletin of Pure and Applied Sciences.
Geology (Geological Science), Vol.41F, No.2,
July-December 2022: P.182-195
Original Article

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI: 10.5958/2320-3234.2022.00016.6
Available online at www.bpasjournals.com

Hydromorphometry of the Warana River Basin Maharashtra, India: An Insight for Irrigation Water Management in Agricultural Dominated Area

[1]Suraj Kalgonda Patil*, [2]Tejaswini Nikhil Bhagwat

Author's Affiliations:
[1]Assistant Professor, Department of Civil Engineering, DKTEs Textile and Engineering Institute, Ichalkaranji, Maharashtra 416115, India.
[2]Associate Professor, Department of Studies in Civil Engineering, University B.D.T. College of Engineering, Davangere, (Affiliated to Visvesvaraya Technological University, Belagavi) Karnataka 577004, India.

***Corresponding Author: Suraj Kalgonda Patil,** Assistant Professor, Department of Civil Engineering, DKTEs Textile and Engineering Institute, Ichalkaranji, Maharashtra 416115, India.
E-mail: patilsuru@gmail.com

(Received on 05.05.2022, Revised on 03.07.2022, Accepted on 05.09.2022, Published on 15.12.2022)

How to cite this article: PatilS. K., Bhagwat T.N. (2022). Hydromorphometry of the Warana River Basin Maharashtra, India: An Insight for Irrigation Water Management in Agricultural Dominated Area. *Bulletin of Pure and Applied Sciences- Geology*, 41F (2), 182-195.

Abstract:
Morphometry is a response to specific hydrology and it provides an insight for watershed management especially in agriculture dominated River basins. In this paper an attempt is made to comprehend the morphometric properties of the Warana River basin in order to obtain insight into the hydrological situation of the Warana River basin in Maharashtra. Morphometric parameters were calculated using geo processing techniques in QGIS 3.16. The Warana river is a Seventh-orderbasin, characterized by a dendritic drainage pattern with high stream frequency (2.99/km), infiltration number (7.22), and drainage density (2.41 km/km²), indicating high runoff potential with low Constant of channel maintenance (0.41) and lineament density (0.20 km/km²) indicate moderate recharge potential. Interrelationship among the morphometric parameters indicates that the basin has moderate flood and moderate recharge property. The flood frequency analysis studied for the Shigaon River gauging station indicates frequent floods in the Warana River basin. Water table fluctuations at decadal time scales indicated moderate to high recharge characteristics.

Keywords: *Drainage characteristics, Quantitative geomorphology, Flood frequency analysis, Groundwater fluctuations, Water Management.*

INTRODUCTION

Uneven distribution of water resources over space and time in arid and semi-arid regions forces us to plan, develop, and manage the resources. The drainage pattern is a primary input for analyzing the basin hydrology using morphometric parameters (Rajasekhar et al., 2020) Drainage basin morphometry reflects the basin's distinctive hydrological state, environmental function, geology, and relief (Reddy et al., 2004; Pakhmode et al., 2003). Watershed morphometric appearances (Nag, 1998; Vittala et al., 2004) and groundwater resource potential (Sreedevi et al., 2004; Sreedevi at al., 2009 were used to illustrate watersheds characteristics. Drainage features can be utilised to evaluate the basin's potential for surface and groundwater, because ground and surface waters are complementary components (Nyamathiand Kakkalameli, 2018).Macro and micro levels of watershed management are therefore influenced by quantitative drainage network studies (Jensen, 1991; Sarangi et al., 2004). Drainage characteristics, in combination with geomorphology and geology, provide insight into basin hydrological characteristics for collaborative water resource management (Esper, 2008). Morphometric characteristics of river basins are being explored for locating groundwater resources by analyzing diverse landforms and drainage systems (Adhikari, 2020). Recent years have seen the successful use of satellite data and Geographical Information Systems (GIS) to provide relevant data on spatial changes in drainage features for watershed management (Das & Mukherjee, 2005). Water management planning and operation strategies of the basin in a watershed are also determined by characteristics of the drainage basin. Understanding the character of rock types and geologic structures in the construction of stream networks can be aided by understanding the nature and category of drainage patterns, as well as a quantitative morphometric analysis. A catchment morphometric evaluation can be used to forecast basin travel time and time to the hydrograph peak (basin lag time) at the watershed scale with greater insight and accuracy. Morphometric analysis offers a very good alternative to understand the underlying elements governing the hydrological behavior for unguaged watersheds where data on soil, geology, geomorphology, and other topics are equally limited (Ramshoo et al., 2012). Synthetic hydrographs are necessary for water resource planning and development, notably for the design of hydraulic structures in ungauged basins. The synthetic unit hydrograph (SUH) concept was devised due to the scarcity of observed rainfall-runoff data at the gauging site for hydrograph synthesis (Mishra et al., 2014). To the few visible points of the hydrograph, synthetic unit hydrograph approaches employ a set of empirical equations including the physical features and morphology of the watershed. For both gauged and ungauged basins, the unit hydrograph can be established (Nowicka & Soczynska, 1989; Nasri et al., 2004). The geomorphologic instantaneous unit hydrograph (GIUH) has been utilized by several studies to generate hydrographs for ungauged basins. GIUH has been effectively utilized to calculate discharge features in semi-arid basins that are not gauged (Bhaskar et al., 1997; Jain et al., 2020).

STUDY AREA

The River Warana (16° 47' 00"N to 17°15'15'' N and 73°30'45" E to 74°30'00'' E), a tributary of the River Krishna, begins in the Sahyadri range in Patan Taluka of Satara District, Maharashtra, India, and flows southwest for 160 km. before joining the River Krishna at Haripur near Sangli (Figure 1). In the western part of the Deccan Plateau, the river drains a total area of 2095 sq km. The eastern part of the basin is less mountainous and has a flat rolling landscape than the western part. The basin is located in the Western Ghats' rain-shadow zone and has a moderate climate (source: IMD, Pune) with three distinct seasons: monsoon (June to September), winter (October to January), and summer (February to May).

