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Remote sensing and GIS-based site selection for effective soil and water conservation measures in the Warana river basin

Saurabhkumar Gadakh, Sarika S Wandre, Mangal A Patil and Pradip Dalavi

Abstract
A watershed management plan necessitates current and trustworthy data on elements influencing a watershed's behaviour, such as size, shape, terrain, soil qualities, and land use/land cover. Remote sensing and geographic information systems (GIS) are suitable techniques for gathering this data. In one case study, Indian Remote Sensing Satellite data was used to create a land use land cover map and extract information on morphological parameters such as bifurcation ratio, elongation ratio, drainage density, ruggedness number, relief ratio, and circulatory ratio in the Warana River Basin in Maharashtra, India. These factors were combined with other thematic information including land use land cover, drainage, slope, and soil to find potential locations for soil and water conservation structures such as nala bunds, check dams, percolation tanks, and continuous contour trenches. The study employed multi-criteria evaluation in GIS to find potential zones for water conservation action. The investigation included many levels, including slope, land use/cover, soil texture, soil depth, and soil erosion. Weighted sum analysis was utilized to identify ideal locations for water conservation operations. The program Arc 10.5 was used to analyze remotely sensed data and delineate the watershed, while CHIRPS, Open Land Map, SRTM, and WWF Hydro SHEDS were used to acquire data on precipitation, soil qualities, topography, and watershed borders, respectively. Overall, the findings of the study are useful for building watershed management plans and selecting appropriate areas for soil and water conservation structures and water conservation activities. The employment of remote sensing technologies with GIS allows for the rapid and reliable capture of data, making it an essential tool for watershed management planning.

Keywords: Remote sensing technology, GIS, land use land cover mapping, soil and water conservation structures, ArcGIS

Introduction
Natural resources, such as water and land, are critical to a country's social, economic, and political power, and their correct management and protection should be prioritized for long-term usage (Sharma and Paul, 1998) [81]. The principal supply of water in India is precipitation, largely in the form of rainfall, however, the distribution is unequal due to the monsoon climate and land-mountain structure (Sharma and Paul, 1998) [81]. The total amount of water on Earth is believed to be 1.4 billion km3, yet only 2.5% of it is freshwater, with the rest trapped in ice and glaciers or underground as groundwater (CWC, 2010). Rainwater collecting, water conservation, and reuse are vital to protecting the planet's finite freshwater resources (CWC, 2010). Groundwater is the principal source of water for agriculture and drinking in India, with 89% utilized for irrigation, 9% for residential consumption, and 2% for industrial usage (CGWB, 2019). Groundwater resource over-exploitation has become a global problem, with 20% of the world's aquifers currently over-exploited, resulting in catastrophic implications (Gleeson *et al*., 2012) [79].
The United Nations World Water Development Report 2022 emphasizes the necessity of long-term groundwater management in addressing water shortages and climatic unpredictability. Groundwater is poorly managed due to its invisibility, although it accounts for half of all home water and one-fourth of agricultural water. With an increasing population, especially in developing nations, clean water shortage is a major concern. India, for example, is anticipated to be in a water-scarce zone by 2050, potentially resulting in economic losses. Freshwater resource management must be sustainable to ensure availability for current and future generations. Watersheds are natural land units that collect and direct water to a single point of discharge. They are critical for freshwater resource management as well as the long-term

viability of local ecosystems and human livelihoods. Dams and ponds, for example, are crucial components of watershed development. The involvement and cooperation of local communities and stakeholders are typically critical to the success of watershed development programs. Several models for estimating surface runoff have been developed, with the USDA NRCS-CN technique being the most widely used in India.

The collection and storage of rainwater and runoff for irrigation, human and livestock consumption. The phrase "water harvesting" was coined by Myors (1975). Water harvesting is an old water conservation technique that has been used in India for generations. The Nabataeans, who lived almost 2000 years ago, were famed for their skill in water gathering, which they regarded as an art form. According to the book, there are two primary ways for water gathering for irrigation. The first approach includes collecting rainfall and enabling it to be kept in the soil for immediate use, whereas the second way involves storing rainwater in reservoirs and ponds for later use. Modern technology may be used to capture water more efficiently, either via the construction of appropriate buildings or by improvements in land and water management practices. By capturing runoff, water may be used to improve infiltration and conservation. Despite the development of different large-scale water collecting systems, such as dams and reservoirs, a considerable quantity of accessible surface water still flows into the oceans, emphasizing the need for more small-scale water harvesting systems at the micro-watershed level to trap the available surface water. (Ramakrishnan *et. al.*, 2009, Sharma and Paul, 1998, Gaur *et. al.*, 1994) [57, 81, 80]

The essay also emphasizes how current water collection systems can considerably boost groundwater levels and agricultural output. Implementing soil and water conservation practices, such as contour bunding, has been demonstrated to improve groundwater recharge. Remote sensing (RS) and geographic information systems (GIS) are increasingly being utilized for watershed runoff determination because they enable the detection of physical elements such as stream networks, land use, soil surface, and water bodies. The science and practice of acquiring information about items, regions, and occurrences without physically touching them are known as remote sensing (RS). A Geographic Information System (GIS) is a computer system designed to collect, store, manage, alter, analyze, and display spatial or geographical data. (Pandey *et al*., 2011) [50] Land use and land cover data from RS and GIS are accurate, which is a crucial input parameter for the SCS model. It is simpler to construct management plans for the sustainable use and development of watersheds by integrating RS, GIS, and the SCS model.

