

**Land Resource Inventory for 14 Selected Watersheds of  
Maharashtra for Land Use Planning Using Geo-spatial Techniques  
(PMKSY 2.0)**

**(WDC-2.0)2/2021-22: Roha, Dist - Raigad**



**ICAR-National Bureau of Soil Survey and Land Use Planning  
Nagpur, Maharashtra**



**Vasundhara Watershed Development Agency  
Pune, Maharashtra**



## About the ICAR-NBSS&LUP

The ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP), Nagpur was set up in the year 1976 with the objective to prepare soil resource maps at the national, regional, state and district levels, to provide research inputs for land evaluation, land use planning, land resource management and database management using GIS, and to impart training on soil survey and land use planning. The Bureau has the mandate to correlate and classify soils of the country and maintain a National Register of all the established soil series.

During the past decades, ICAR-NBSS&LUP provided the country with the first comprehensive soil resource maps of India and her states on 1:1 million and 1:250000 scales, respectively. The Bureau generated land resource inventories (LRIs) on different scales (1: 50,000 or larger) at watershed, block and district levels to aid planning agencies in the formulation and implementation of agricultural land use plans. Other landmark data products generated by the Bureau include the land degradation map of India, potential soil loss maps of different states, and agro-ecological region and sub-region maps of the country. The Institute has received commendable mention by the NITI Aayog for providing land use plans in respect of 27 Aspirational districts of India. Taking cognizance of the demands of various agencies to develop regional land use plans in the shortest possible time, the Bureau has recently developed a revised standard operating protocol (SOP) by combining traditional knowledge with GIS and machine learning tools. The revamped SOP was successfully adopted for bringing out the Land Resource Inventory of Bundelkhand, Vidarbha, Bikaner, Kachchh and South Gujarat regions of India. The Bureau has also released the first soil depth map and the National Soil Spectral Library of the country and is in the process of bringing out the digital soil map of Maharashtra state. ICAR-NBSS&LUP has also assisted several state governments in watershed planning through LRI under the PMKSY 2.0.

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**To obtain copies of this report please write to:**

**The Director, ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP), Amravati Road, NAGPUR-440 033, India.**

Phone : (0712) 2500386, 2500545, 2500664  
E-mail : [director-nbsslup@icar.org.in](mailto:director-nbsslup@icar.org.in), [director.nbsslupngp@gmail.com](mailto:director.nbsslupngp@gmail.com),  
Website URL : <https://icar-nbsslup.org.in>

## Project Team

<b>Scientific Staff</b>	<b>Technical Staff</b>
Dr. H. Biswas (Principal Investigator)	Sh. V.T. Sahu
Dr. D. Vasu (Co-PI)	Sh. R.K. Bhalsagar
Dr. Sirisha Adamala (Co-PI)	Ms. K.B.J. Prasanna Rani
Dr. P.C. Moharana (Co-PI)	Smt. Nisha A. Lade
Dr. Jyotiprava Dash (Co-PI)	Dr. P.S. Butte
Dr. R.K. Naitam (Co-PI)	Sh. Anmol Ukey
Dr. A.O. Shirale (Co-PI)	
Dr. M.S. Raghuvanshi (Co-PI)	<b>Cover Page Design and Layout</b>
Sh. H.L. Kharbikar (Co-PI)	Sh. Prakash V. Ambekar
Dr. B. Dash	
Dr. U. Surendran (Co-PI)	
<b>Contractual Project Staff (Field and Laboratory)</b>	
Sh. Anantraj Jadhav	Ms. Chetana Thawale
Dr. Abhay Gedam	Ms. Anamika Singh
Er. Aniket Rajput	Ms. Neha Gautam
Sh. Bhushan Deshkar	Ms. Roshani Narse
Sh. Prashant Pakhare	Ms. Kalpana Ghate
Sh. Nihal Uike	Dr. Snehalata Chaware
Sh. Ravi Warhade	Ms. Babali Mange
Sh. Dinesh Sawale	Ms. Vishakha Thakre
Sh. Pratik Borkar	Ms. Shabana Sheikh
Sh. Saurabh Chinchkhede	
Sh. Yash Raut	
Sh. Deepesh Goswami	
Sh. Aaditya Nimbalkar	
Sh. Umesh Dolaskar	

## PREFACE

Watershed development requires the systematic and integrated planning of social and technological interventions based on its socio-economic and bio-physical characteristics. Activities related to conservation/management of natural resources, enhancement of systems' productivity, livelihood support through micro-enterprises and businesses, are all planned in a holistic manner for ensuring sustainable gains from the watershed programme. Implementation of watershed plans follows the preparation of detailed project report (DPR), which in turn is based on comprehensive information obtained through on- and off-field surveys. While the data requirement for DPR preparation is substantial, adoption of a minimum data set covering major aspects of the watershed through use of advanced RS, GIS and machine learning tools could significantly reduce time taken for the same, while making it more pragmatic and user-friendly.

Comprehensive land use planning of any area begins with large-scale land resource inventory, which provides valuable data for crop and nutrient management planning, and supports scientific decision-making. Generation of Land Resource Inventory (LRI) by the ICAR-NBSS&LUP during the last two decades has been a proven critical input for planned agricultural development. Encouraged by the success of LRI based watershed programmes in Karnataka, many states have started using soil/land data for rural development. It is essential that LRI based development is extended to other parts of India through spreading awareness of its benefits. Administrators at national and state level(s) have recognized it and instructed that at least 10% area of the watersheds be covered under LRI in the plateau and upland region under the section 19.1.2 (b) of WDC-PMKSY 2.0 guidelines.

Being a frontrunner on several aspects of agricultural development, the Government of Maharashtra, through the Vasundhara Watershed Development Agency (VWDA), proactively entrusted the Bureau with the generation of LRI for 14 selected watersheds across different agro-ecological sub regions of Maharashtra for formulation of scientific land use plans using geo-spatial techniques. This report presents a comprehensive understanding of soils of the watershed in terms of their physical and chemical characteristics, nutrient status, crop suitability and soil and water conservation requirements. It is expected that this report will serve as a valuable resource for land users, watershed planners, researchers and policy developers in rationalizing land use and for implementing ongoing agricultural development schemes.



(N.G. Patil)

Director,  
ICAR-NBSS&LUP, Nagpur



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Project Team  
ICAR-NBSS&LUP, Nagpur



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## **EXECUTIVE SUMMARY**

The Pradhan Mantri Krishi Sinchayee Yojana - Watershed Development Component (PMKSY-WDC 2.0) emphasizes a scientific and participatory approach to watershed development through systematic assessment and management of land and water resources. In this context, Land Resource Inventory (LRI) provides a critical technical input for informed planning, prioritization of interventions, and sustainable management of natural resources. The ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP) was entrusted with the responsibility of conducting the LRI and offering technical assistance in the formulation of a holistic watershed development plan in accordance with the PMKSY-WDC 2.0 guidelines. ICAR-NBSS&LUP conducted the assessment for the Roha (WDC-2.0)2/2021-22 watershed located within the Roha Taluka of Raigad District, Maharashtra, underlain with the characteristic basaltic terrain of the Deccan Traps of the Deccan Plateau, with the Kundalika River traversing the area. Agriculture constitutes the dominant land use within this watershed, primarily dependent upon monsoon precipitation, augmented by groundwater resources and various soil conservation structures.

The primary objectives of the study were to systematically characterize soil and land resources at watershed level, assess land capability and crop-site suitability, support watershed-based land use planning, and evaluate groundwater potential to aid sustainable watershed development under PMKSY-WDC 2.0. The assessment was conducted using the standard methodologies prescribed by ICAR-NBSS&LUP, involving pre-field analysis, detailed soil survey, laboratory characterization of soil samples, and GIS-based spatial analysis. Base maps and landform maps were prepared using authenticated datasets. Soil characteristics were recorded through field observations and laboratory analysis and subsequently classified following established soil classification systems. The watershed exhibits variability in landforms, slope, soils, and land use, which governs runoff generation, soil erosion, moisture availability, and groundwater occurrence. Soils show variations in depth, texture, drainage, and fertility status, reflecting differences in terrain position and land management practices. Hydrological assessment and groundwater potential evaluation were carried out using integrated thematic analysis to support identification of suitable areas for soil and water conservation and groundwater recharge interventions. The outcomes of the Land Resource Inventory provide a scientific basis for watershed-level land use planning, identification of resource constraints, and prioritization of soil and water conservation measures. The technical inputs generated by ICAR-NBSS&LUP are intended to support implementing agencies in designing location-specific interventions and promoting sustainable management of land and water resources under PMKSY-WDC 2.0. In conclusion, the Land Resource Inventory and watershed assessment carried out by ICAR-NBSS&LUP for the Roha sub-watershed constitutes an provide a comprehensive technical framework for scientific watershed planning and sustainable resource management, in accordance with the objectives and guidelines of PMKSY-WDC 2.0.



## CHAPTER 1

### INTRODUCTION

A region, block, district, or village's Land Resource Inventory (LRI) has proven to be an essential component of planned agricultural development. This inventory provides critical baseline data for effective watershed management and sustainable land use planning, particularly through the application of advanced geospatial technologies. Encouraged by the success of LRI-based watershed programs in Karnataka, many states have started using soil/land data for rural development.

Administrators at the national and state level(s) have recognized the significance of LRI and documented in the PMKSY 2.0 document that at least 10% area of the watersheds be covered under LRI in the plateau and upland region of the country. In addition to LRI, the agro-ecological zone approach is deemed to be most effective for regeneration of *in-situ* resources for sustaining the biological growth and, in turn, soil health. Agro-ecological regions and subregions delineated by the ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP) therefore form the ideal base for selection and planning of watershed development, as our understanding of soil-crop and weather interactions is greatly enhanced under this approach.

The Government of Maharashtra directed the Bureau to conduct a Land Resource Inventory (LRI) in 14 watersheds located in different agro-ecological zones of the state. The objective is to measure improvements and ensure the long-term health of farming and related activities in rainfed areas, which will benefit the local farmers.

The process for selecting these watersheds was designed to fairly represent where existing projects were located across Maharashtra's distinct regions. As a result, four watersheds were selected for both the Vidarbha and Konkan regions, as they had a high number of ongoing projects. Western Maharashtra, Marathwada, and Northern Maharashtra were each assigned two watersheds, reflecting a lower concentration of implemented projects.

The project, planned for 48626 ha was implemented with the following objectives:

1. To characterize and map the soil and water resources of the watersheds.
2. To assess the soil-site suitability of the crops based on land evaluation at the watershed level.
3. To develop watershed-based alternate land use options and soil and water conservation plans.
4. To assess and characterize the groundwater potential of the watersheds.

This report presents the Land Resource Inventory (LRI) conducted in the Raigad-Roha (WDC-2.0/2/2021-22) sub-watershed of Raigad-Roha under the Pradhan Mantri Krishi Sinchayee Yojana - Watershed Development Component (PMKSY-WDC 2.0). The study involved detailed field visits, soil observations, mapping, and assessment of local hydrological conditions. The information collected was carefully analyzed to understand land capability, soil suitability, drainage patterns and groundwater potential. These

findings provide a practical foundation for planning watershed development and soil and water conservation measures suited to local conditions.