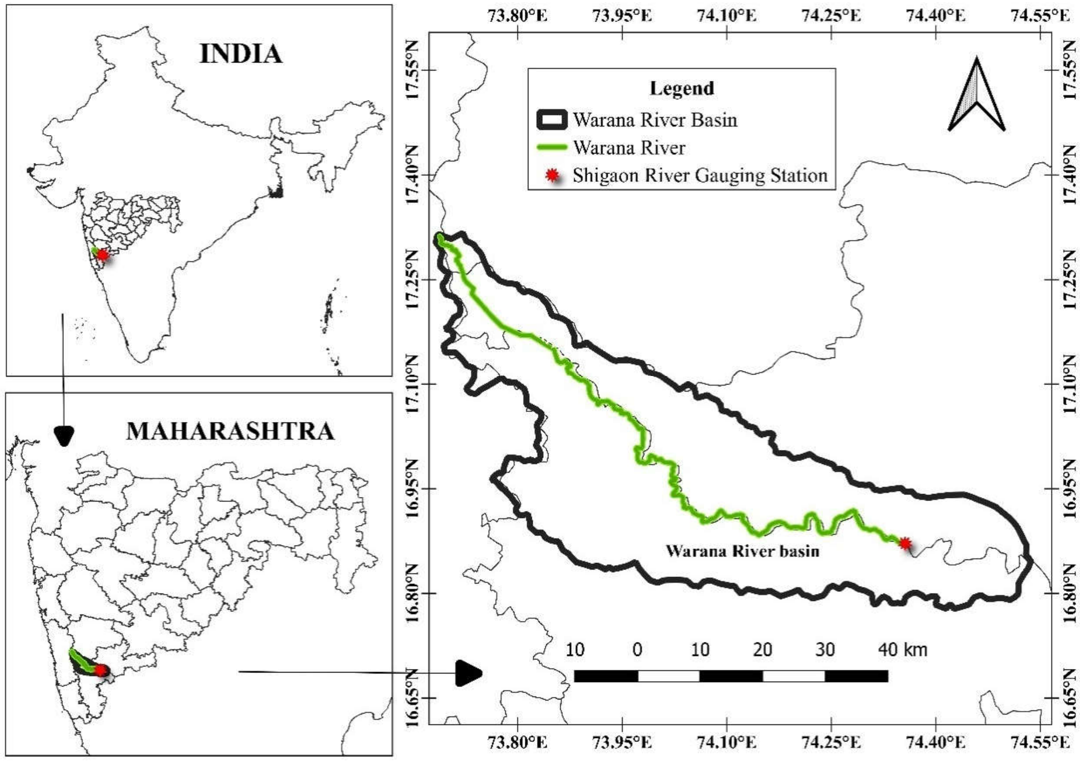


Figure 1: Location of the Warana River basin in Western Ghat region, Maharashtra, India

Climate, Geology & Soil

The River basin has a wide range of rainfall from 600 mm in the upstream to 4000 mm in the ridges. Eighty five percent of rain occurs in June and September. The temperature in the basin area is moderate, ranging between 20 and 30 degrees Celsius in the winter and up to 45 degrees Celsius in the summer. The Warana River basin is located in south India's Deccan Trap volcanic area. Laterites and bauxites cover the flat tops of the Warana basin's high plateau in the western area. The colluvium can be found near the base of steep scarps and on hill slopes. The lateritic screen can be seen in the basin's higher reaches. The terrain is tinted red due to the gravel and colluvium. Hard massive basalts have been coated in the eastern half of the basin by in-situ weathering material, also known as moorum, which is dark red-brown cream in color.

The soils are dark red in color and dominate in the basin's extreme western section, which receives high rainfall. Red soils are the products of weathering of basalts, red boles, and are partly mixed by lateritic material. Black cotton soils can be found primarily in the second and third segments of the main River Warana, notably along the river's banks and on flat structural terraces (Figure 2).

MATERIAL AND METHODS

Quantum Geographical Information Systems (QGIS) 3.16 open-source software is used to analyze morphometry of the Warana River basin (Figure 1). The River basin and its drainage network were digitized at a scale of 1:50,000 from Survey of India topographic sheets 47G/12, 47G/6, 47H/13, 47K/4, 47L/1, 47L/5, 47L/9. USGS Earth Explorer was used to import a 30 m digital elevation model from the Shuttle Radar Topographic Mission (SRTM) (Figure 2). The parameters for the aerial and relief elements were determined. For additional morphometric study, a digital database for drainage networks was constructed. The classical method (Horton, 1945; Strahler, 1957) was used to analyze drainage characteristics. The Indian Remote Sensing satellite Resourcesat-1's Linear Imaging Self Scanning Sensor (LISS III) dataset was used to locate lineaments and study their orientations. The flood frequency curve was plotted using the normal distribution approach with daily and yearly maximum peak values of 25 years (1986-2010). Pre and post-monsoon fluctuation maps of groundwater table for the basin are generated using data from dug wells for a ten-year period (2007–2016).