Study Area

The Warana river basin in Maharashtra's Ratnagiri, Kolhapur, and Sangli districts has been chosen for the study. The research region is located between latitude 16º0'47" N and longitude 73º30'15" E. The Warana River basin is located in a tropical and subtropical climatic zone, hence it has pleasant temperatures all year. The temperature in the basin can fluctuate between 30 °C and 40 °C. The Warana River basin has an area of 1,965 square km. Figure 1 depicts the research area's location map.

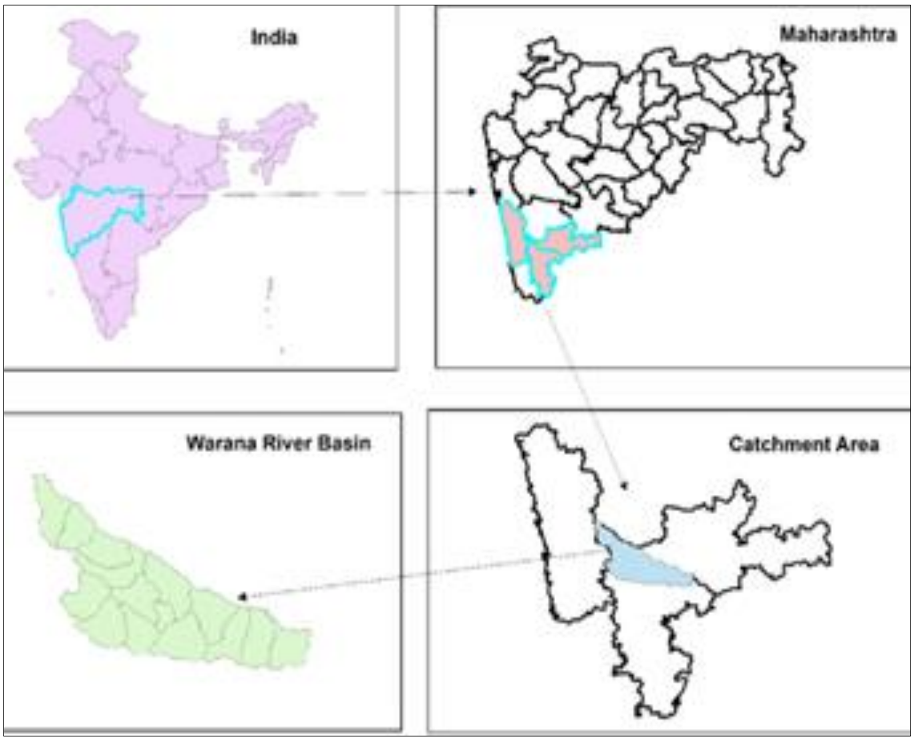


Fig 1: Location map of the study area

Material and method

Data Collection

The study's diverse information was gathered from a variety of sources.

The following is an overview of the data to be collected:

1. Land Use and Land Cover (LULC): Data on the physical and biological properties of the Earth's surface derived via supervised classification of Bhuvan and MODIS sentinel 2 images.

2. Precipitation: CHIRPS (Climate Hazards Group Infrared Precipitation with Station data) statistics on rainfall patterns and quantities overtime during the previous 30 years.

3. Soil: Open Land Map, a free and open-source global soil information system, provides data on soil qualities such as texture.

4. Digital Elevation Model (DEM): SRTM data on the topography and elevation of the Earth's surface.

5. Boundaries: Data on watershed boundaries for spatial analysis and mapping purposes from WWF HydroSHEDS.

Software used
The program Arc 10.5 was used to process remotely sensed data to delineate watersheds and generate various maps such as stream order maps, land use land cover maps, soil maps, and so on.

Delineating a watershed entails determining the drainage area for a collection of points using a Digital Elevation Model (DEM). A DEM with a spatial resolution of 30 meters was collected from SRTM for this study and processed in ArcGIS software using different approaches such as filling, flow direction, flow accumulation, and adding pour points. The extracted watershed, which is trimmed from the DEM, is the final result.

Thematic maps
Thematic maps such as drainage, slope, land use/cover, soil, and hydrological soil group were made utilizing multiple data sources and tools in ArcGIS. These maps are useful for analyzing water discharge and developing appropriate water conservation systems.