**List of micro watersheds (MWS) earmarked for LRI studies by the ICAR-NBSS&LUP**

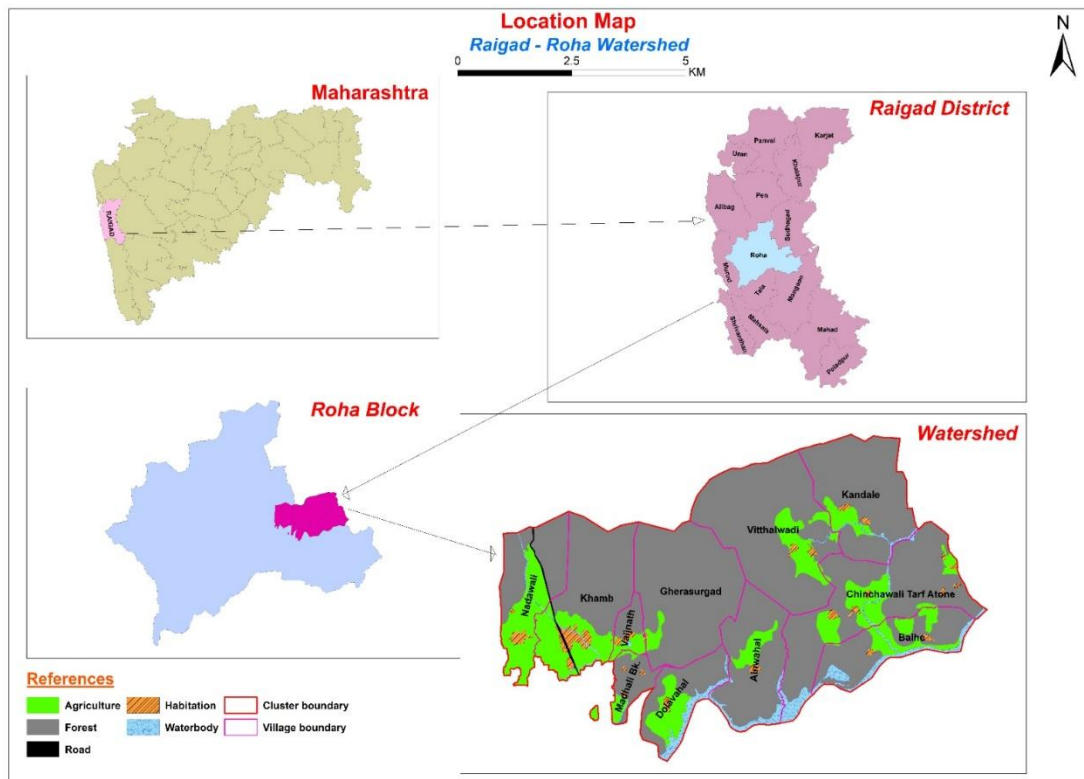
<b>District</b>	<b>Project name</b>	<b>Block</b>	<b>No. of MWS</b>	<b>No. of villages</b>	<b>Area (ha)</b>
Akola	Akola (WDC-2.0)1/2021-22	Barshitakli	11	8	4898.0
Buldhana	Buldhana (WDC-2.0)3/2021-22	Lonar	21	4	2498.5
Nandurbar	Nandurbar (WDC-2.0)4/2021-22	Nandurbar	5	14	3533.2
Nashik	Nashik (WDC-2.0)3/2021-22	Malegaon	7	7	2760.4
Osmanabad	Osmanabad (WDC-2.0)3/2021-22	Tuljapur	25	10	3380.0
Palghar	Palghar (WDC-2.0) 6/2021-22	Dahanu	7	23	3926.2
Parbhani	Parbhani (WDC-2.0)3/2021-22	Gangakhed	8	9	3791.0
Raigad	Raigad (WDC-2.0)/2/2021-22	Roha	3	11	3825.0
Ratnagiri	Ratnagiri (WDC-2.0)3/2021-22	Chiplun	13	9	2548.0
Sangli	Sangli (WDC-2.0)3/2021-22	Jath	23	5	3200.0
Sindhudurg	Sindhudurg (WDC-2.0)3/2021-22	Dodamarg	5	5	3604.4
Solapur	Solapur (WDC-2.0)2/2021-22	Mangalwedha	31	7	4198.1
Wardha	Wardha (WDC-2.0)3/2021-22	Seloo	12	7	2657.5
Washim	Washim (WDC-2.0)5/2021 -22	Malegaon	21	8	3806.1
<b>Total</b>			<b>192</b>		<b>48626.9</b>

## CHAPTER 2

### RAIGAD-ROHA WATERSHED AT A GLANCE

#### 2.1 Location and Extent

The watershed is situated in Roha Taluka which is one of the fourteen administrative subdivisions of Raigad district, located in the central-western part of Raigad District within the Konkan region of Maharashtra. The study area lies between 18°17'3.81" to 18°36'28.05" N latitude and 72°57'33.9" to 73°20'5.81" E longitude. Roha taluka is part of the Konkan revenue division and is predominantly rural, with a mix of forested hills and narrow river valleys. The Kundalika River, originating from the Sahyadri ranges, is the major river flowing through the taluka, serving as the primary water source for irrigation, domestic use, and industrial activities.



**Fig. 2.1: Location map of the Raigad-Roha watershed**

The watershed villages are largely rural, hilly, and mostly rainfed, with agriculture being the primary livelihood. The region is prone to high surface runoff during monsoons, leading to soil erosion, declining groundwater levels, and water scarcity during the post-monsoon months. This situation, which persists despite high annual rainfall, formed the rationale for selecting this area for watershed-based natural resource management interventions. Table 2.1 provides the general profile in respect of the watershed.

**Table 2.1: Geographical and administrative profile**

Sr. No.	Particulars	Details
1	District	Raigad
2	Taluka	Roha
3	Revenue Division	Raigad
4	Total sub-watershed Area	4430 ha (Approx)
5	Villages	11 (Nadawali, Khamb, Vajinath, Gherasurgad, Vitthalwadi, Kandale, Chinchawali, Balhe, Ainwahal, Dolavahal, and Madhali)
6	Major River	Kundalika River
7	Climate	Humid
8	Average annual Rainfall	1804 mm

## 2.2 Geology

Geologically, the watershed in Roha Taluka of Raigad District is primarily underlain by the Deccan Trap basalt formations of the Western Ghats. These basaltic lava flows, formed during the Late Cretaceous period, occur as horizontal or gently dipping layers and commonly display massive and amygdaloidal structures. Due to the region's humid tropical climate and intense monsoonal rainfall, the basalt has undergone extensive weathering, resulting in the development of lateritic caps and thick soil profiles in many areas. The terrain therefore consists of low hills, dissected plateaus, and narrow valleys typical of the Konkan landscape. These geological formations strongly influence soil characteristics, surface runoff behaviour, and groundwater occurrence, thereby playing a significant role in shaping land use patterns and agricultural practices within the watershed.

## 2.3 Geomorphology

The geomorphology of the Roha watershed in Raigad District has developed mainly over the Deccan Trap basalt formations of the Western Ghats. The terrain is characterized by low lateritic plateaus, dissected hills, steep slopes, and narrow valleys, reflecting the combined influence of tectonic uplift and intense fluvial erosion under humid tropical climatic conditions. In the valley bottoms and along river courses such as the Kundalika River, narrow alluvial plains have developed due to the deposition of transported sediments. Prolonged weathering of basalt under high rainfall conditions has also led to the formation of lateritic surfaces and deeply weathered profiles across upland areas. These geomorphic features strongly influence the drainage pattern, soil formation, groundwater occurrence, and land use distribution within the watershed, representing the typical denudational landscape of the Konkan region.

## 2.4 Physiography and Soil

The physiography of the study area in Roha Taluka, Raigad District, consists of a varied landscape shaped by the foothills of the Western Ghats and the Konkan coastal plains. The terrain includes dissected hills and ridges, lateritic plateaus, gentle slopes, narrow valleys,

and alluvial plains along the river courses, particularly the Kundalika River and its tributaries. These landforms create a landscape ranging from elevated uplands to low-lying valley floors. The slope across the watershed varies from nearly level surfaces in valley bottoms and floodplains to steep gradients on hill slopes and plateau edges, reflecting the natural relief typical of the Konkan region. The soils of the area are predominantly lateritic and red loamy soils derived from weathered basalt, along with patches of alluvial soils in valley bottoms and along riverbanks. In upland areas, soils are generally shallow to moderately deep, well-drained, and slightly gravelly, whereas deeper and more fertile soils occur in the valley plains.

## **2.5 Climate**

The watershed in Roha Taluka experiences a humid tropical monsoon climate, which is characteristic of the coastal Konkan region of Raigad District. The area receives heavy rainfall during the southwest monsoon due to its location on the windward side of the Western Ghats, resulting in warm and humid conditions for most of the year. The climate is strongly influenced by the southwest monsoon, which brings the majority of rainfall between June and September. The average annual rainfall in the region ranges from about 1800 mm, reflecting the high rainfall regime typical of the Konkan belt. Most of this precipitation occurs during the monsoon months, while the post-monsoon and winter seasons remain comparatively dry. Temperature variation is moderate due to the influence of the nearby Arabian Sea; May is generally the hottest month, while January is the coolest. Relative humidity remains high throughout the year, with peak humidity during the monsoon season.

## **2.6 Drainage**

The drainage system of the watershed in Roha Taluka is primarily controlled by the Kundalika River, which forms the principal channel draining the surrounding hills, plateaus, and valleys of the region. The river and its tributaries collect runoff from the dissected lateritic uplands and forested hill slopes of the Western Ghats. Numerous seasonal streams and natural nalas contribute to the drainage network, flowing actively during the southwest monsoon when rainfall is intense. These tributaries transport surface runoff from upland areas into the main river channel, forming a dendritic drainage pattern typical of basaltic and lateritic terrains. Steeper hill slopes generate rapid surface runoff, while valley floors and low-lying plains act as natural zones for water accumulation and sediment deposition. Overall, the drainage network plays a crucial role in conveying monsoonal runoff, influencing groundwater recharge, and shaping land use and agricultural activities within the watershed.

## **2.7 Cropping Patterns, and Demography and Socioeconomics**

### **2.7.1 Cropping Pattern**

The agricultural landscape of Roha is overwhelmingly dominated by rice cultivation, solidifying its status within Maharashtra's 'rice bowl'. The availability of perennial

canal irrigation facilitates double-cropping, allowing for paddy cultivation in both the Kharif and Summer seasons. Kharif paddy occupies approximately 46.64% of the cropped area, while summer paddy accounts for 42.91%, resulting in a substantial cropping intensity of 186.11%. Beyond rice, 'Dali' lands are utilized for coarse grains like nagli and vari, while Rabi pulses and horticultural crops including Mango, Cashew, and Coconut form an integral part of the regional cropping system.

### **2.7.2 Demographic and Socioeconomic Status**

According to the 2011 Census, Roha taluka encompasses a geographical area of 656.98 square kilometers with a total population of 167,110, reflecting a high population density of approximately 254.36 persons per square kilometer. The demographic structure is predominantly rural, with 119,775 residents living across 167 villages, while the urban population centered in towns such as the Roha Ashtami municipal council stands at 47,335. The subdivision comprises a total of 39,012 households, with an average household size of 4.28 persons influencing the socioeconomic fabric of the community.

## **2.8 Water Resources**

### **2.8.1 Surface Water**

The Kundalika River is the principal river in this region. Though it carries a substantial volume of water during the monsoon, most of this runoff is not stored or utilized due to limited harvesting infrastructure. Seasonal nalas and micro-streams drain rapidly into the main river without adequate intervention for slowing or storing the flow. There is major canal network but covered limited cluster area, and surface water use is limited to a few small percolation tanks, check dams, and farm ponds many of which are silted or non-functional

### **2.8.2 Groundwater**

Groundwater occurs mostly in weathered and fractured zones of basalt rock. According to the Dynamic Ground Water Resources of Raigad District (CGWB), 2024, annual extractable ground water resources place the region under the “safe” category, with the groundwater extraction level under is 10.2%

### **2.8.3 Irrigation and Water Management**

While much of Raigad district faces significant irrigation constraints due to impervious rock layers and brackish coastal groundwater, Roha is a notable exception with robust water infrastructure. The taluka reports the highest total irrigated area in the district at 2,838 hectares, ensuring that 11.56% of the cropped area receives stable irrigation. The presence of major reservoirs and canal networks, supported by rivers like the Kundalika, enables cultivation beyond the monsoon season; however, water

management faces modern challenges as industrial consumption and pollution from surrounding chemical units create ecological pressures for the farming community.

## **2.9 Constraints**

The following key issues were observed in the cluster villages, both through field surveys (2024-2025) and community consultations:

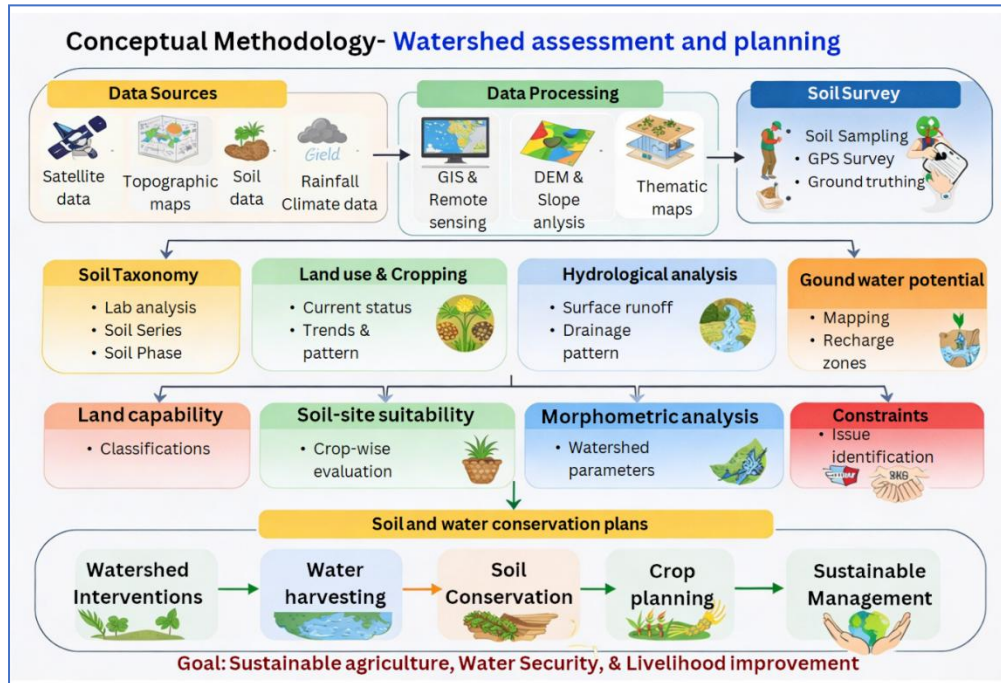
1. **High Runoff Losses:** Despite receiving over 4294 mm of rainfall annually, some of it is lost as surface runoff due to lack of water-harvesting structures and steep terrain.
2. **Soil Erosion:** In upper catchments, there is significant loss of topsoil due to unchecked water flow. This has reduced soil fertility and increased siltation in downstream structures.
3. **Declining Water Availability:** Dug wells and handpumps show rapidly declining yield post-monsoon.
4. **Low Irrigation Coverage:** Irrigation is limited to 1–2% of total cultivated area, mostly in valley zones. Upland farming is purely rainfed
5. **Abandoned Farmlands:** Due to unreliable water, labor shortages, and low returns, several farmers have left their lands fallow.
6. **Weak Asset Maintenance:** Existing check dams, and old bunds built under earlier schemes (like IWMP or Jalyukt Shivar) are in poor repair, lacking community ownership or technical upkeep.