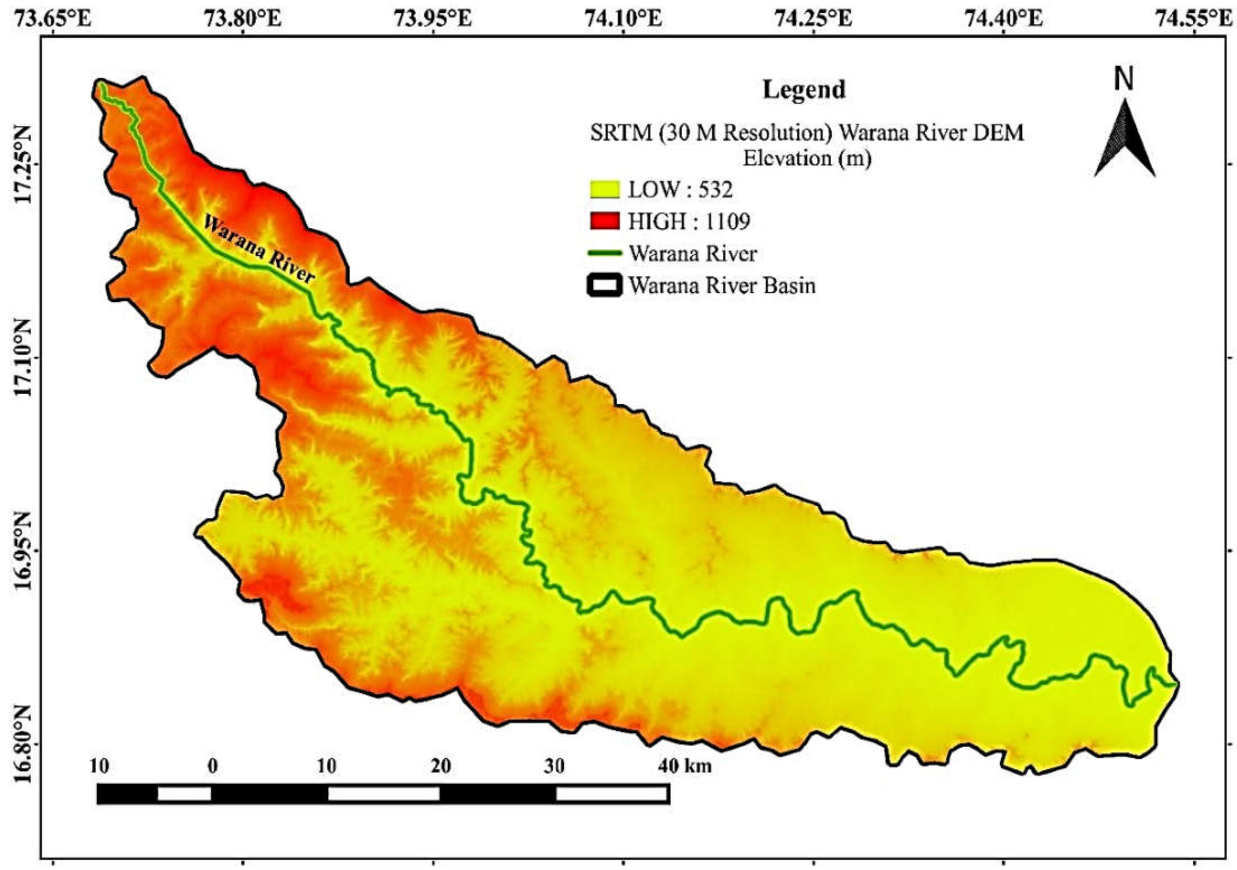


Figure 2: Shuttle Radar Topographic Mission (SRTM) (30 m Resolution) Digital Elevation Model of Warana River basin

Morphometry

Basin Linear aspects

Stream Order (Su) and Stream Length (Lu)

Streams usually start with low resistance, either by creating valleys whose rock is readily erodible or by following a steeper slope gradient. The Warana River is a 7th order stream (Figure 3) (Table 1) (Strahler, 1964). Stream order is a function of the proportion size of streams. This suggests a well-drained basin with a dendritic structure (Figure 3). Average stream length for the first order basin is found to be more whereas for the fourth and fifth order streams it is lesser (Figure 4). This indicates that the basin has a steep slope upstream and a gentle in downstream.

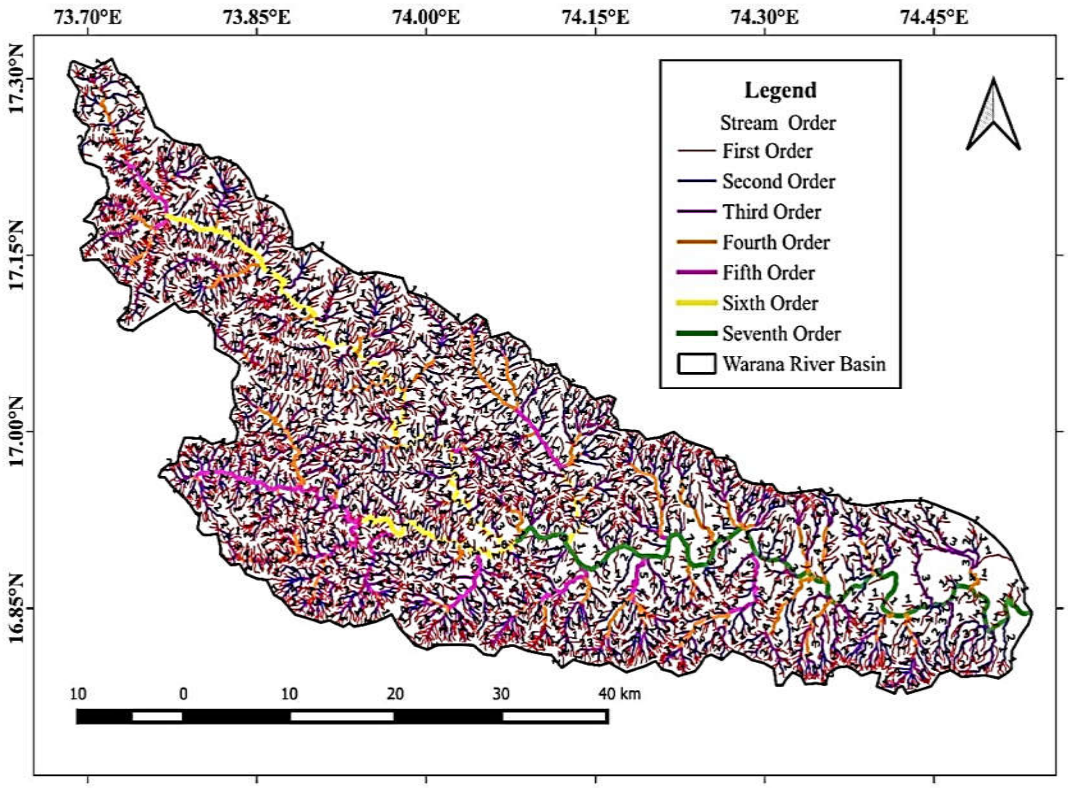


Figure 3: Stream Order map by (Strahler method) Warana River basin

Bifurcation Ratio (Rb)