Morphometric characteristics of the watershed

Table 1: Morphometric characteristics of watershed

Sr. No.	Morphometric characteristics	Formula / Definition
		Linear aspects of Drainage networks
1	Basin Perimeter	ArcGIS measures the basin's watershed perimeter along its dividing ridge.
2	Basin Length	Stream length is the straight-line distance from the mouth to the farthest point of its drainage divide.
3	Stream Order	Stream order ranks streams by size and branching, starting with first-order tributaries in a drainage basin.
4	Bifurcation Ratio (R_b)	$R_b = N_u/N_{u+1}$ Where, N_u = Number of stream segments presenting the given order, N_{u+1}= Number of segments of the next higher order
5	Stream Length (L_u)	Length of the Stream (km)
6	Stream Length Ratio (R_L)	$R_L= L_u/L_{u-1}$ Where, L_u = Total stream length of order (u), L_{u-1}= The total stream length of Its next lower order
		Areal aspects of watershed
7	Area of watershed (A)	ArcGIS estimates watershed area in hectares using the vertical projection of its drainage divide on a horizontal plane.
8	Form Factor (R_f)	$R_f = \frac{A}{L_b^2}$ Where, A = Area of watershed L_b = Length of the basin
9	Circularity Ratio (R_c)	$R_c = 4\,\pi A/P^2$ Where, A_u= Basin Area (km^2), P= Perimeter of the basin (km) Π= 3.14
10	Elongation Ratio (R_e)	$R_e= 4\pi Au/ L_{b2}$ Where, A_u = Area of the Basin (km^2), L_b=Maximum Basin length (km) Π = 3.14
11	Drainage Density (D_d)	$D_d = \frac{L}{A}$ Where, D_d = Drainage density, L = Total length of the stream, A = Area of the basin.
12	Stream Frequency	It is defined as the number of streams segmented per unit area.
13	Length of main channel	Main stream length is the longest distance from a stream's confluence to its upper limit, calculated by measuring the total length of higher-order streams.
		Relief aspects of channel network
14	Maximum watershed relief (H)	Maximum watershed relief (H) is the elevation difference, measured in meters, between the discharge point and the highest point on a basin's perimeter.
15	Relative Relief (R_R)	$R_R = \frac{H}{L_p} \times 100$ Where, H = Watershed relief, L_p=Length of perimeter.
16	Relief Ration (R_r)	$R_r = \frac{Bh}{L_b}$ Where, B_h = Watershed relief, L_b = Basin Length
17	Ruggedness Number (R_N)	$RN = Bh \times Dd$ Where, D_d = Drainage density, B_h = Basin relief.

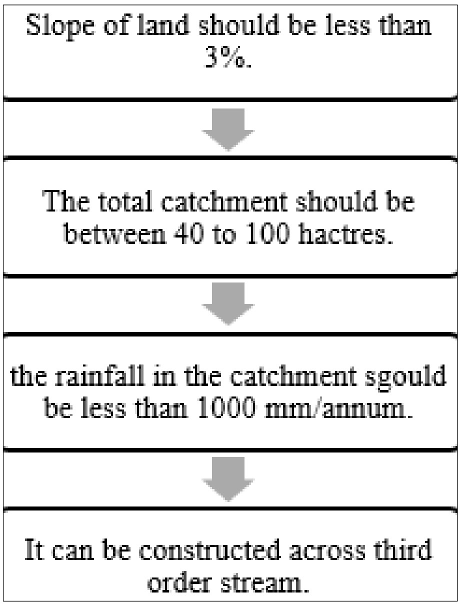
Soil and Water Conservation Measures
A micro watershed's soil and water conservation methods are determined by soil type, land slope, rainfall, and runoff characteristics. Agronomical/vegetative measures and engineering measures are the two categories of measures. Agronomical/vegetative techniques are effective in regions with slopes of less than 2%, whereas engineering solutions entail the construction of barriers to slow down water flow and are more effective in places with slopes of more than 2%. This research looks in depth at engineering measures.

Cement Nala Bund

Since 1969, constructing nala bunds over water channels has been a significant activity in Maharashtra for boosting soil moisture and water storage. Cement nala bunds built of stone masonry are chosen since they require less upkeep.

Site Suitability of Cement Nala Bund

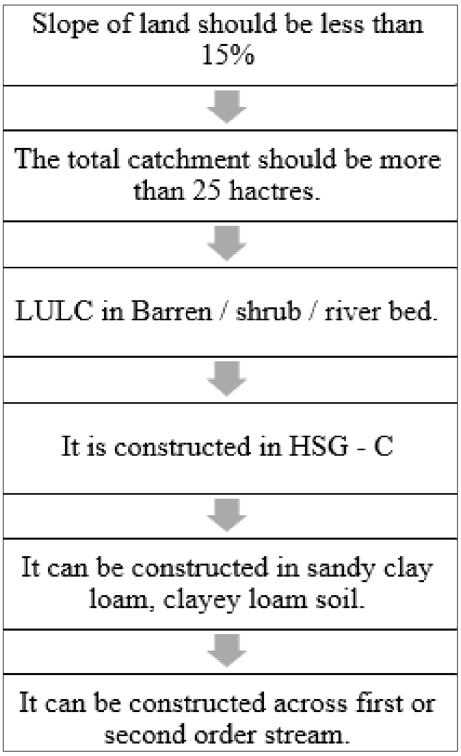
For selecting a site for cement nala bunds following conditions are considered:



Check dam

Check dams are constructed to hold water on the flat to mild slopes of lower-order streams. The area should be at least 25 hectares, with soil permeability ranging from low to medium. They are economically efficient when positioned near agricultural or population regions.