## CHAPTER 3

### METHODOLOGY

#### 3.1 Overview of Activities

The following figure depicts the overall flow of activities adopted for the project:



The various activities involved in the generation of land resource data and maps can be broadly grouped under pre-field, soil survey, post-field and post-LRI activities, as listed below:

#### A. Pre-field

- Procurement of high-resolution satellite imageries, cadastral maps, geology/physical maps
- Image interpretation for physiography/landforms/land use
- Finalization of physiography/landform map with legend as base maps.

#### B. Soil Survey

- Selection of transects (cutting across as many physiographic units as possible)
- Digging of soil profile pits up to 1.5 m depth or hard rock, whichever is earlier
- Examination and description of soil profiles in transects
- Study and record of soil-site characteristics
- Collection of soil samples from the pedons of each soil series
- Field review (preliminary, progressive and final) for soil correlation
- Grouping of soil profiles studied at each transect into soil series
- Development of progressive soil legend
- Mapping of soil phases (management units)

- Mapping of current land use/land cover, existing soil and water conservation structures etc.

### ***C. Post-field phase***

- Processing of soil samples, and laboratory analysis for physical, physico-chemical properties
- Compilation and interpretation of data
- Generation of thematic maps (slope, erosion, soil depth, drainage, pH, SOC, N, P, K and micronutrients, etc.)
- Land evaluation for various suitability classes for different crops and irrigation
- Preparation of soil and water conservation maps
- Developing soil mapping unit wise alternate land use options
- LRI Report write-up

### **3.2 Preparation of Base Maps**

Spatial data preparation began by georeferencing Survey of India (SOI) toposheets at a 1:50,000 scale, utilizing the WGS 84 datum and UTM projection supported by field - verified Ground Control Points (GCPs). Landform delineation was executed within a GIS environment, integrating 30 m resolution SRTM Digital Elevation Models (DEM) with systematic on-screen visual interpretation. This geomorphic analysis relied on fundamental image elements - including shape, tone, colour, pattern, shadow and texture - to identify land features. To enhance interpretation, False Colour Composites (FCC) were generated through various satellite band combinations. Final mapping of land use/land cover (LULC) and landform units was conducted using ArcGIS software.

### **3.3 Ground-truth Verification**

The area was traversed to identify different landform units, slope and present land use/land-cover (LULC) classes, and correlated with image interpretation units. The boundaries that were originally derived during the base map preparation were verified and corrected wherever necessary. To understand the soil variability in the study area, representative sites on each landform unit were selected, located using handheld Global Positioning System (GPS) and 30 profiles observations were taken and studied for morphological properties in the field following the guidelines for field soil descriptions (Soil Survey Division Staff 2000) and were recorded in the standard format.

### **3.4 Soil Sampling and Analysis**

Soil samples from each horizon of all of the representative soil series were collected for laboratory studies. The soil samples collected during the fieldwork were initially air dried in the laboratory at room temperature, ground using a wooden pestle and mortar, screened through a 2 mm sieve, properly labelled, and stored in polythene bags for laboratory analysis. The soil samples were analysed in the laboratory for physical and chemical parameters using standard procedures. The particle size analysis was done by international pipette method. A combined glass-calomel electrode was used to determine the pH measured (1:2.5 soil/solution ratio). Soil organic carbon (SOC) was determined using the wet digestion method of Walkley and Black (1934). Available nitrogen (N) was measured

by the alkaline permanganate method as described by Subbiah and Asija (1956). Available phosphorus (P) was determined by the Bray II method (Bray and Kurtz 1945). Cation exchange capacity (CEC) of soil was measured as per the procedure outlined by Jackson (1976). Exchangeable cations [calcium (Ca), potassium (K), and magnesium (Mg)] were extracted with 1 M ammonium acetate (NH<sub>4</sub>Oac) (pH 7.0). Potassium content was determined by flame photometry (Rich 1965), while Ca and Mg were determined in ethylene diamine tetra acetic acid (EDTA) titration. Exchangeable Al was extracted with 1 N potassium chloride (KCl) solution and titrated with 0.1 N sodium hydroxide (NaOH) solution. Available micronutrient content [copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn)] were determined by diethylene triamine penta-acetic acid (DTPA) extraction (Lindsay and Norvell 1978), followed by atomic absorption spectrophotometry. Soils were classified according to Keys to Soil Taxonomy (Soil Survey Staff 2010).

### **3.5 Development of Soil Mapping Legend**

In the present study, soil series phases were used as the basic mapping units. A soil series refers to a group of soils or polypedons that exhibit similar horizon sequences and share closely related properties within a narrow range of variation (Soil Survey Division Staff, 2000). The phases considered in this study included soil depth, surface texture, slope, erosion status and flooding conditions. Soil profiles were examined and correlated within each major landform and soil series were identified accordingly. The identified soil series information was then extended to the sub-units of major landforms based on diagnostic soil characteristics observed from soil profile descriptions and auger observations. A detailed soil map depicting soil series and their respective phases was prepared at a scale of 1:10,000. The soil legend code developed for the map represents the soil series name followed by surface texture, slope class, erosion status and soil depth, as described by Singh et al. (2016).

### **3.6 Surface Runoff Estimation**

Direct surface runoff occurring in the Raigad-Roha watershed was estimated using the Soil Conservation Service Curve Number (SCS-CN) method, employing daily rainfall data from 2014 to 2024. The SCS-CN method is widely used for estimating surface runoff as it establishes a functional relationship between rainfall, land use, soil conditions, and the physical characteristics of the landscape. The method is based on the Curve Number (CN), a dimensionless parameter that reflects the runoff potential of an area depending on land use, soil type, and hydrologic condition. The CN plays a decisive role in determining the proportion of rainfall that contributes to direct runoff. The watershed area was delineated into individual spatial polygons representing homogeneous units of land use, soil, and slope characteristics to capture spatial variability across the landscape. For each polygon, the appropriate Hydrologic Soil Group (HSG) was assigned based on soil infiltration capacity and other physical characteristics. The Curve Number (CN) for each polygon was determined according to its corresponding land use and soil group combination. This polygon-based approach enabled a more spatially refined estimation of runoff, as runoff potential varies across different parts of the watershed.

The Antecedent Moisture Condition (AMC), a measure of soil moisture based on the previous rainfall events, was computed daily. The AMC plays an important role in adjusting the CN because soils that are already saturated are more likely to produce runoff than those that are dry. The AMC was computed using the rainfall data from the previous five days, and based on the resulting moisture condition, the CN for the day was adjusted accordingly. This adjustment helps account for variations in runoff potential that result from antecedent moisture conditions. After calculating the CN for each unit, the weighted average CN for the entire study area was computed, considering the area of each polygon. The initial abstraction (S), which represents the portion of rainfall that does not contribute to runoff (e.g., water that is stored in depressions, infiltrates into the soil, or evaporates), was also estimated using CN values. The runoff for each month and year was then calculated, with data from 2014 to 2024 providing insights into seasonal and yearly runoff patterns within the watershed.

### **3.7 Groundwater potential zone mapping**

The groundwater potential of the watershed was determined using a comprehensive approach that integrates eight thematic layers to provide valuable insights for the sustainable management of this critical resource. Each of the thematic layer represents a factor influencing groundwater availability, and include soil, slope, drainage density, elevation, land use/land cover (LULC), rainfall, geomorphological landform units, and lithology. A multi-criteria decision-making (MCDM) approach was adopted to integrate these layers for assessing the groundwater potential across the region. Each thematic layer contributes uniquely to the understanding of groundwater potential. For instance, the type and permeability of soil play a vital role in groundwater recharge and storage capacity. The slope of the land influences the infiltration rate and surface runoff, with steeper slopes typically having lower groundwater recharge potential. Drainage density, which refers to the network of streams or rivers in the area, affects groundwater recharge by facilitating water flow into the ground. Elevation is another important factor, as it dictates the direction of water flow, with lower areas often being more favorable for groundwater accumulation. The land use/land cover type also has a direct impact, with urban areas typically having lower groundwater potential due to impervious surfaces, while agricultural and forested areas are generally more conducive to recharge. Rainfall is a key driver of groundwater replenishment, as it is the primary source of recharge, with the quantity, distribution, and seasonality of rainfall significantly influencing groundwater availability. The geomorphological landforms also play an essential role in shaping groundwater potential, as different landforms, such as valleys and plateaus, influence the movement and storage of groundwater. Lastly, lithology, or the geological composition of the region, determines the porosity and permeability of rocks, which in turn affects groundwater storage and movement.

The relative importance of each of these factors was assessed by employing the Analytical Hierarchy Process (AHP), a decision-making tool that allows the integration of expert opinions and subjective judgment in a structured manner. AHP assigns weights to each thematic layer based on its significance in influencing groundwater potential. Expert

opinions, along with a thorough review of existing literature, guide the determination of these weights, ensuring that all relevant factors are carefully considered. The weight assigned to each layer reflects its relative contribution to groundwater availability in the watershed. This step is crucial for ensuring that the final groundwater potential map accurately reflects the different factors that affect groundwater in the region. Once the weights are assigned, the study applies the Weighted Sum Method (WSM) to integrate the normalized thematic layers into a composite groundwater potential index. The normalization process ensures that each thematic layer contributes appropriately to the overall assessment, regardless of its numerical scale. The WSM method allows for a systematic integration of the layers, combining them in a way that reflects their relative importance and generating a comprehensive map of groundwater potential zones in the Raigad-Roha watershed. This composite groundwater potential index is then used to classify the region into five distinct categories: very poor, poor, moderate, good, and very good potential. These categories represent the varying levels of groundwater availability across the region, helping to identify areas where groundwater resources are abundant, as well as those where availability is limited.

### **3.8 Land Evaluation**

The evaluation of soil-site suitability was carried out to understand how well the land resources of the watershed can support sustainable crop production under existing environmental conditions. The approach combines information on soil properties, terrain features, and climate to assess the capability of different land units to meet the growth requirements of various crops, thereby supporting scientific land-use planning. The assessment was conducted using the maximum likelihood method based on the guidelines proposed by Sys et al. (1993) and Naidu et al. (2006). Detailed field surveys, laboratory analysis of soil samples, and interpretation of spatial datasets were used to generate a comprehensive soil and site database. Since the watershed area is relatively small, temperature and rainfall were considered uniform across the entire area and treated as constant climatic inputs for the suitability evaluation.

Soil wetness conditions, including drainage status and the possibility of flooding, were examined to understand soil aeration and moisture availability. Physical soil characteristics such as surface texture and effective soil depth were assessed to evaluate their influence on root growth, water retention, and nutrient uptake. Soil fertility indicators, including pH, soil organic carbon, apparent cation exchange capacity, base saturation, and exchangeable cations, were analyzed to determine the nutrient-supplying capacity of soils. In addition, terrain features such as slope and erosion risk were considered to understand their impact on runoff, soil loss, and field operations. Each soil and site factor was rated according to its degree of limitation to crop growth, and the combined effect of these limitations was used to determine overall land suitability. Based on this integrated analysis, soils were grouped into five suitability classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). This classification helps in identifying suitable crops, planning appropriate management practices, and promoting sustainable agricultural development within the watershed.