An important statistic for evaluating the stages of river development is the bifurcation ratio, which is calculated by dividing the number of streams in the N^{th} order by the $N+1^{th}$ order (McCullagh, 1978). In an aged basin with even relief, there is orderly stream development and a relatively constant bifurcation ratio (Strahler, 1957). Although the bifurcation ratio differs from order to order, Horton's stream number law is based on the fact that it is relatively constant across the basin. Therefore, Strahler and Schumm (Strahler, 1957) (Schumm, 1956). proposed weighted bifurcation ratio. Any variation from the mean bifurcation ratio in any of the orders indicates a drainage irregularity that is crucial for watershed management

Table 1: Drainage Characteristics of Warana River Basin

Stream Order (Su)	Number of Streams (Nu)	length of Stream (Lu) (Km)	Bifurcation Ratio (Rb)	Mean of Stream Length (Lu/Nu)	Ratio of Stream Length (Lu/Nu)
I	4828	3033.00	4.39	0.63	2.95
II	1101	1029.15	4.20	0.94	2.08
III	262	494.52	4.37	1.89	2.06
IV	60	240.09	4.62	4.00	2.62
V	13	91.82	4.33	7.06	1.01

VI	3	90.93	3.00	30.31	1.17
VII	1	77.67	NA	77.67	NA
Total	6268	5057.18	Mean (Rb_m) = 4.15		

The Average of Bifurcation Ratio of the drainage order pair is utilized to calculate Mean Bifurcation Ratio (Rb_m) and results are summarized. The Warana River basin's mean bifurcation ratio is 4.15 (Table 1), indicating that geological formations did not affect drainage patterns (McCullagh, 1978). A bifurcation ratio is a crucial representative characteristic of a drainage basin, because it controls the volume of flow after an unexpected heavy rain. Low bifurcation ratios are generated by the stream's branching being constrained by the relatively moderate slope (low relief) and correspondingly hard rock formations. Whereas uniform bifurcation values result, where nearly uniform and systematic stream branching patterns exist, which is caused by the underlying geological condition (Manu & Anirudhan, 2008).

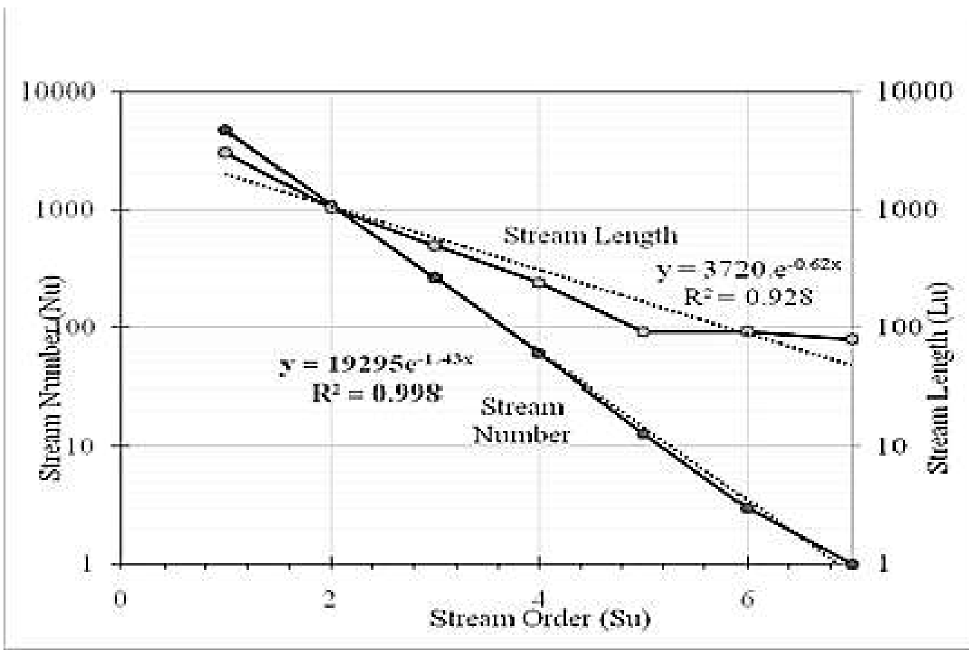


Figure 4: Plot of Stream Order (Su) v/s Stream Number (Nu) for the Warana River basin

1. Aerial aspects of basin

1.1 Elongation Ratio (Re)

Elongation ratio (Re) is defined as the ratio of the diameter of a circle with the same area at of the basin to the longest length of the basin (Schumm, 1956). The elongation ratio (Re), which normally ranges from 0.6 to 1.0, is influenced by geology and climate. While values between 0.6 and 0.8 are related to significant relief and a steep ground gradient, values close to 1.0 are linked to low relief (Strahler, 1964). Based on the elongation ratio three categories are established: round (>0.9), oval (0.9-0.8), and elongated (0.7) (Nyamathi & Kakkalameli, 2018). The Warana River basin's Elongation Ratio is 0.59 (Table 2), which suggests that the basin is elongated (Dhiman & Sharma, 2005).

1.2 Form factor ratio (Rf)

The form factor ratio (Rf), a dimensionless ratio of the basin's area to its square length, can be used to calculate the drainage basin's outline (Horton, 1945). A basin with a perfectly circular form has a shape factor greater than 0.785. As the basin length increases its form factor decreases. Basins with higher form factors values have larger peak discharges with shorter periods, whereas those with low form factors have reduced peak flows with long periods. The form factor ratio for the Warana River basin is 0.28 (Table 2), which illustrates the basin's elongated shape and suggests a longer periodtor each its peak.

1.3 Circulatory Ratio (Rc)

The circulatory ratio is the ratio of the basin area to the area of a circle with the same circumferences that of the basin (Miller, 1953). It is affected by slope characteristics and basin drainage patterns, as well as the length, frequency, and slope of streams of various orders (Strahler, 1957). Value of Rc ranges from '0' (least circularity) to '1' (maximum circularity). Stream frequency, geological structure, drainage density, climate, slope, relief, and other factors all influence Rc values in any basin. Rc value of 0.22 (Table 2) for the Warana River basin indicates that it is significantly elongated and has a high peak flood flow during the monsoon season (Miller, 1953).