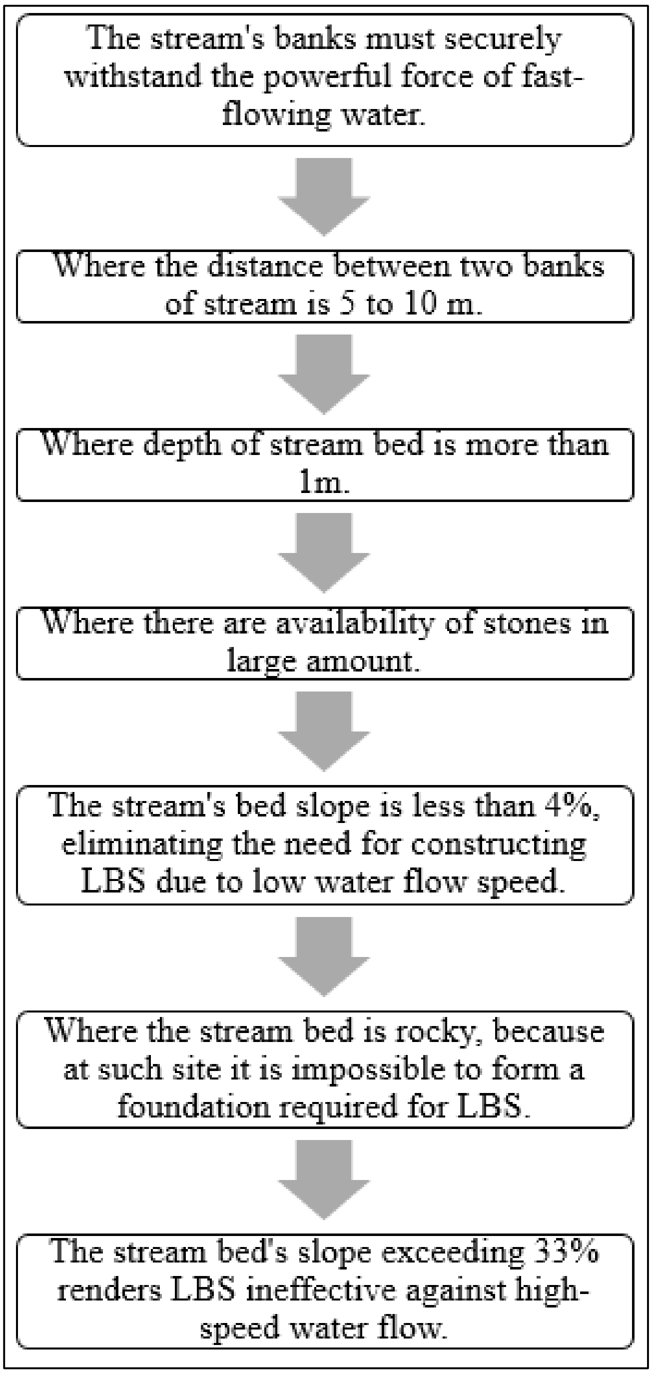
Site suitability of check dam (Ramakrishnan *et. al.*, 2009) [57]



Loose boulder structure

A loose boulder structure in a stream is a modest barrier built of boulders and gravel that decreases water velocity, enabling the material to settle and reducing erosion. It also encourages groundwater recharge during rainy seasons for usage during dry seasons, minimizes soil erosion, and allows sediment-free water flow into downstream storage facilities.

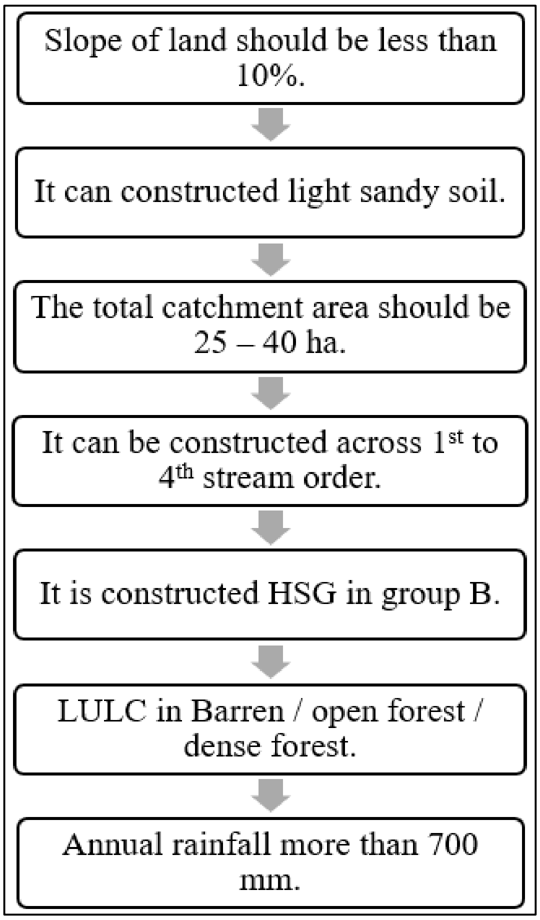
Site selection criteria of LBS



Percolation Tanks

Percolation tanks are structures that collect rainfall runoff and use it to replenish groundwater. They aid in the conservation and management of water in resource-constrained locations, increasing agricultural output and alleviating water shortages.

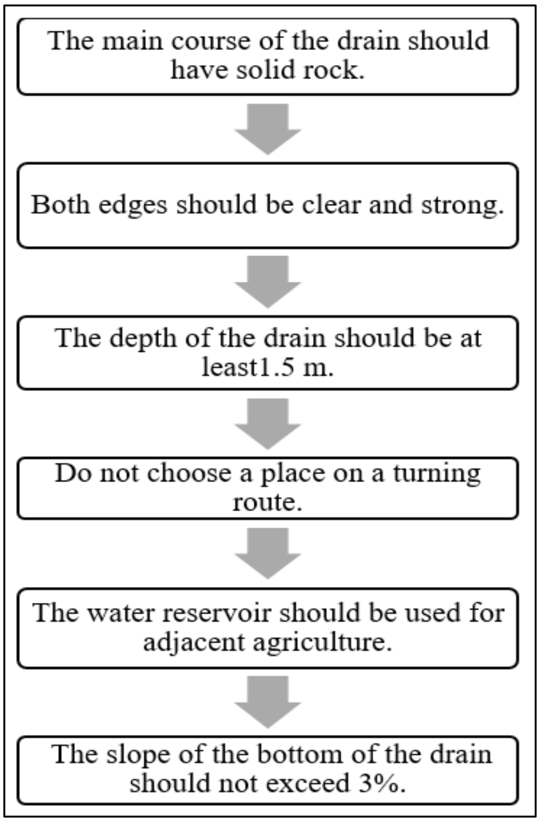
Site selection criteria (Ramakrishnan *et al.*, 2009) [57]



K. T. (Kolhapur Type) Weirs

The K.T. weir, also known as a bridge-cum-bandhara, is a bridge as well as a water storage facility. It is made up of a bridge and a bandhara, which can be a composite construction or two distinct structures depending on the circumstances. The clear span between two piers should be determined by the availability of gates and their dimensional sizes.