### **3.10 Identification of Soil and Water Conservation Measures**

The identification and spatial allocation of soil and water conservation (SWC) measures within the village cluster watershed of Raigad-Roha Taluka were carried out through an integrated geospatial and land resource assessment approach. A comprehensive spatial database was prepared using high-resolution satellite imagery, digital elevation models (DEM), soil resource maps, land use/land cover data, and drainage network information. From the DEM, slope classes, flow accumulation, and drainage patterns were derived to understand runoff movement and erosion-prone areas within the watershed. Soil resource information, including soil depth, texture, and drainage characteristics, was integrated with land use data to assess land capability and constraints affecting agricultural productivity.

Based on these datasets, land capability assessment and terrain analysis were performed to delineate management units within the watershed. Each unit was evaluated for its suitability for specific conservation interventions by considering parameters such as soil depth, slope gradient, existing land use, runoff potential, and proximity to drainage lines. Decision rules commonly used in watershed planning were applied to assign appropriate measures. For example, field bunding and strengthening of existing bunds were recommended in cultivated lands with gentle slopes to reduce runoff and enhance in situ moisture conservation, while conservation bench terraces were proposed in unbundled agricultural areas with moderate slopes where soil depth permitted terracing. The Broad Bed and Furrow (BBF) system was identified for agricultural fields, particularly in medium to deep soils, to improve surface drainage and soil moisture distribution under rainfed conditions.

Water harvesting interventions were identified based on runoff contributing areas, drainage density, and storage potential. Farm ponds were proposed in agricultural fields with suitable catchment areas, while lined farm ponds were recommended in locations with higher seepage potential. Structural measures such as cement nala bunds (CNB) and earthen nala bunds (ENB) were proposed along drainage lines after evaluating channel characteristics, contributing catchment area, and groundwater recharge potential. Renovation and desilting of existing water bodies and farm ponds were suggested based on field observations and spatial identification of existing structures.

Vegetative interventions were planned in areas characterized by scrubland, degraded lands, or drainage margins, where afforestation and stream bank plantations could help stabilize soil and reduce erosion. Horticultural plantations supported with in situ moisture conservation practices were proposed in suitable land parcels to enhance land productivity. Additional measures such as rooftop rainwater harvesting in built-up areas and road-side drainage protection works were identified to capture and safely manage runoff from non-agricultural surfaces. Through the integration of terrain analysis, soil resource information, land use assessment, and hydrological considerations, site-specific conservation measures were systematically identified and spatially allocated within the watershed. This approach ensured that the proposed interventions are technically suitable, hydrologically effective, and aligned with the existing land resource conditions of the watershed.

## CHAPTER 4

### RESULTS AND INTERPRETATIONS

#### 4.1 Irrigation, Cropping Patterns, and Demography and Socioeconomics

A field survey was conducted to document the availability of water resources, cropping patterns, and the demographic and socio-economic characteristics of farmers in the watershed. The results obtained from this survey are presented in the following sub-sections.

##### 4.1.1 Irrigation and Water Management

The irrigation pattern of the Roha watershed is presented in Table 4.1. Canal irrigation contributes 93.1% of the total irrigated area in the cluster, indicating the importance of canals as the primary source of irrigation. Well irrigation contributes about 6.9% of the total irrigation, indicating its supportive role in providing irrigation water during the Kharif and Rabi seasons. The irrigation system of the cluster is primarily canal-based with minor groundwater support.

**Table 4.1 Seasonal distribution of irrigation sources in the Raigard-Roha watershed**

Sr. No.	Number of Farmers Interviewed (n)	Irrigation Source	Seasonal Water Availability	Contribution to Season's Total Irrigation (%)
1	70	Canal	Kharif, Rabi & Summer	93.1
2	139	Rainfed	Kharif	0.0
3	4	Well	Kharif & Rabi	6.9

##### 4.1.2 Cropping Pattern

The cropping pattern of the Roha cluster is presented in Table 4.2. The gross cropped area of the cluster is 171.88 ha, while the net sown area is 105.16 ha. The cropping intensity of the area is calculated as 163.5%, indicating that a part of the area of agricultural land is cultivated more than once during the year.

$$\text{Cropping intensity}(\%) = \frac{\text{Gross cropped area}}{\text{Net sown area}} \times 100$$

$$\text{Cropping intensity}(\%) = \frac{171.88}{105.16} \times 100 = 163.5\%$$

In the Kharif season, rice is the dominant crop, occupying 57.6% of the total cropped area with a productivity of 1403.27 kg/ha. Finger millet covered 5.0% of the cropped area with a productivity of 731.91 kg/ha. In the Rabi season, Rice covered 17.7% of the cropped area with a productivity of 1983.55 kg/ha, indicating higher productivity compared to the Kharif

season. Green gram occupies 5.7% of the total cropped area with a productivity of 130.02 kg/ha. Mango is cultivated as a perennial horticultural crop, occupying 4.3% of the cropped area with a productivity of 462.5 kg/ha. The cropping pattern of the cluster is characterized by rice cultivation in Kharif and Rabi seasons. The relatively high cropping intensity reflects the practice of multiple cropping under rainfed conditions, contributing to better utilization of available agricultural land.

**Table 4.2 Crop-wise Distribution in the Roha, watershed**

Sr. No.	Season	Crop	No. of Farmers Interviewed (n)	Irrigation Type	Total Cropped Area (%)	Productivity (kg/ha)
1	Kharif	Rice	69	Rainfed	57.6	1403.27
2	Rabi	Rice	57	Rainfed	17.7	1983.55
3	Rabi	Green Gram	36	Rainfed	5.7	130.02
4	Kharif	Finger Millet	15	Rainfed	5.0	731.91
5	Perennial	Mango	14	Rainfed	4.3	462.5

### 4.1.3 Socioeconomic Status

#### 4.1.3.1 Land holding pattern

The landholding pattern of farmers in the Roha cluster is presented in the Table 4.3. From the table, it was observed that marginal farmers (<1 ha) has the highest population with 88.14% of the total farmers having an average landholding of 0.44 ha. This indicates that most of the farmers in the study area have small landholdings. It is followed by small farmers (1–2 ha) constitute 10.31% of the farmers with an average landholding of 1.18 ha. Semi-medium farmers (2–4 ha) have only 1.55% of the total farmers with an average landholding of 2.17 ha. No farmers were recorded under the medium (4-10 ha) and large farmer (>10 ha). Average landholding size in the study area was found to be 0.54 ha, indicating that agriculture in the region is characterized by very small and fragmented landholdings.

**Table 4.3 Land holding pattern in Roha watershed**

Category	Criteria Land (ha)	No. of Farmers Interviewed (n)	Farmers (%)	Average Land Holding (ha)
Marginal Farmers	<1	171	88.14%	0.44
Small Farmers	1-2	20	10.31%	1.18
Semi-Medium Farmers	2-4	3	1.55%	2.17
Medium Farmers	4-10	0	0.0%	0
Large Farmers	>10	0	0.0%	0
<b>Average land holding</b>				0.54

#### 4.1.3.2 Income distribution

The data with respect to crop-wise income is presented in Table 4.4. Rice covers 73.53% of the total cropped area, with an average income of 21,000 Rs. Green gram occupied 6.2% of the cropped area, with an average income of 41,000 Rs. Nachani (Finger Millet) covers 5.02% of the cropped area and plays an important role in supporting household food security. Mango occupied 4.19% of the cropped area, with an average income of 58,000 Rs. The results show that rice dominates the cropping pattern, while green gram and mango provide comparatively higher economic returns.

**Table 4.4 Average annual income of farmers in Raigad-Roha watershed**

Name of Crops	No. of Farmers Interviewed (n)	Crop Area (%)	Average Income (Rs.)
Rice	70	73.53%	21000
Green gram	37	6.2%	41000
Nachani (Finger Millet)	16	5.02%	-
Mango	14	4.19%	58000

#### 4.1.3.3 Education

The educational profile of the population in the villages of the watershed is presented in Table 4.5. Vitthalwadi recorded the highest illiteracy rate (60%), followed by Kandale (38%), Chinchawali (36%), and Nadawali (33%), indicating lower educational attainment in these villages. Moderate levels of illiteracy were observed in Madhali Bk. (29%) and Vajjnath (24%), while lower illiteracy was recorded in Khamb (14%), Ainwahal and Gherasurgad (10% each). With respect to primary education, the highest population was recorded in Kandale (56%), followed by Chinchawali (45%), Vajjnath (41%), Ainwahal and Gherasurgad (40%), and Khamb (39%), while Madhali Bk. recorded the lowest population (7%). With respect to secondary education level, Dolwhal recorded the highest population (78%), followed by Ainwahal and Gherasurgad (50% each), Madhali Bk. (50%), Khamb (42%) and Nadawali (33%). Villages such as Vajjnath (29%), Chinchawali (18%) and Vitthalwadi (10%) recorded comparatively lower population. The results indicate that primary and secondary education dominate across the villages, while higher levels of education are limited. Some villages still show considerable levels of illiteracy, which may influence awareness levels, adoption of improved agricultural practices, and participation in extension and developmental programs in the watershed area.

**Table 4.5 Education profile of villages in Raigad-Roha watershed by population**

Village	No Education (%)	Primary (%)	Secondary (%)	Higher Secondary (%)	Higher Studies (%)
Ainwahal	10	40	50	0	0
Chinchawali	36	45	18	0	0
Dolwhal	0	22	78	0	0
Gherasurgad	10	40	50	0	0
Kandale	38	56	6	0	0

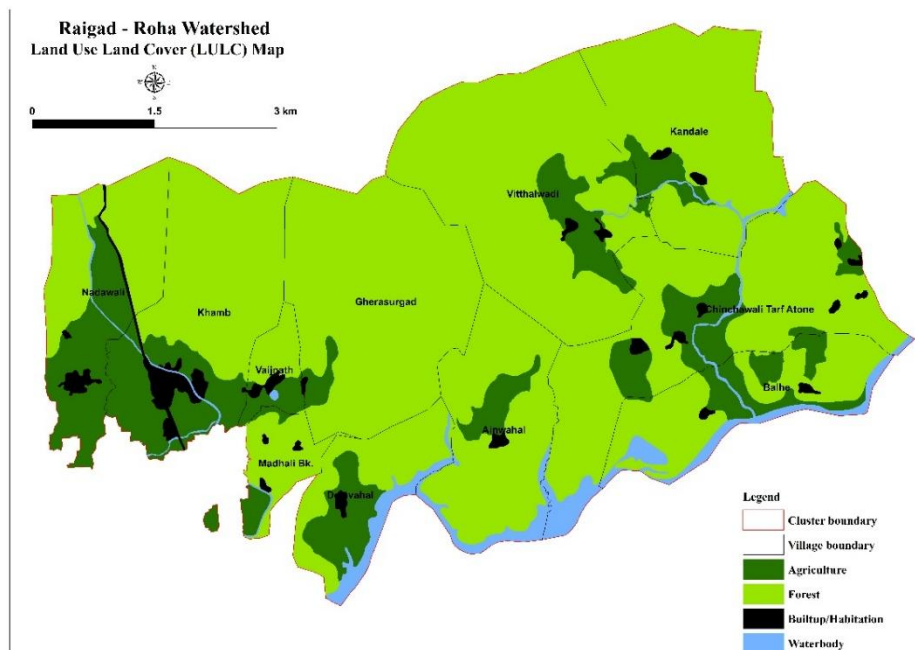
Khamb	14	39	42	0	6
Madhali Bk.	29	7	50	0	14
Nadawali	33	29	33	0	4
Vaijnath	24	41	29	0	6
Vitthalwadi	60	30	10	0	0

#### 4.2 Land-use/Land-cover

The classification of the area reveals that agriculture occupying 759.3 ha, and constitutes 17.1% of the total area (Table 4.6 and Fig. 4.1). Forestland covering 3398.8 ha (76.7%) of the area, which may indicate areas unsuitable for cultivation. Waterbodies are limited to 176.8 ha, making up 4% of the total area, reflecting the presence of limited surface water resources in the region. This LULC distribution highlights the primarily of agricultural and forest activities in the area with secondary coverage by Habitation and Waterbody categories.