Table 2: Morphometric Parameters of Warana River basin

Basin characteristics	**Parameters Values**
Basin area (Sq.km)	2095.00
Basin perimeter (km)	343.46
Relative perimeter (km)	6.10
Length of basin (km)	104.72
Mean basin width (km)	20.10
Maximum elevation (m)	1109
Minimum elevation (m)	532
Watershed relief (m)	577
Main stream length (L) (km)	160.40
Slope of Watershed (S) (m/km)	3.60
Infiltration Number (If)	7.22
Form Factor ratio (Rf)	0.28
Length of Overland Flow (Lo) (km)	0.20
Constant of channel maintenance (C)	0.41
Elongation ratio (Re)	0.59
Drainage texture (Rt)	18.25
Circularity ratio (Rc)	0.22
Time of Concentration (Tc) (hr)	28.45
Stream Frequency (F) (no/km^2)	2.99
Drainage Density (D) (km/km^2)	2.41

1.4 Drainage Texture (Rt)

In drainage morphometric analysis, drainage texture is an important feature that is controlled by the terrain's soil type, infiltration capacity, and relief. There are five different drainage texture types: very fine (>8), fine (6-8), moderate (4-6), course (2-4) and extremely coarse (2). The drainage texture rating for the Warana River basin is very fine (18.25) (Table 2), indicating moderate infiltration capacity, rock permeability, and sparse vegetation, all of which facilitate drainage development.

1.5 Stream Frequency (F)

Stream frequency was defined by Horton (Horton, 1964) as the ratio of a number of streams (Nu) to total area of the basin. It serves as an indicator for closeness of the drainage.

Low drainage frequency suggests greater percolation, which raises the probability of groundwater, while high drainage frequency indicates greater surface runoff (Sreedevi et al., 2004). It is a measure of the drainage basin for runoff development. The Warana River basin has a high stream frequency (2.99/km) (Table 2) and is positively correlated with drainage density, indicating that the population of streams is growing as drainage density increases. In mountainous regions, higher slopes and more rainfall facilitate increase in the stream frequency (F).

1.6 Drainage density (D)

The total length of streams in a catchment divided by the basin's area provides the drainage density (D), a measure of the basin's wetness. It is a typical geomorphological parameter used to connect the behavior of several watershed parameters to perform hydrological study. It evaluates a variety of catchment parameters, such as soil, slope, climate, vegetation, lithology, land use and the response of the watershed to rainfall (Kelson & Wells, 1989). Where impermeable rocks are present, a higher drainage density is achieved. Catchment geology, weathering resistance, and permeability of rock formations, as well as temperature and vegetation, all influence drainage density (D). Low relief, highly unaffected permeable materials with vegetation cover are found to have low drainage density (D)(Chopra et al., 2005). In areas with poor and impermeable underlying material, little vegetation, and mountainous relief, the drainage density (D) is higher. Drainage density (D) of 2.41 (Table 2), for the Warana River basin suggest that is comprised of impermeable material having moderate relief.

1.7 Time of Concentration (Tc)

Time of concentration is a key parameter for watershed analysis. The longest amount of time needed for a particle to reach watershed outlet from a watershed divide is defined as time of concentration (Vittala et al., 2004). It is employed to determine the watershed's peak discharge. Time of concentration is determined by using the Kirpich equation. The longest watercourse in the watershed (L), its average slope (S), and a coefficient reflecting the kind of groundcover are required inputs for calculation of the time of concentration. Using QGIS 3.16, "L" and "S" are determined (Table 2) and the time of concentration is calculated following the equation

$$Tc=0.0662*L^{0.77}*S^{(-0.305)}$$

The concentration time of 28.45 hours for the Warana River basin shows the hydrograph of the basin is characterized by a high peak and a moderate to high base period (Table 2).

1.8 Overland flow length (Lo)

It is the time taken by the rainwater once it reaches the ground to get localized into the channel. Low value (<0.2), moderate value (0.2–0.3), and high value (> 0.3) are the three categories under which Lo is divided. Low Lo values represent high relief, shorter flow paths, greater runoff, and reduced infiltration, all of which raise the possibility of flash flooding (Horton, 1945). The Lo values of the Warana River basin (Table 2), indicates that there is moderate runoff and moderate infiltration, making the area more susceptible to flooding.

1.9 Infiltration Number (If)

The river basin's infiltration characteristics are expressed by the infiltration number, which is a product of drainage density and stream frequency (Manu & Anirudhan, 2008). It is reciprocal of infiltration number and runoff have a positive relationship; Lower infiltration number values (<6) indicate low run-off in watersheds. Infiltration number values of 7-10 indicate moderate infiltration and moderate runoff potential in watersheds. Watersheds with high infiltration number values (>10) have a strong runoff potential hence very low infiltration. The Warana River basin's infiltration number is 7.22 (Table 2), indicating moderate infiltration, hence moderate to high runoff.