Site selection criteria of K. T. Weirs



Digital Delineation of Watershed

By picking pour locations along stream linkages, the study proposes a flexible and effective computerized technique for designating watersheds of various sizes. The resultant borders give a clear picture of the watershed region, which is useful for hydrological modeling and conservation plannin

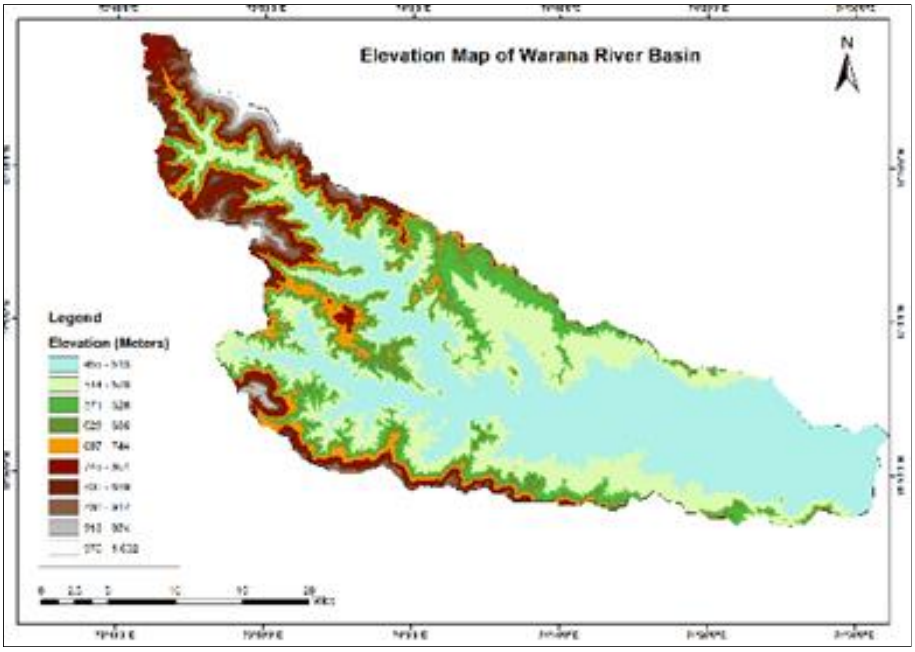


Fig 2: Digital delineation of warana river basin

Slope map

The Warana River Basin slope map shows slopes ranging from 0% to over 33%, with the majority being less than 10%. Mountainous areas have slopes that surpass 25%, impacting hydrology, flora, and fauna. The map may be used to plan land use, manage water, and save resources.

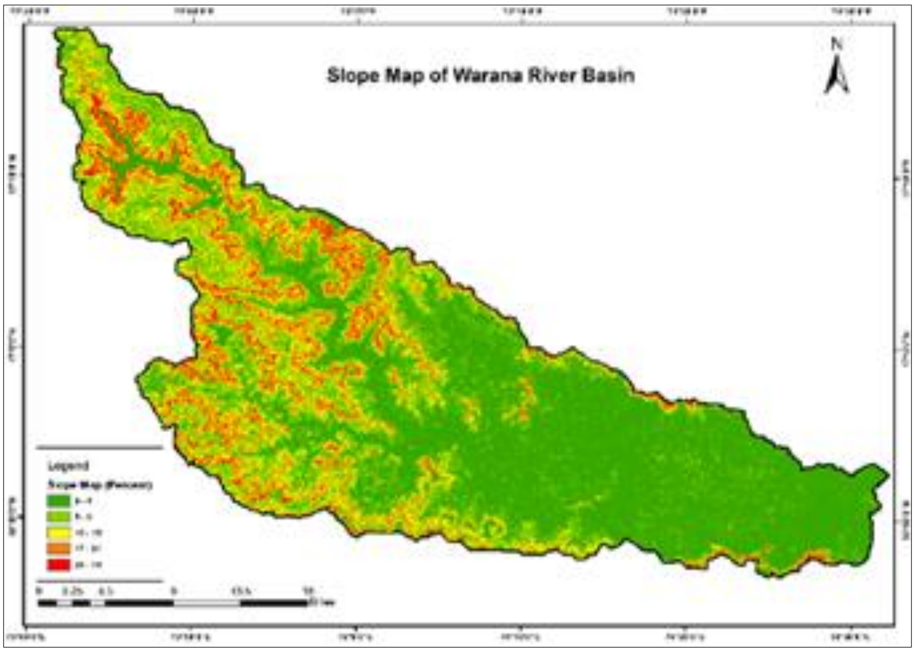


Fig 3: Slope map of warana river basin

Stream Order

The stream order in the Warana River Basin was determined using Strahler's (1964) approach, which resulted in the identification of 3059 streams, with the smallest labeled as order 1. The stream order indicates the size, runoff, and drainage area of the stream, which are all closely connected to the size of the watershed. According to the research, the Warana River Basin comprises 2367 streams of order I, 545 streams of order II, 119 streams of order III, 23 streams of order IV, 4 streams of order V, and 1 stream of order VI spread across an area of 1965 km^2. A large number of streams of category I indicate undulating terrain. Figure 4.5 depicts a stream-order map that is critical for water resource management and planning, assisting in the identification of regions with high and low stream densities that necessitate conservation and management activities.