**Table 4.6 Land-use/land-cover statistics of Raigad-Roha watershed**

Sr No.	Land use	Area(ha)	Percent (%)
1	Forest	3398.8	76.7
2	Agriculture	759.3	17.1
3	Waterbody	176.8	4.0
4	Habitation	81.9	1.8
5	Road	12.2	0.3
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



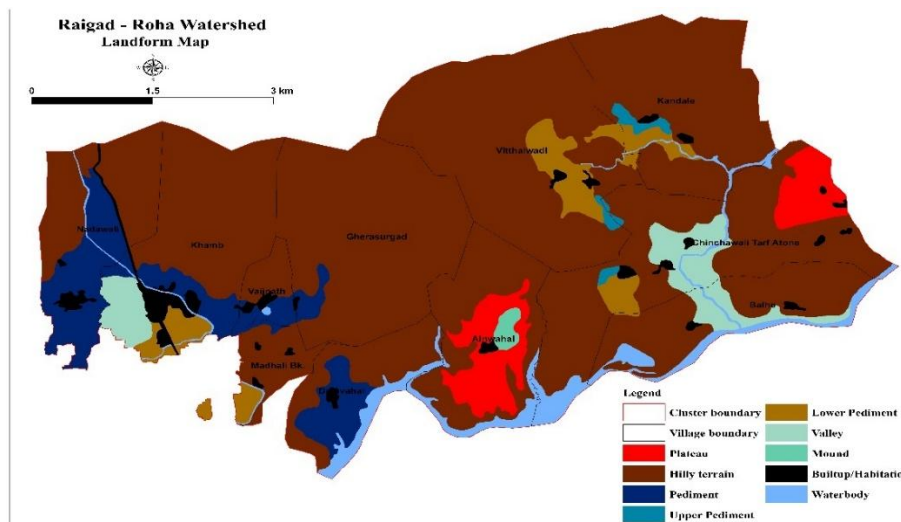
**Fig. 4.1: Land-use/land-cover map**

### 4.3 Landform Delineation

The landform characteristics of the watershed show a heterogeneous geomorphological pattern with different terrain features. Hilly terrain is the most dominant landform (Table 4.2), covering 3273.8 ha, which constitutes 73.9% of the total watershed area. This indicates that the region mainly consists of rugged and elevated landscapes. Pediment areas extend over 314.0 ha (7.1%), representing gently sloping surfaces formed at the base of hills. The plateau landform covers 188.0 ha (4.2%), while water bodies and lower pediments each account for 4.0% of the watershed area. Valley regions occupy 164.1 ha (3.7%), reflecting zones influenced by drainage processes. Built-up or habitation areas represent 2.1% of the total area. Minor landforms such as upper pediment (0.5%) and mound features (0.4%) occur in small patches. Overall, the watershed is largely dominated by hilly terrain with scattered pediments, valleys, and plateau areas, as shown in Fig. 4.2.

**Table 4.7: Landform features existing in Raigad-Roha watershed**

Sr. No.	Landform	Area	Percent
1	Plateau	188.0	4.2
2	Hilly terrain	3273.8	73.9
3	Pediment	314.0	7.1
4	Upper Pediment	24.1	0.5
5	Lower Pediment	178.5	4.0
6	Valley	164.1	3.7
7	Mound	15.5	0.4
8	Built-up/Habitation	94.1	2.1
9	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



**Fig. 4.2: Landform map of Raigad-Roha watershed**

#### 4.4 Soil series and phases

Nineteen soil series have been identified and mapped with 27 soil mapping units (phases of series) (Fig 4.4). The taxonomic classification and mapping legend of the soil series along with its landform and TMU were shown in Table 4.4. The detailed descriptions of each series are given in Table 4.5.

**Table 4.8. Dominant soil series identified in the watershed**

Sr. No.	Series	Area (ha)	Percent (%)
1	Ainwahal 1	11.9	0.3
2	Ainwahal 2	78.7	1.8
3	Ainwahal 3	17.2	0.4
4	Chinchalwadi	340.2	7.7
5	Dolwahal 1	117.8	2.7
6	Dolwahal 2	15.2	0.3
7	Dolwahal 3	70.0	1.6
8	Gharbat	4.3	0.1
9	Gherasurgurd 1	15.6	0.4
10	Gherasurgurd 2	95.1	2.1
11	Khamb	16.9	0.4
12	Nadwali 1	44.4	1.0
13	Nadwali 2	51.6	1.2
14	Nadwali 3	131.3	3.0
15	Vaijnath 1	4.7	0.1
16	Vaijnath 2	32.5	0.7
17	Vitthalwadai 1	40.8	0.9
18	Wadachiwadi	73.2	1.7
19	Forest	2996.8	67.7
20	Builtup/Habitation	94.1	2.1
21	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>

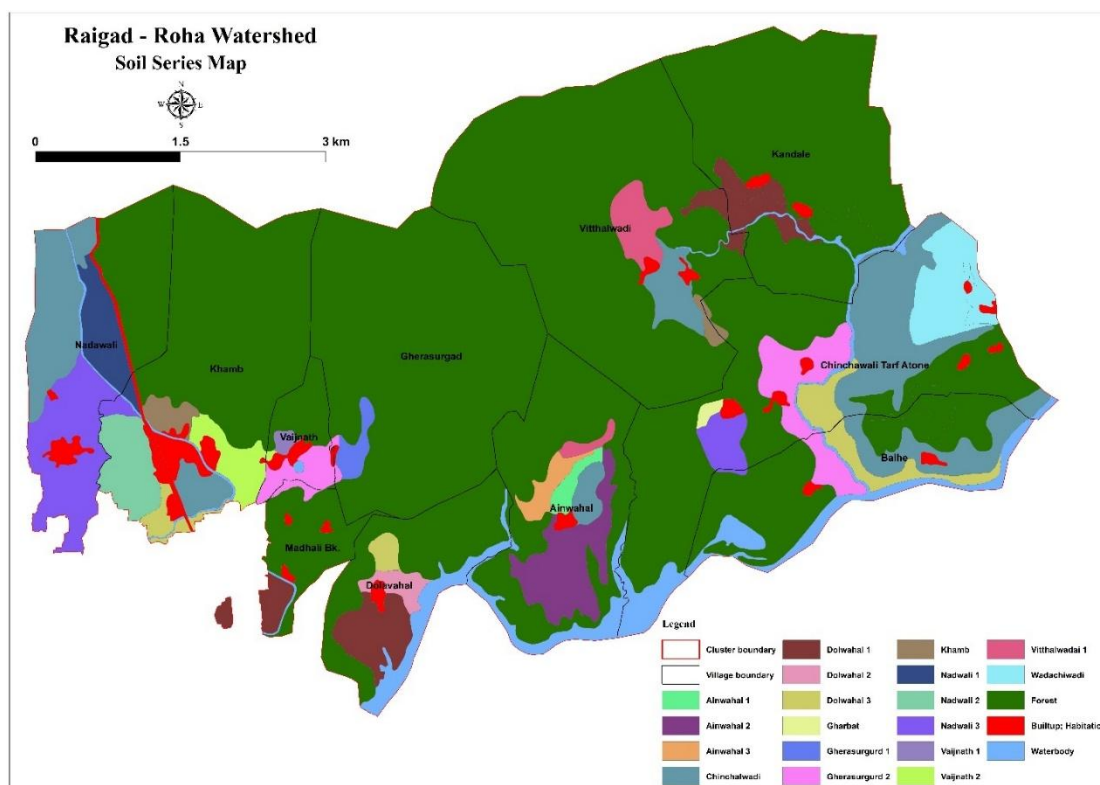
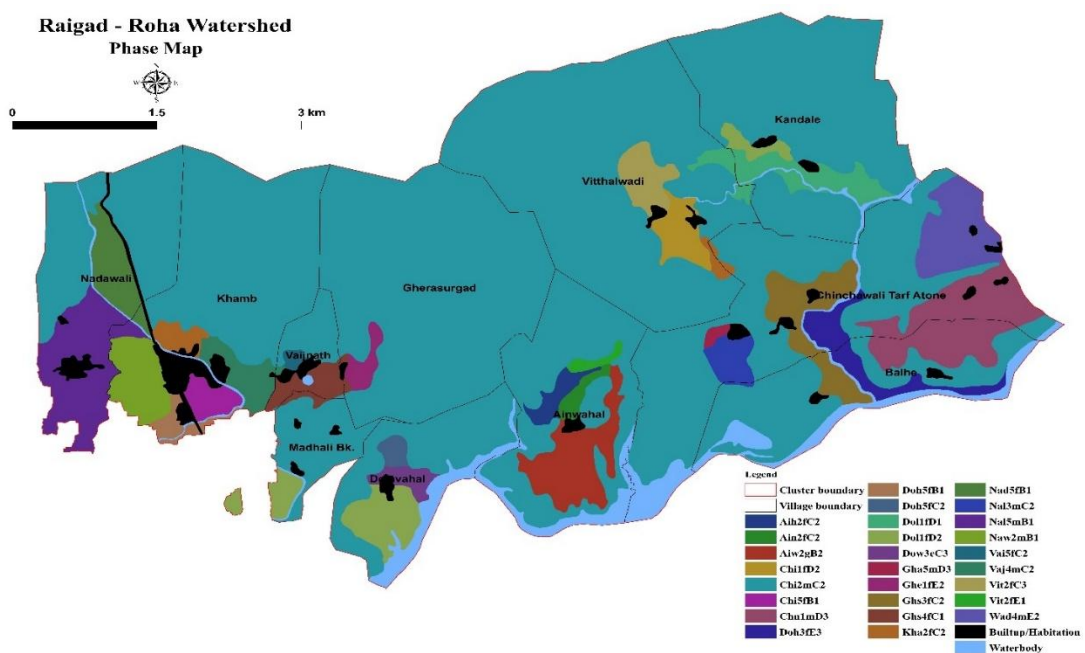


Fig. 4.3: Soil series map of Raigad - Roha watershed.

Table 4.9. Soil phases existing identified in Raigad - Roha watershed

Sr. No.	Phase	Area(ha)	Percent (%)
1	Aih2fC2	17.2	0.4
2	Ain2fC2	11.9	0.3
3	Aiw2gB2	78.7	1.8
4	Chi1fD2	31.7	0.7
5	Chi2mC2	3134.1	70.8
6	Chi5fB1	20.7	0.5
7	Chn1mD3	128.7	2.9
8	Doh3fE3	45.4	1.0
9	Doh5fB1	14.7	0.3
10	Doh5fC2	9.9	0.2
11	Dol1fD1	56.7	1.3
12	Dol1fD2	77.5	1.8
13	Dow3eC3	15.2	0.3
14	Gha5mD3	4.3	0.1
15	Ghe1fE2	15.6	0.4
16	Ghs3fC2	67.1	1.5
17	Ghs4fC1	28.1	0.6
18	Kha2fC2	22.4	0.5
19	Nad5fB1	44.4	1.0

20	Nal3mC2	24.4	0.6
21	Nal5mB1	106.9	2.4
22	Naw2mB1	51.6	1.2
23	Vai5fC2	4.7	0.1
24	Vaj4mC2	32.5	0.7
25	Vit2fC3	33.6	0.8
26	Vit2fE1	7.2	0.2
27	Wad4mE2	73.2	1.7
28	Built-up/Habitation	94.1	2.1
29	Waterbody	176.8	4.0
		<b>4429.0</b>	<b>100.0</b>



**Fig. 4.4: Soil Phase map of Raigad - Roha watershed**

## 4.5 Soil Survey Interpretation

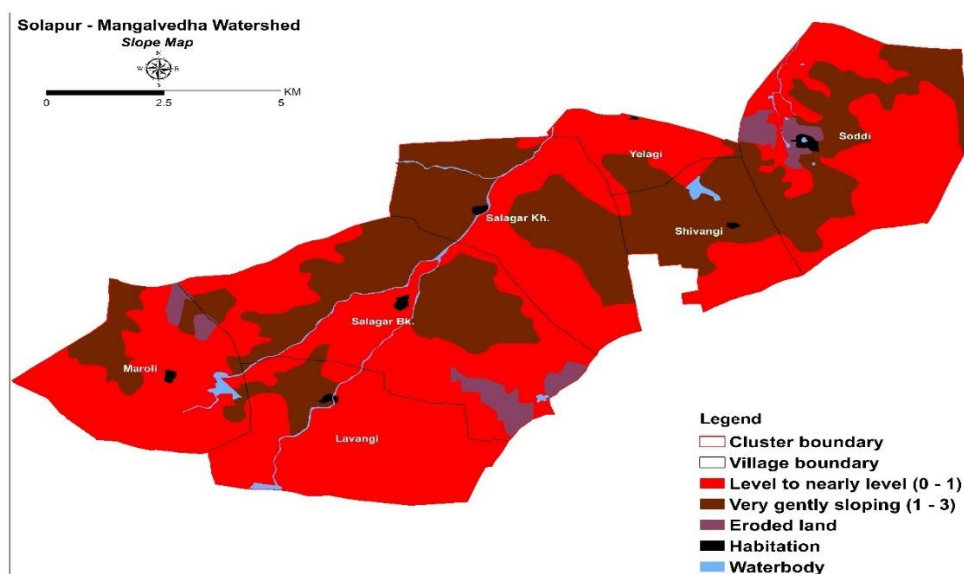
### 4.5.1 Slope

Land slope plays a crucial role in agriculture, as it affects water drainage, soil erosion, and the ease with which crops can be cultivated. Gentle slope tends to have higher rates of surface runoff, which can lead to soil erosion and loss of valuable topsoil, reduce soil fertility and compromise crop yields. On the other hand, very gently sloping lands allow for better water retention, easier mechanization, and more efficient irrigation practices, leading to higher productivity. The slope also influences the microclimate of the area, with sloped terrains potentially being more prone to temperature extremes or frost in certain regions. By considering the slope of land, farmers can implement soil conservation techniques, such as terracing, bunding or contour farming, to reduce erosion and optimize land use. Among the different slope classes (Table 4.10, Fig. 4.5)

the maximum area of watershed is under gently sloping (3 - 8%), covering 83.4% followed by very gently sloping (3-8%) covering 7.2% and moderately sloping (8 – 15%) covering 3.3%. The analysis indicates that no steep slope categories are present in the watershed, suggesting that the area is primarily characterized by gentle terrain, which is favourable for agricultural activities and reduces the risk of severe soil erosion.