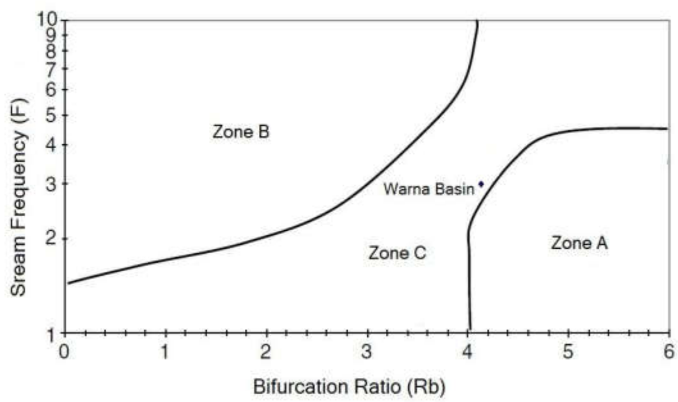
2. Relief parameters of the basin

2.1 Constant of channel maintenance (C)

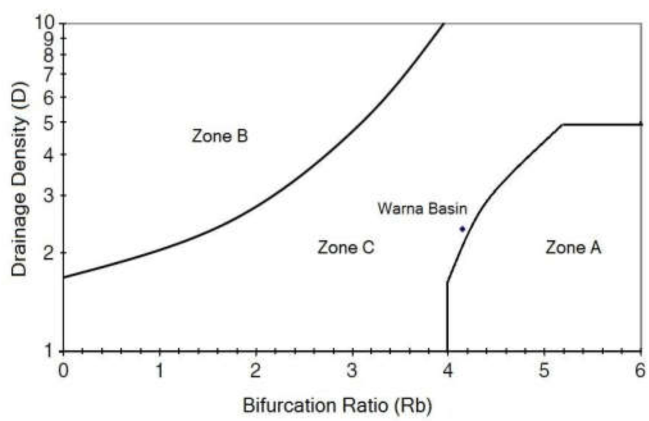
By Schumm (1956) the constant of channel maintenance is defined as the inverse of drainage density. The lithology, relief, and climate of the basin all influence channel maintenance. It reduces when erodibility increases. Higher values of the channel maintenance constant indicate that more area is required to generate surface flow, increasing the probability that some water will be lost through evaporation, infiltration, as well as other means; relatively low value shows that there are very few possibilities of percolation/infiltration and thus more surface runoff. The present study area's Constant of Channel Maintenance value is low (0.41) (Table 2), indicating moderate permeability and moderate runoff and flood potential.

Relationships among different morphometric parameters

Basin is assessed for flood assessment and recharge potential using the Relationship between stream frequency and bifurcation ratio and drainage density (Al-Saud, 2009; Bhagwat et al., 2011) (Figures 5a and 5b). The Warana River Basin is classified as "Zone C" due to its stream frequency, bifurcation ratio and drainage density. This means the Warana River basin has a moderate flood potential and a moderate recharge property.



(a)



(b)

Figure 5a and **Figure 5b:** Potential of Warana River basin based on Morphology parameters.
Zone A: Low flood probability and high recharge property,
Zone B: High flood probability and low recharge property,
Zone C: Moderate to high flood property and moderate recharge property.

Surface and Groundwater Potential

Flood Frequency Analysis

The Warana River Basin is gauged at Shigaon (Figure 1). Daily maximum peak values of 25 years (1986-2010) were used to plot the flood frequency curve (Figure 6). Normal distribution method was used for flood frequency analysis. For the return period, the probability factor was evaluated in percentage. In the process of Normal distribution method frequency analysis, initially data has been organized in descending order and then allotted ranks to each value. Flood frequency curve indicates the recurrence interval of known discharge. The observation and river cross-section details at Shigaon river gauging station shows that the threshold is 1500 m^3/sec once in three year implying that basin experiences flood once in three years.

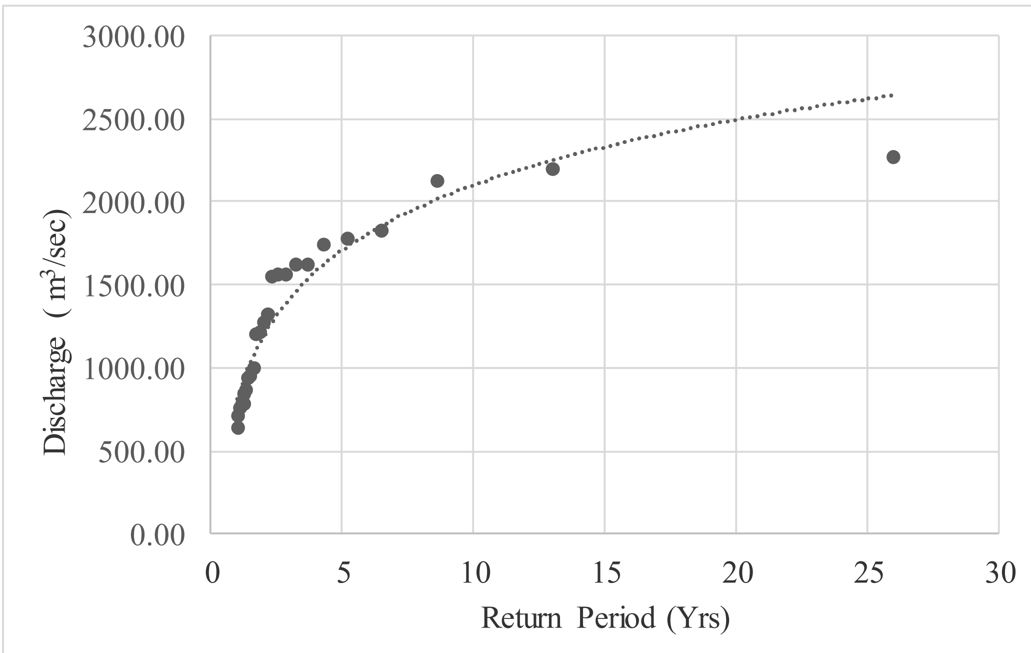


Figure 6: Flood Frequency analysis for 25 years (1986-2010) discharge gauged at Shigaon, Warana River basin

Lineament density

Lineaments are geological formations that may be seen clearly in satellite images and range in shape from straight to curved. Specific tonal, textural, relief, and drainage qualities apply to these lineaments. They frequently indicate faults, joints, or limits between stratigraphic or lithologic deposits, and are considered to be possible sites for groundwater percolation. The lineament density is the sum of the lineaments per unit area. More percolation is possible where denser the lineaments are, Linear density in the Warana River basin is 0.20 km/km^2 (Figure 7) and can be categorized as moderate. Higher density of lineaments is observed in the middle reaches of the basin implying potential of the middle part of the basin for percolation

Ground Water Table fluctuation

Precipitation in semi-arid and Hard-rock terrain, where groundwater originates in shallow weathered zones, is directly responsible for the rise in ground water level. The eastern portion of the Warana River basin has fluctuations exceeding 5.0 m between pre and post monsoon season (Figure 7), showing that groundwater in these areas is intensively used. As a result, recharging these places leads to long-term viability. The western section of the basin has a groundwater fluctuation of more than 3.0 m, indicating that it has a moderate groundwater recharge property.