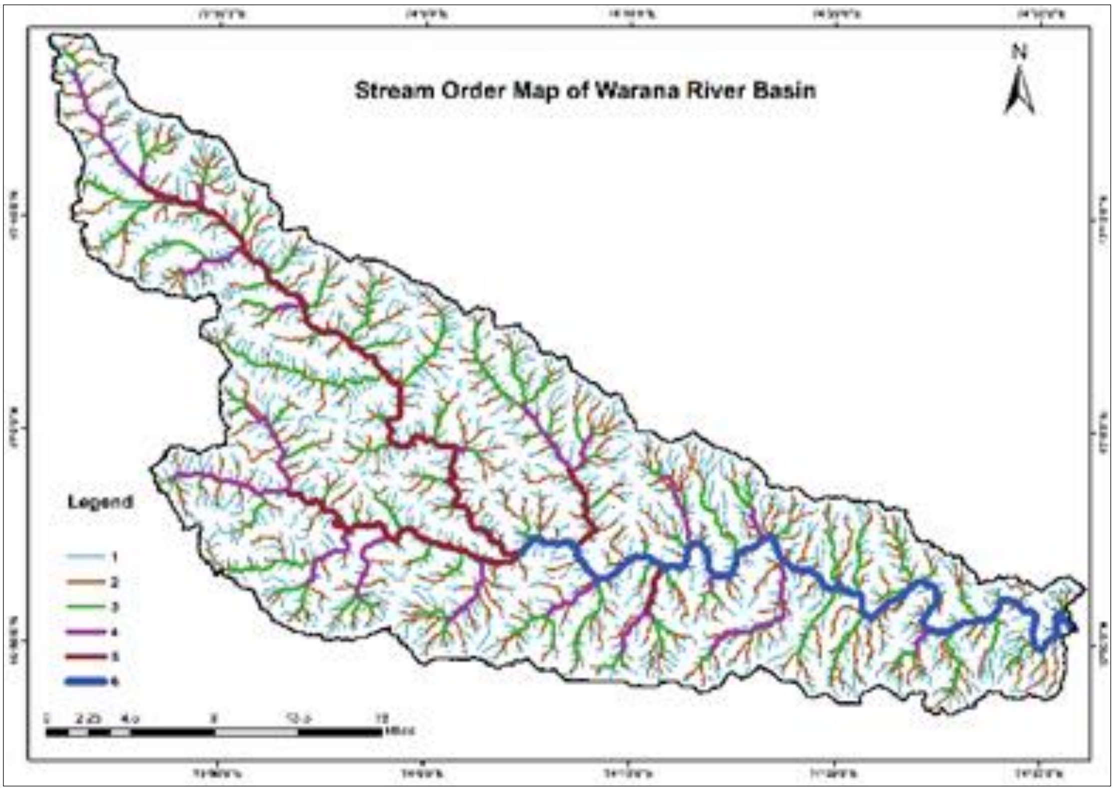


Fig 4: Stream order map of warana river basin

Soil Map

The Warana River Basin is mostly made up of clay and clay loam soils, which cover 64,873 and 127,339 hectares, respectively. This suggests that the area is ideal for agriculture. The least prevalent soil types, on the other side, are loam and waterbody, which cover 222 and 4,197 hectares, respectively. The basin's rarest soil type is sandy clay loam, which covers only 30 hectares. It is vital to highlight that the existence of water bodies in the region is noteworthy since they play a key part in the area's ecological and economic elements. Overall, the table contains useful information regarding the soil types in the Warana River Basin and their potential consequences for the region.