**Table: 4.10. Land slope classes in Raigad-Roha watershed**

Sr. No.	Slope Class (%)	Area (ha)	TGA (%)
1	Very gently sloping (1 - 3)	317.1	7.2
2	Gently sloping (3 - 8)	3695.4	83.4
3	Moderately sloping (8 - 15)	145.7	3.3
4	Built-up/Habitation	94.1	2.1
5	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



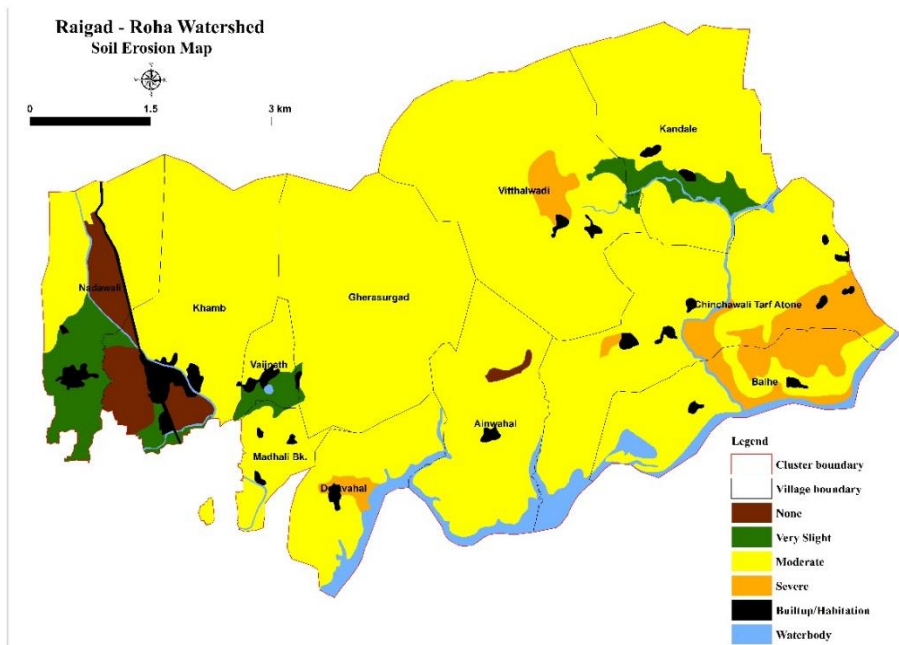
**Fig. 4.5: Slope map of Raigad-Roha watershed**

#### 4.5.2 Soil Erosion

Soil erosion in the Raigad-Roha watershed varies from none to severe depending on local terrain and land conditions (Table 4.11). The analysis indicates that the majority of the watershed area, about 81.3%, falls under the moderate erosion category, suggesting that soil loss is present but generally easy to manageable. A small portion of the area, 5.1%, experiences severe erosion, indicating relatively constraints to manage soil conditions with conservation agriculture practices and 4.7% of the watershed is affected by very slight erosion. However, about 2.8% of the watershed is affected by none erosion, representing zones were soil relatively stable soil conditions with minimal loss.

**Table 4.11: Soil erosion status in Raigad-Roha watershed**

Sr. No.	Erosion class	Area (ha)	Percent (%)
1	None	124.0	2.8
2	Very Slight	206.4	4.7
3	Moderate	3600.6	81.3
4	Severe	227.2	5.1
5	Builtup/Habitation	94.1	2.1
6	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



**Fig. 4.6: Erosion map of Raigad-Roha watershed**

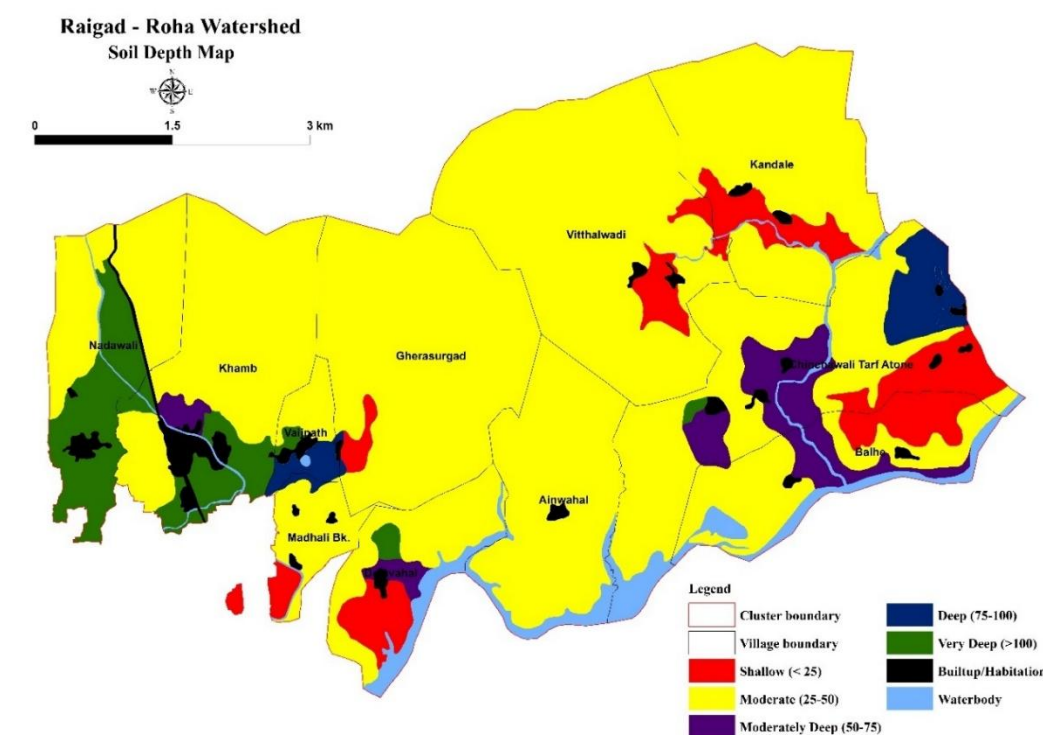
### 4.5.3 Soil Depth

Soil depth is an important physical property that strongly influences soil productivity and land use suitability. It determines the effective rooting zone available for plants and affects the storage and movement of water and nutrients within the soil profile. Variations in soil depth are mainly controlled by factors such as parent material, landscape position, erosion and deposition processes, and long-term weathering. Deeper soils generally support better crop growth because they allow greater root penetration and retain more moisture and nutrients, whereas shallow soils often limit root development and reduce water availability during dry periods. The spatial pattern

of soil depth in the Raigad–Roha watershed is illustrated in Fig. 4.7, while the areal distribution of different depth classes is summarized in Table 4.8. The soils of the watershed range from shallow (<25 cm) to very deep (>100 cm), indicating noticeable variability across the area. Among the different classes, moderate depth soils (25–50 cm) dominate the watershed, covering 3341.3 ha, which accounts for 75.4% of the total area. This suggests that most parts of the watershed possess soils with moderate rooting depth and reasonable water holding capacity. Very deep soils (>100 cm) occupy 238.2 ha (5.4%), followed by moderately deep soils (50–75 cm) covering 167.3 ha (3.8%). Deep soils (75–100 cm) occur in relatively smaller patches and cover 101.3 ha (2.3%) of the total area. In contrast, shallow soils (<25 cm) extend over 310.1 ha (7.0%), which may restrict root growth and limit moisture availability for crops. Overall, the predominance of moderately deep soils indicates moderate agricultural potential in the region.

**Table 4.12. Soil depth classes in Raigad – Roha watershed**

Sr. No.	Depth Class (cm)	Area (ha)	TGA (%)
1	Shallow (< 25)	310.1	7.0
2	Moderate (25 - 50)	3341.3	75.4
3	Moderately Deep (50-75)	167.3	3.8
4	Deep (75-100)	101.3	2.3
5	Very Deep (>100)	238.2	5.4
7	Built-up/Habitation	94.1	2.1
8	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



**Fig. 4.7 Soil Depth map of Raigad – Roha watershed**

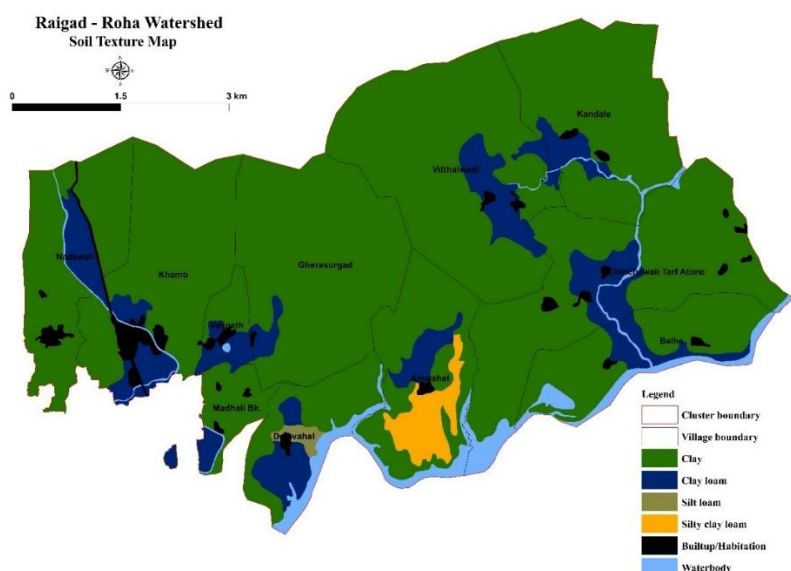
#### 4.5.4 Surface texture

Soil texture is a fundamental physical property that influences several important soil characteristics, including water retention, aeration, drainage and nutrient availability. It also affects root penetration, crop growth and overall soil productivity. The relative proportion of sand, silt and clay particles determines soil texture and plays a significant role in deciding appropriate crop selection and soil management practices. Fine-textured soils, particularly clay, are capable of holding large amounts of water and nutrients but may experience limited drainage and aeration. In contrast, medium-textured soils generally provide a more balanced environment for plant growth by allowing better movement of air and water within the soil profile. Therefore, knowledge of soil texture distribution is essential for effective land management and sustainable agricultural planning.

The spatial distribution of surface soil texture in the Raigad–Roha watershed is illustrated in Fig. 4.8, while the areal extent of different texture classes is given in Table 4.9. The soils of the watershed are mainly grouped into four texture classes, along with built-up areas and water bodies. Among these, clay is the most dominant texture, covering 3577.6 ha, which represents 80.8% of the total watershed area. This dominance indicates that a large portion of the watershed possesses soils with high moisture and nutrient holding capacity. The clay loam texture occupies 486.7 ha (11.0%), representing the second most extensive soil texture class in the watershed. These soils generally provide favorable conditions for crop growth due to a balanced combination of water retention and aeration. Silty clay loam soils cover 78.7 ha (1.8%), while silty loam soils occupy a very limited area of 15.2 ha (0.3%). Overall, the predominance of clay soils suggests that the watershed has good moisture retention potential, although proper soil management practices are necessary to maintain favorable conditions for crop production.