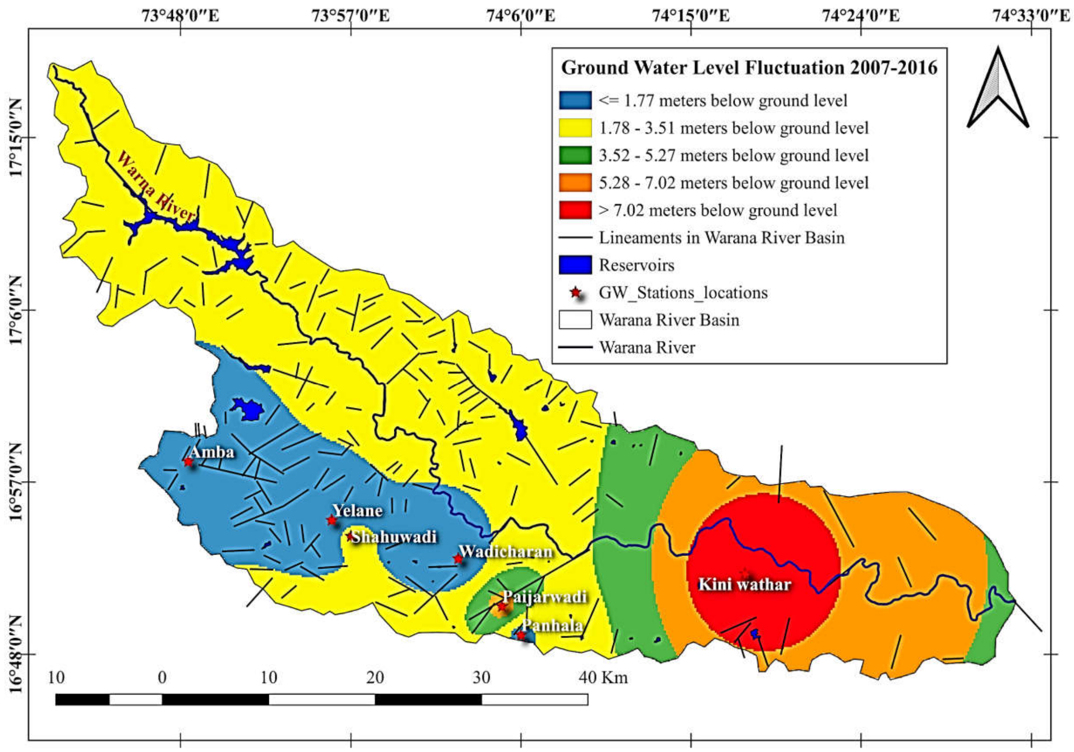


Figure 7: Groundwater Table Fluctuation Map of Pre and Post Monsoon season for 10 years (2007-2016) based on groundwater monitoring stations in theWarana River Basin

Implications on Irrigation water management

Surface water harvesting and watershed management plans benefit greatly from morphometric studies of the basin area (Jahan et al., 2018; Rai et al., 2019; Gidey et al., 2021). Irrigation water management in semiarid River basins that have moderate groundwater potential and moderate to high flood property suggests that surface water storage provisions serve as flood control and ground water harvesting structures. Higher values of Stream frequency and lineament density in the higher reaches of Warana River basin suggest a significant surface water resource potential and recharge opportunity that might be utilized to create various water conservation structures and irrigation projects in the area (Jahan et al., 2018). The Warana River basin's pre- and post-monsoon groundwater table fluctuation show that the basin has a moderate recharge property and that there is potential for the development of various groundwater recharge structures in the basin's lower reaches in the south-east. Integration of spatial and non-spatial data such as lineament- intersection are more appropriate locations for various conservation structures (Bhagwat et al., 2018). The Warana River basin's morphometric and flood frequency analysis suggests moderate to high flood property in the basin's upper reaches in the north-west. Findings from the study will be useful for classifying river basins for future water resource development and management for deciding on suitable locations for water-conservation infrastructure such check dams, percolation tanks, and artificial groundwater recharge

(Chhuanga et al., 2021). Additionally, a variety of ground water extraction plans can be built, including ones for irrigation at lower ranges of the basin's southeast. The current study is helpful for determining the qualitative basin potential, choosing the best techniques for locating water resources, and providing appropriate guidelines for irrigation watershed management at the upper and lower portions of the Warana River basin. It also helps to make decisions regarding suitable sites for various watershed management plans in the higher reaches of the Warana River basin.

Acknowledgements

Authors sincerely thank the authorities of the University B.D.T. College of Engineering, Davangere and D.K.T.E. Textile and Engineering Institute, Ichalkaranji for the facility extended to carry out the present work and its publication. Authors also thank Hydrology Project Water Planning Division (Surface Water) Nashik for extending their support to carry out this work. Authors sincerely thank the anonymous reviewers for their critical comments and useful suggestions that helped in improving the quality of the manuscripts