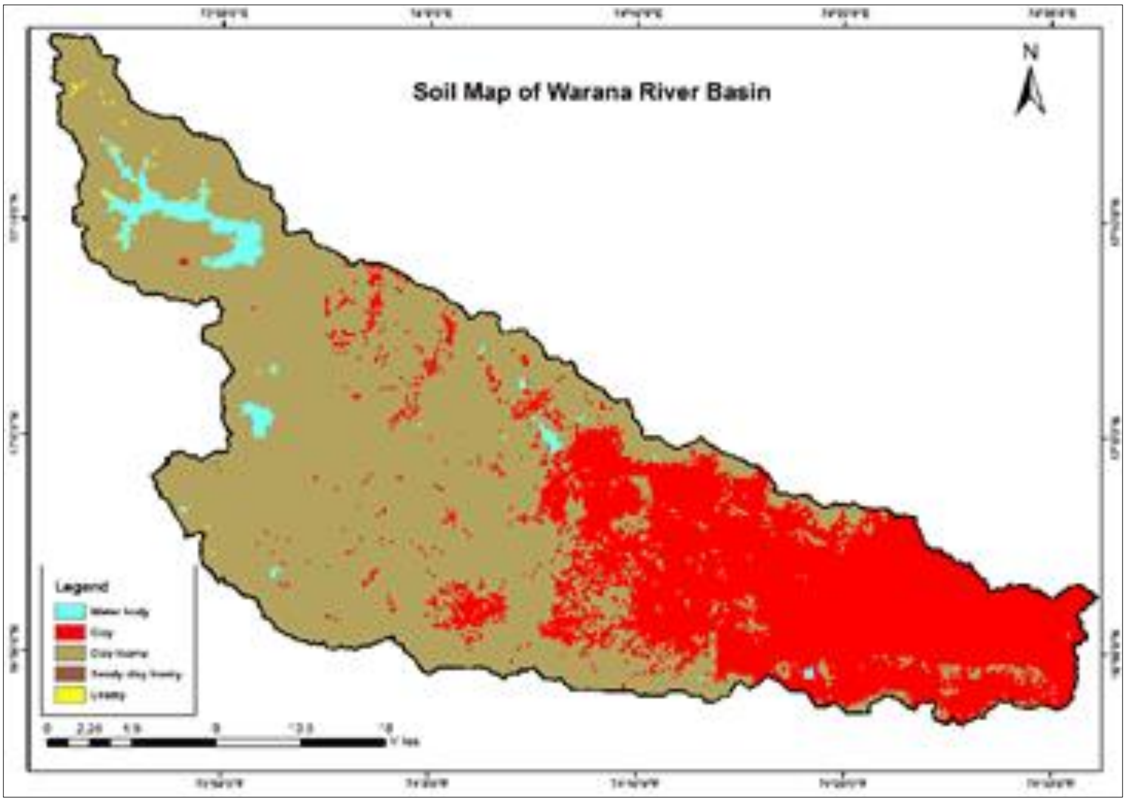


Fig 5: Soil map of warana river basin

Hydrologic Soil Group

Table 2: Area covered by each hydrological soil group

HSG	Textural Class	Area (ha)
Group A	Deep, well-drained sands and gravel	4264.294
Group B	Moderately deep, well-drained with moderate	65277.88
Group C	Clay loams, shallow sandy loam, soils with moderate to fine textures	126765.3
Group D	Clay soils that swell significantly when wet	299.88
Total Area		196604.3

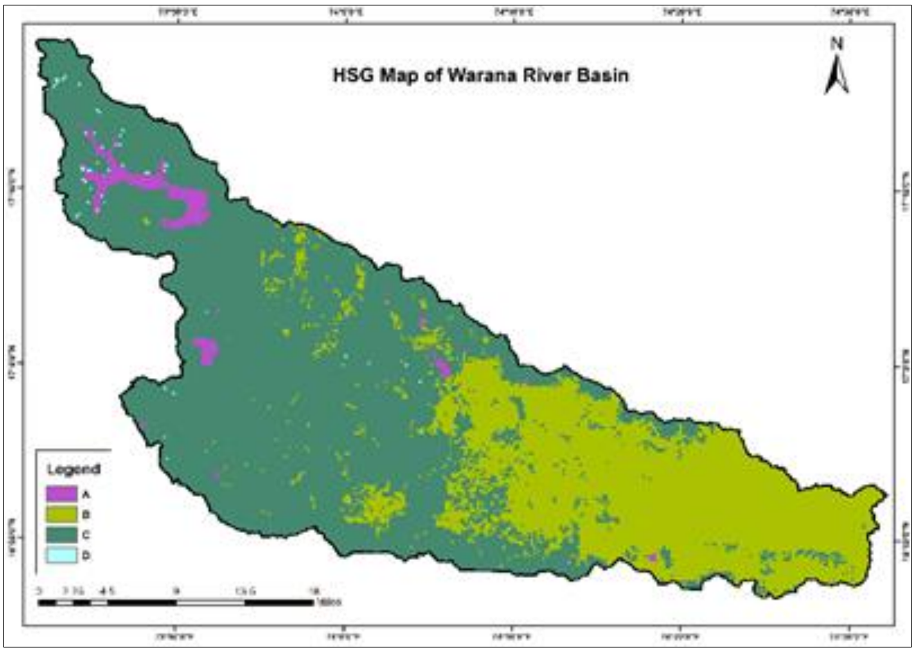


Fig 6: HSG map of warana river basin

Land Use Land Cover of the Watershed

The Warana River Basin land use land cover map was made using ArcGIS software and Landsat 8 satellite images downloaded from the USGS earth explorer. The map was separated into five unique groups to categorize the watershed: agricultural land, forest land, barren land, urban regions, and water bodies. The majority of the land was classed as barren land, accounting for around 54% of the total area of the watershed. Forest land accounted for 8% of the total, followed by agricultural land (34%), urban areas (2%), and aquatic bodies (2%). Figure 5 illustrates the Warana River Basin's resultant land use land cover map.