**Table 4.13: Soil texture distribution in Raigad – Roha watershed**

Sr. No.	Texture	Area (ha)	TGA (%)
1	Clay	3577.6	80.8
2	Clay loam	486.7	11.0
3	Silty loam	15.2	0.3
4	Silty clay loam	78.7	1.8
5	Built-up/Habitation	94.1	2.1
6	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



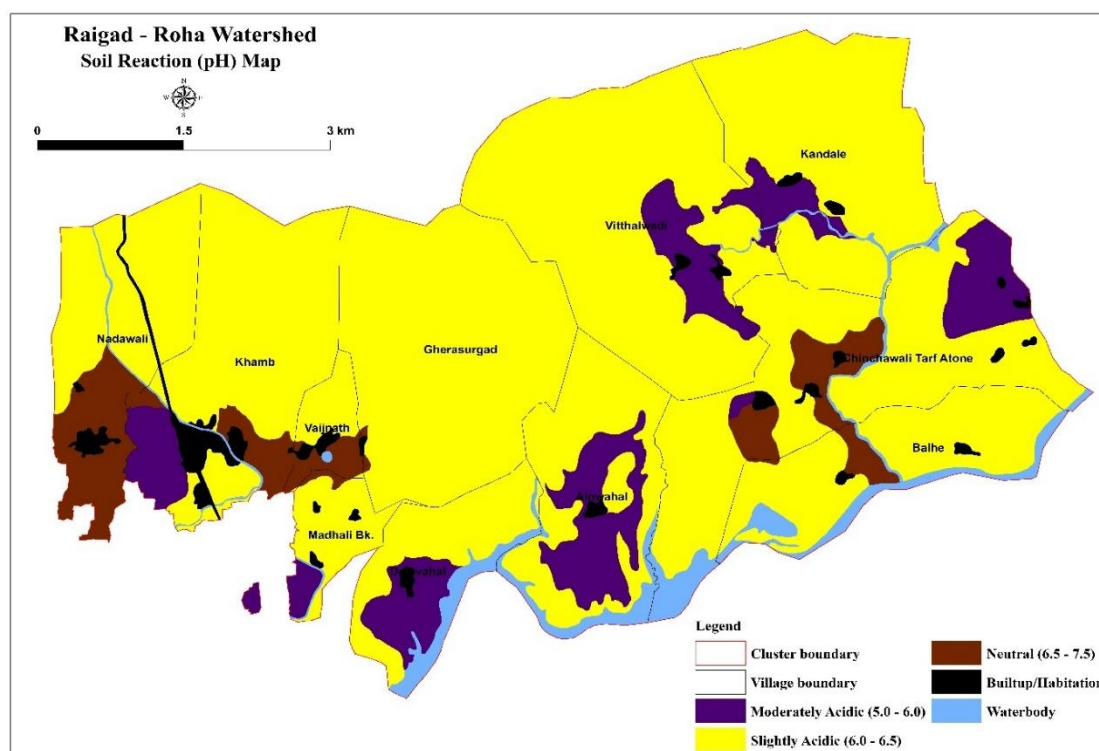
**Fig. 4.8: Soil texture map of Raigad – Roha watershed**

#### 4.5.5 Soil reaction

Soil reaction (pH) indicates the level of acidity or alkalinity in soil and is an important factor affecting nutrient availability, microbial processes, and plant growth. It plays a key role in determining soil fertility and agricultural productivity within a watershed. The soil pH analysis of the Raigad–Roha watershed shows that slightly acidic soils (pH 6.0–6.5) are predominant, covering 3456.9 ha (78.1%) of the total geographical area. Moderately acidic soils (pH 5.0–6.0) occupy 442.2 ha (10.0%), while neutral soils (pH 6.5–7.5) cover 258.9 ha (5.8%). The overall distribution indicates that slightly acidic soil conditions dominate the watershed, which are generally suitable for a wide range of agricultural crops.

**Table 4.14. Soil pH distribution in Raigad-Roha watershed**

Sr. No.	Soil pH	Area (ha)	TGA (%)
1	Moderately Acidic (5.0 - 6.0)	442.2	10.0
2	Slightly Acidic (6.0 - 6.5)	3456.9	78.1
3	Neutral (6.5 - 7.5)	258.9	5.8
4	Built-up/Habitation	94.1	2.1
5	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



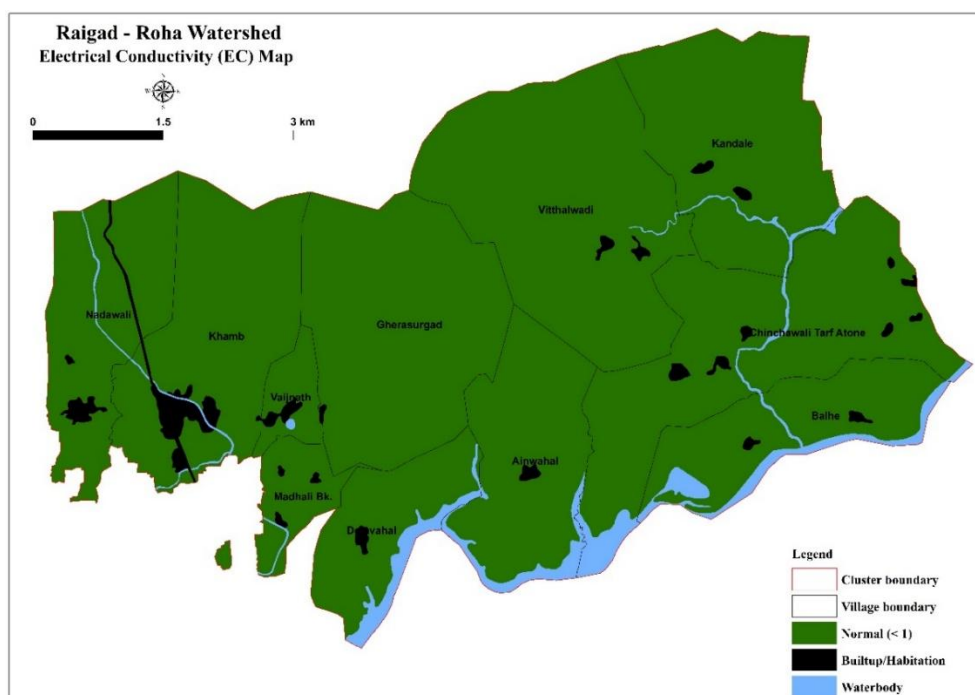
**Fig. 4.9: Soil pH map of Raigad-Roha watershed**

#### 4.5.6 Soil salinity

Soil salinity refers to the concentration of soluble salts present in the soil and is commonly evaluated using electrical conductivity (EC). It is an important soil property because excessive salt accumulation can negatively influence plant growth, nutrient uptake, and overall soil productivity. The analysis of electrical conductivity in the Raigad–Roha watershed indicates that most of the area falls under the normal salinity class ( $EC < 1 \text{ dS m}^{-1}$ ). This class occupies 4158.1 ha, representing 93.9% of the total geographical area (Table 4.15 and Fig. 4.10). The predominance of normal EC values suggests that the soils in the watershed are generally non-saline and suitable for agricultural use, providing favorable conditions for crop growth and soil management practices.

**Table 4.15. Soil salinity classes in Raigad-Roha watershed**

Sr. No.	Electrical conductivity ( $\text{dSm}^{-1}$ )	Area (ha)	TGA (%)
1	Normal ( $< 1$ )	4158.1	93.9
2	Built-up/Habitation	94.1	2.1
3	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



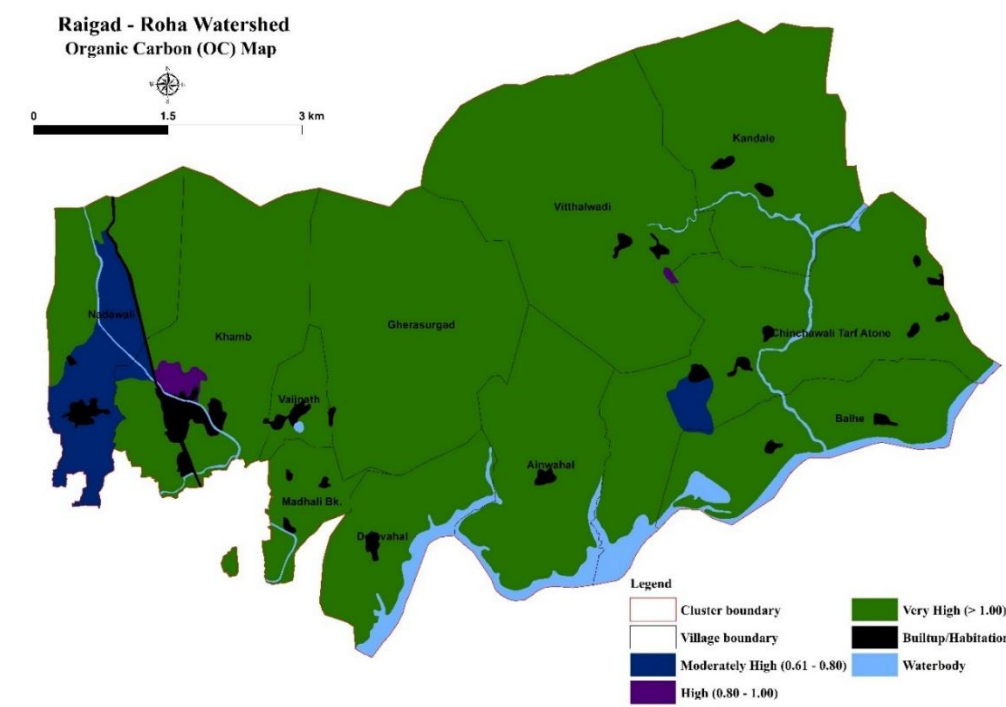
**Fig. 4.10: Soil EC map of Raigad-Roha watershed**

#### 4.5.7 Soil organic carbon

Soil organic carbon (SOC) is an important indicator of soil quality and plays a major role in maintaining soil productivity. It is mainly formed from the decomposition of plant residues, roots, and other organic materials present in the soil. SOC improves soil structure, enhances water-holding capacity, and supports microbial activity. It also helps in storing carbon in the soil, which contributes to reducing the concentration of carbon dioxide in the atmosphere and supports climate change mitigation. Monitoring SOC is essential for sustainable soil management. Continuous removal of crop residues, deforestation, and intensive cultivation practices can reduce organic carbon levels in soil, leading to soil degradation and lower crop productivity. Therefore, maintaining adequate organic matter through proper land management practices is important for improving soil health. The distribution of soil organic carbon in the Raigad–Roha watershed is presented in Table 4.16 and Fig. 4.11. The analysis shows that very high SOC content ( $>1.00\%$ ) dominates the area, covering 3965.5 ha, which accounts for 89.5% of the total geographical area. Moderately high SOC (0.61–0.80%) occupies 175.7 ha (4.0%), while high SOC (0.80–1.00%) covers 16.9 ha (0.4%). The results indicate that the soils of the watershed generally possess high organic carbon content.

**Table 4.16 Soil organic carbon status of Raigad-Roha watershed**

Sr. No.	Organic carbon (%)	Area (ha)	TGA (%)
1	Moderately High (0.61 - 0.80)	175.7	4.0
2	High (0.80 - 1.00)	16.9	0.4
3	Very High ( $> 1.00$ )	3965.5	89.5
4	Built-up/Habitation	94.1	2.1
5	Waterbody	176.8	4.0
<b>Total</b>		<b>4429.0</b>	<b>100.0</b>



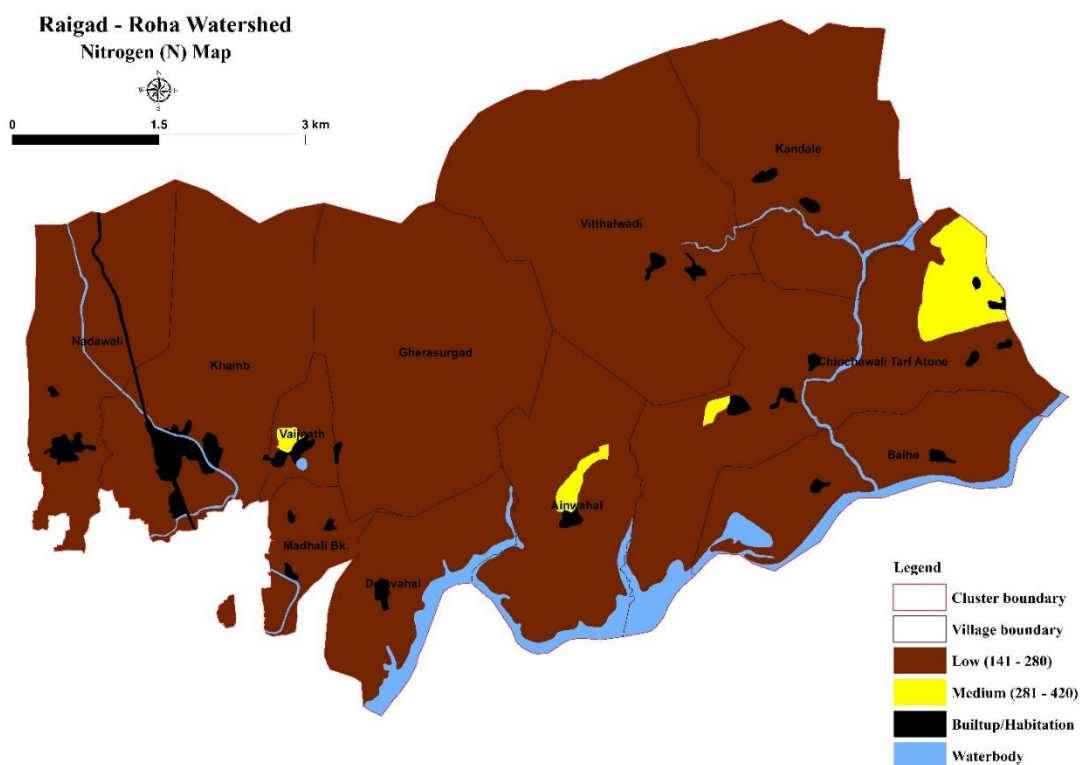
**Fig. 4.11: Soil organic carbon map of Raigad-Roha watershed**

#### 4.5.9 Available nitrogen (N)

Available nitrogen is one of the most important nutrients required for plant growth and development. It is a key component of proteins, amino acids, and chlorophyll, which are essential for photosynthesis and overall crop productivity. Adequate nitrogen in soil promotes healthy plant growth, improves leaf development, and enhances crop yield. Therefore, evaluating the nitrogen status of soils is essential for effective nutrient management and sustainable agricultural production. The distribution of available nitrogen in the soils of the Raigad–Roha watershed is presented in Table 4.17 and Fig. 4.12. The analysis shows that low nitrogen content (141–280 kg ha<sup>-1</sup>) is the dominant category, covering 4064.1 ha, which accounts for 91.8% of the total geographical area. Medium nitrogen levels (281–420 kg ha<sup>-1</sup>) are found in 94.0 ha (2.1%) of the area. The results indicate that most soils in the watershed have low nitrogen availability, highlighting the importance of proper nutrient management practices.