REFERENCES

1. Adhikari, S. (2020). Morphometric Analysis of a Drainage Basin: A Study of Ghatganga River, Bajhang District, Nepal, The Geographic Base, 7, 127-144
2. Al-Saud, M. (2009). Morphometric analysis of Wadi Aunah Drainage system, Western Arabian Peninsula, The Open Hydrology Journal, 3, 1–10
3. Bhagwat, T.N., Shetty, A. and Hegde, V.S. (2011). Spatial variation in drainage characteristics and geomorphic instantaneous unit hydrograph (GIUH); implications for watershed management—A case study of the Varada River basin, Northern Karnataka, Catena an Interdisciplinary Journal of Soil Science and Geomorphology, 87, 52-59.
4. Bhagwat, T.N., Hegde, V.S. and Shetty, A. (2018). Application of remote sensing and GIS for identification of potential ground water recharge sites in Semi-arid regions of Hard-rock terrain, in north Karnataka, South India. Sustain. Water Resour. Manag. 4, 1063–1076
5. Bhaskar, N.R., Parida, B. and Nayak, A.K. (1997). Flood estimation for ungauged catchments using GIUH, Journal of Water Resources Planning and Management ASCE, 123, 228–238
6. Chopra, R., Dhiman, R. and Sharma, P.K. (2005). Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using Remote sensing and GIS techniques, Journal of the Indian Society of Remote Sensing, 33, 531–539
7. Chhuanga, V., Jena, R., Moharana, P., Kumar, N., Sharma, R., & Kumar, S. (2021). Morphometric analysis for prioritizing sub-watersheds and management planning and practices in the north-eastern frontier Himalayan ranges of India. Journal of Soil and Water Conservation. 20. 279-289.
8. Das, A.K. and Mukherjee, S. (2005). Drainage morphometry using satellite data and GIS in Raigad district Maharashtra. Journal Geological Society of India, 65, 577–586
9. Esper, A.M.Y. (2008). Morphometric analysis of Colanguil river basin and flash flood hazard, San Juan Argentina. Environmental Geology, 55,107–111
10. Giday, G., Ketema, T., Gashu, G. and Deressa, S. (2021). GIS Based Morphometric Analysis of Gudina Wacho Watershed, Western Ethiopia: Suggestion for Surface Irrigation Development, Journal of Water Resources and Ocean Science, 10, 92-99
11. Jahan, C., Rahaman, M.d., Arefin, R., Ali, S., & Mazumder, Q. (2018). Morphometric Analysis and Hydrological Inference for Water Resource Management in Atrai-Sib River Basin, NW Bangladesh Using Remote Sensing and GIS Technique. Journal of the Geological Society of India. 91. 613-620.
12. Jain, S.K., Singh, R.D. and Seth, S.M. (2000). Design flood estimation using GIS supported GIUH approach, Water Resources Management, 14, 369–376.
13. Jensen, S.K. (1991). Application of hydraulic information automatically extracted from

digital elevation models, Hydrological Processes, 5, 31–44

14. Horton, R.E. (1945). Erosional development of streams and their drainage basins, a hydro-physical approach to quantitative morphology, Geological Society of America Bulletin, 56, 275–370

15. Kelson, K.I. and Wells, S.G. (1989). Geologic influences on fluvial hydrology and bed load transport in a small mountainous watershed, northern New Mexico, U.S.A. Earth Surface Processes Landform, 14, 671–690.

16. Manu, M.S. and Anirudhan, S. (2008). Drainage characteristics of Achankovil river basin Kerala, Journal Geological Society of India, 71, 841–850.

17. McCullagh, P. (1978). Modern Concepts in Geomorphology, Oxford University Press, University of Michigan.

18. Miller, V.C. (1953). A quantitative study of drainage basin characteristics in the mountain area, Virginia and Tennessee, Technical report. Office of Naval research, Department of Geology, Columbia University, New York.

19. Mishra, N., Khare, D., Gupta, K.K. and Shukla, R. (2014). Impact of Land Use Change on Groundwater - A Review, Advances in Water Resource and Protection (AWRP), 2, 28-41

20. Nag, S.K. (1998). Morphometric analysis using remote sensing techniques in the Chaka sub basin Purulia district, West Bengal, Journal of Indian Society of Remote Sensing, 26, 69–76.

21. Nasri, S., Cudennec, C., Albergei, J. and Berndtsson, R. (2004). Use of a geomorphological transfer function to model design floods in small hillside catchments in semiarid Tunisia. Journal of Hydrology, 287,197–213.

22. Nowicka, B. and Soczynska, U. (1989). Application of GIUH and dimensionless hydrograph models in ungauged basins, International Association Hydrological Sciences Publication, 87, 197–203.

23. Nyamathi, S.J. and Kakkalameli, H.S. (2018). Morphometry and Soil Loss Estimation of Malaprabha Watershed, Impact of Global Atmospheric Changes on Natural Resources, 08, 192-196.

24. Reddy, O., Maji, A.K. and Gajbhiye, K.S. (2004). Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India-a remote sensing and GIS approach, International Journal of Applied Earth and Geoinformation, 6, 1–16.

25. Pakhmode, V., Kulakarni, H. and Deolankar, S.B. (2003). Hydrological drainage analysis in watershed programme planning: a case from the Deccan basalt, India, Journal of Hydrogeology, 11, 595–604.

26. Rajasekhar, M., Raju, G., Sudarsana, R. and Siddi, R. (2020). Morphometric analysis of the Jilledubanderu River Basin, Anantapur District, Andhra Pradesh, India, using geospatial technologies, Groundwater Sustainable, 11, 428-434.

27. Rai, P., Singh, P., Mishra, V., Singh, A., Sajan, B. and Shahi, A. (2019). Geospatial Approach for Quantitative Drainage Morphometric Analysis of Varuna River Basin, India, Amity Journal of Landscape Ecology,12, 21-26

28. Romshoo, S.A., Bhat, S.A., and Rashid, (2012). Geoinformatics for assessing the morphometric control on hydrological response at watershed scale in the Upper Indus basin. Journal of Earth System Science, 121, 3, 659–686

29. Sarangi, A., Madramootoo, C.A. and Singh, D.K. (2004). Development of ArcGIS assisted user interfaces for estimation of watershed morphologic parameters, Journal of Soil and Water Conservation, 10, 139–149.

30. Schumm, S.A. (1956). Evolution of drainage systems and slopes in badlands at Perth, Amboy, New Jersey. Geological Society of America, Bulletin, 67, 597–646.

31. Sreedevi, P.D., Subrahmanyam, K. and Ahmed, S. (2004). The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain, Environmental Geology, 47, 412–420

32. Sreedevi, P.D., Owais, S., Khan, H.H. and Ahmed, S. (2009). Morphometric analysis of a watershed of South India using SRTM data and GIS Journal of Geological Society of India, 73, 543–552.

33. Strahler, A. (1957). Quantitative Analysis of Watershed Geomorphology, Transactions, American Geophysical Union, 38, 913-920.

34. Strahler, A.N. (1964). Quantitative geomorphology of drainage basins and channel networks. In: Chow, VR (Ed.), Handbook of Applied hydrology, Mc-Graw-Hill, New York, 4, 40–74.

35. Vittala, S.S., Govindaih, S. and Gowda, H.H. (2004). Morphometric analysis of sub-watershed in the Pavada area of Tumkur district, South India using remote sensing and GIS techniques, Journal of Indian Remote Sensing, 32, 351–362.

****