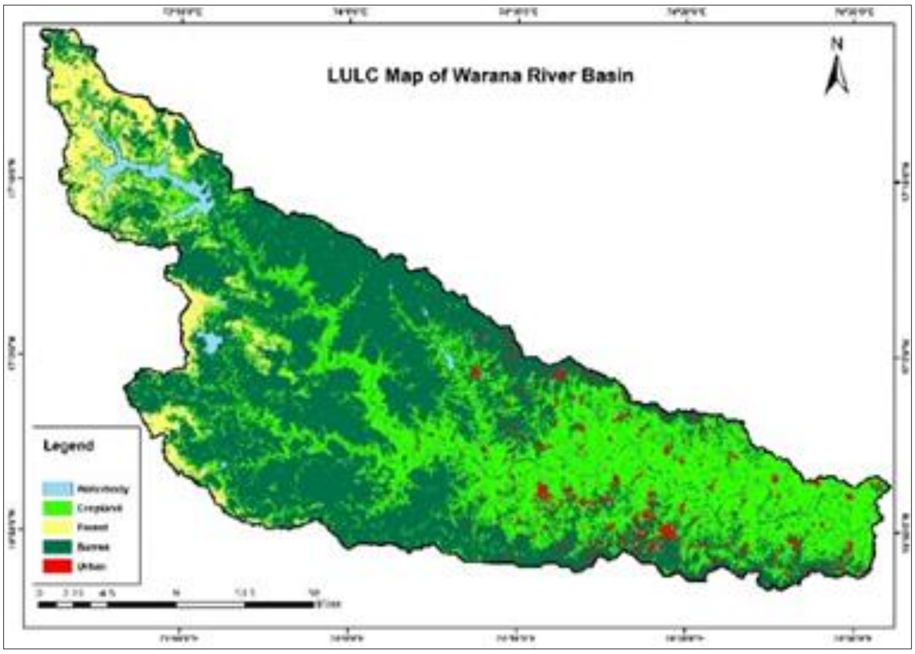


Fig 7: LULC map of the warana river basin

Morphometric characteristics of Warana River Basin

Table 3: Morphometric characteristivs of warana river bsin

Sr. No.	Characteristics	Estimated Value
	Linear aspects	
1.	Basin perimeter	343 km
2.	Basin Length	154 km
3.	Stream Order	Number of Streams in given Order
	I	2367
	II	545
	III	119
	IV	23
	V	4
	VI	1
4.	Stream Order	The sum of length of streams of given order
	I	1642 Km
	II	765 Km
	III	333 Km
	IV	133 Km
	V	101 Km
	VI	77 Km
5.	Stream Order	Mean Stream Length
	I	46 m
	II	43 m
	III	86 m
	IV	897 m
	V	4948 m
	VI	76797 m
6.	Stream Length Ratio	
	RL1	0.46
	RL2	0.43
	RL3	0.39
	RL4	0.75
	RL5	0.76
7.	Bifurcation Ratio R_b	4.16
	Areal Aspects	
8.	Area of watershed	1965 km^2
9.	Form Factor	0.08
10.	Circularity Ratio	0.20
11.	Elongation Ratio	0.32
12.	Drainage Density	1.55 km/km^2
	Relief Aspects	
13.	Relief	586 m
14.	Relief Ratio	3.80
15.	Relative Relief	0.17%
16.	Ruggedness Number	0.90

Proposed Soil and Water Conservation Measures of Warana River Basin

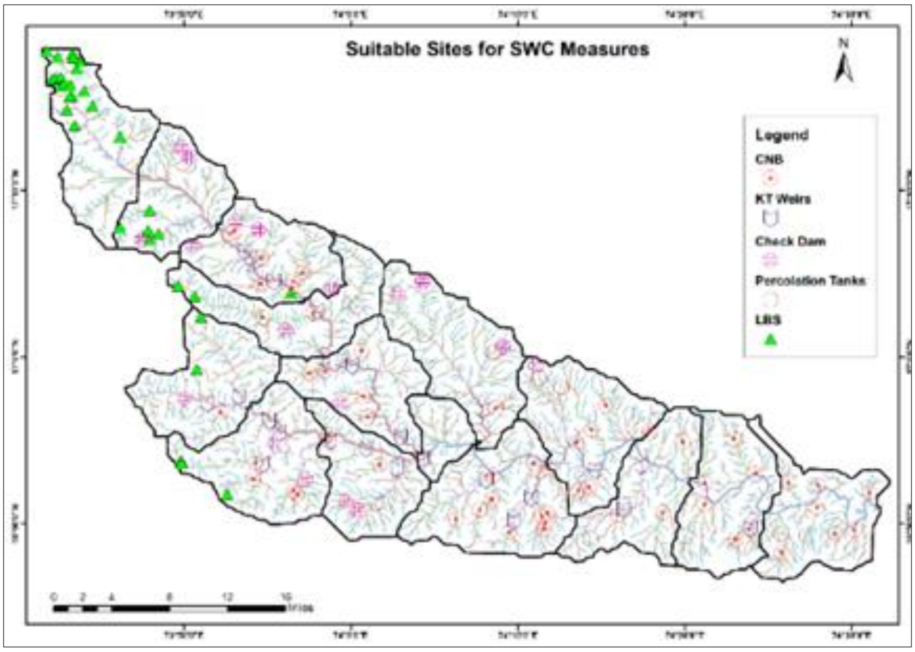


Fig 8: Site suitability map of soil and water conservation measures of warana river basin

After analyzing rainfall, runoff, land use, and topography, appropriate soil and water conservation strategies for the watershed were established. These solutions are anticipated to enhance rainwater use and increase production. Using ArcGIS parameters, structure site selection evaluates aspects such as slope, rainfall, and stream order. Ground truthing confirms selected sites, and the final positions for different constructions are depicted in the diagram below.

Conclusion

The adoption of ArcGIS software and digital elevation models (DEMs) has developed a practical strategy for watershed identification and planning for soil and water conservation. Our findings show that a systematic framework, together with morphometric parameters, thematic maps, and remote sensing data, may be utilized to identify ideal structures and prioritize regions for development and control. The suggested conceptual framework offers a logical and complete approach to developing a soil and water conservation plan. Check dams, cement nala bunds, percolation tanks, LBS, and the K.T. Weir are examples of suggested constructions with particular characteristics that may be modified to equivalent topographical situations. The use of high-resolution satellite data has significantly decreased the requirement for thorough field surveys while also providing accurate data for analysis. The effective application of this system can serve as a model for long-term watershed management and development, resulting in optimal rainwater use and increased production.

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