**Table 4.17: Available N content in soils of Raigad-Roha watershed**

Sr. No.	Available N (kg ha <sup>-1</sup> )	Area (ha)	TGA (%)
1	Low (141 - 280)	4064.1	91.8
2	Medium (281 - 420)	94.0	2.1
3	Built-up/Habitation	94.1	2.1
4	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



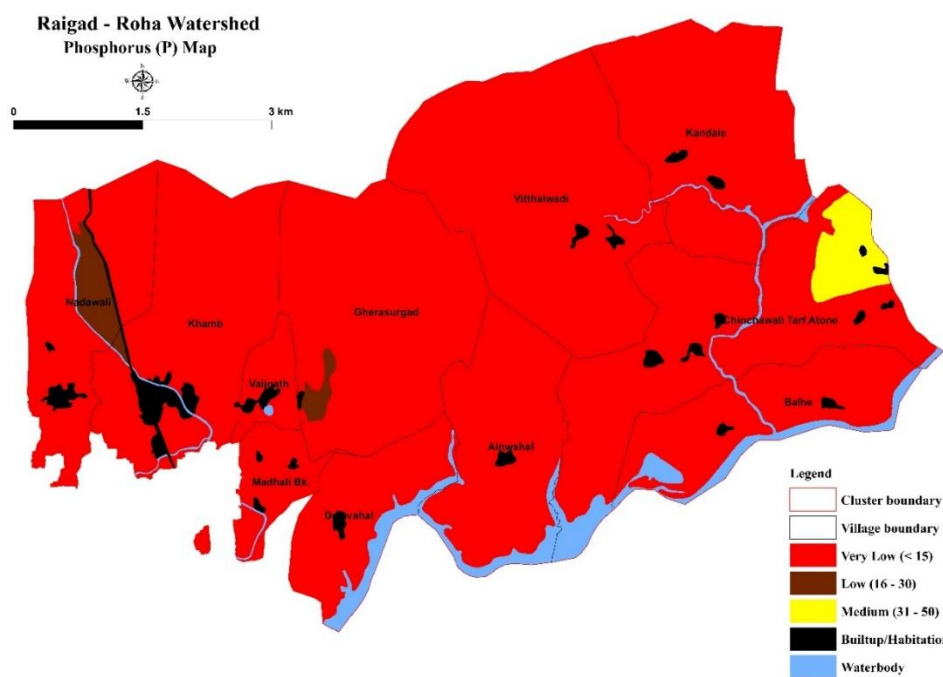
**Fig. 4.12: Available soil nitrogen map of Raigad-Roha watershed**

#### 4.5.10 Available Phosphorous (P)

Phosphorus (P) is an essential plant nutrient that plays a key role in several physiological and biochemical processes. It is important for root development, flowering, seed formation, and overall plant growth. Phosphorus is also involved in photosynthesis, energy transfer, and metabolic activities through compounds such as ATP and ADP. Therefore, the availability of phosphorus in soil is an important factor influencing crop productivity and soil fertility. The distribution of available phosphorus in the soils of the Raigad–Roha watershed is shown in Table 4.18 and Fig. 4.13. The analysis indicates that very low phosphorus content ( $<15 \text{ kg ha}^{-1}$ ) is the dominant category, covering 4024.9 ha, which accounts for 90.9% of the total geographical area. Low phosphorus levels ( $16\text{--}30 \text{ kg ha}^{-1}$ ) occupy 60.0 ha (1.4%), while medium phosphorus content ( $31\text{--}50 \text{ kg ha}^{-1}$ ) covers 73.2 ha (1.7%). These results indicate that most soils in the watershed have very low phosphorus availability.

**Table 4.18: Available P content of soils of Raigad-Roha watershed**

Sr. No.	Available P ( $\text{kg ha}^{-1}$ )	Area (ha)	TGA (%)
1	Very Low ( $< 15$ )	4024.9	90.9
2	Low (16 - 30)	60.0	1.4
3	Medium (31 - 50)	73.2	1.7
4	Built-up/Habitation	94.1	2.1
5	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



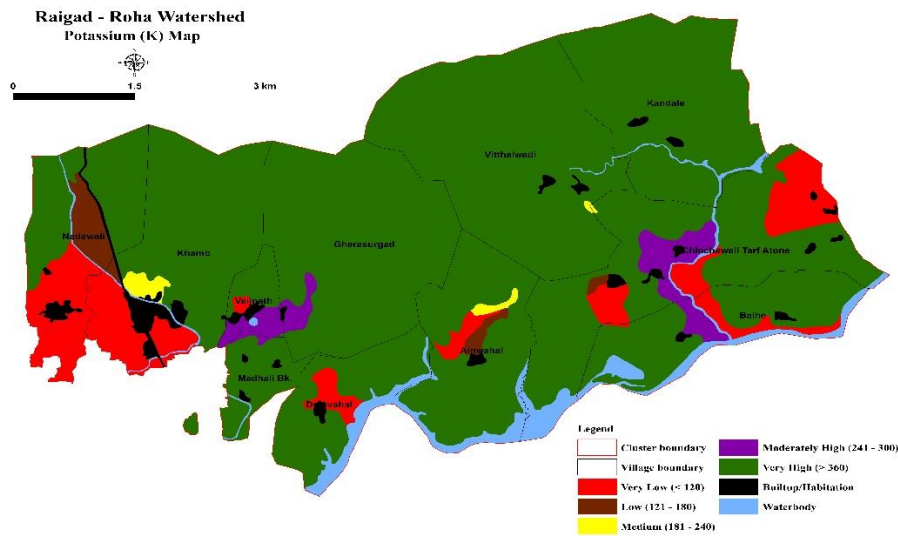
**Fig.4.13: Available soil Phosphorous map of Raigad-Roha watershed**

#### 4.5.11 Available Potassium (K)

Potassium (K) is one of the essential macronutrients required for healthy plant growth and development. It plays a vital role in several plant functions such as enzyme activation, regulation of water balance, photosynthesis, and improving plant resistance to diseases and environmental stress. The assessment of exchangeable or available potassium in soil is commonly used to understand the potassium fertility status and to estimate the nutrient requirement for crops. The distribution of available potassium in the soils of the Raigad–Roha watershed is presented in Table 4.19 and Fig. 4.14. The analysis shows that very high potassium content ( $>360 \text{ kg ha}^{-1}$ ) is the dominant category, covering 3578.9 ha, which accounts for 80.8% of the total geographical area. Moderately high potassium ( $241\text{--}300 \text{ kg ha}^{-1}$ ) occupies 110.7 ha (2.5%), while medium potassium ( $181\text{--}240 \text{ kg ha}^{-1}$ ) covers 24.1 ha (0.5%). Low ( $121\text{--}180 \text{ kg ha}^{-1}$ ) and very low ( $<120 \text{ kg ha}^{-1}$ ) potassium levels are found in 60.6 ha (1.4%) and 383.9 ha (8.7%), respectively. Overall, the soils of the watershed generally show high potassium availability.

**Table 4.19: Available K content of soils of Raigad-Roha watershed**

Sr. No.	Available K ( $\text{kg ha}^{-1}$ )	Area (ha)	TGA (%)
1	Very Low ( $< 120$ )	383.9	8.7
2	Low (121 - 180)	60.6	1.4
3	Medium (181 - 240)	24.1	0.5
4	Moderately High (241 - 300)	110.7	2.5
5	Very High ( $> 360$ )	3578.9	80.8
6	Built-up/Habitation	94.1	2.1
7	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



**Fig. 4.14: Available soil Potassium map of Raigad-Roha watershed**

#### 4.5.12 Micronutrient status of soils

Micronutrients are required by plants in small quantities, but they are vital for maintaining soil fertility and supporting healthy crop growth. Elements such as iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) are involved in several biochemical and physiological processes including enzyme activity, chlorophyll formation, respiration, and nutrient transformation. Therefore, evaluating the availability of these micronutrients is important for effective soil fertility management in the Raigad–Roha watershed. The available iron (Fe) content in the soils of the watershed (Table 4.17; Fig. 4.15) indicates that Fe is generally abundant in the area. A large proportion of the watershed, 4084.9 ha (92.2%), falls under the very high ( $>10.5 \text{ mg kg}^{-1}$ ) category. Only 73.2 ha (1.7%) is classified under the medium ( $4.5\text{--}6.5 \text{ mg kg}^{-1}$ ) category. The distribution of available manganese (Mn) (Table 4.18; Fig. 4.16) shows that the watershed soils are highly rich in Mn. Approximately 4158.1 ha (93.9%) of the total area falls within the very high ( $>9.0 \text{ mg kg}^{-1}$ ) class, indicating sufficient availability of manganese across most parts of the watershed.

Similarly, the copper (Cu) status (Table 4.19; Fig. 4.17) also shows adequate availability in the soils. Nearly 4158.1 ha (93.9%) of the watershed area is categorized under the very high ( $>1.0 \text{ mg kg}^{-1}$ ) class, suggesting that copper deficiency is unlikely to occur in the study region. However, the zinc (Zn) status (Table 4.20; Fig. 4.18) reveals relatively lower availability compared to the other micronutrients. A major portion of the watershed, 3423.1 ha (77.3%), falls under the low ( $0.3\text{--}0.6 \text{ mg kg}^{-1}$ ) category. Smaller areas are distributed under medium (4.7%), moderately high (2.4%), and high (9.5%) classes. This indicates that zinc deficiency may be a concern in many parts of the watershed and appropriate Zn fertilization may be required to sustain crop productivity and soil health.

**Table 4.20: Available Fe content in the soils of Raigad-Roha watershed**

Sr. No.	Available Fe (mg kg <sup>-1</sup> )	Area (ha)	TGA (%)
1	Medium (4.5 - 6.5)	73.2	1.7
2	Very High (> 10.5)	4084.9	92.2
3	Built-up/Habitation	94.1	2.1
4	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>

**Table 4.21: Available Mn content in the soils of Raigad-Roha watershed**

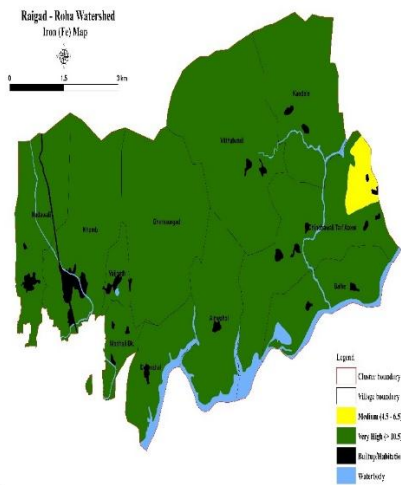
Sr. No.	Available Mn (mg kg <sup>-1</sup> )	Area (ha)	TGA (%)
1	Very High (> 9.0)	4158.1	93.9
2	Built-up/Habitation	94.1	2.1
3	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>

**Table 4.22: Available Cu content in the soils of Raigad-Roha watershed**

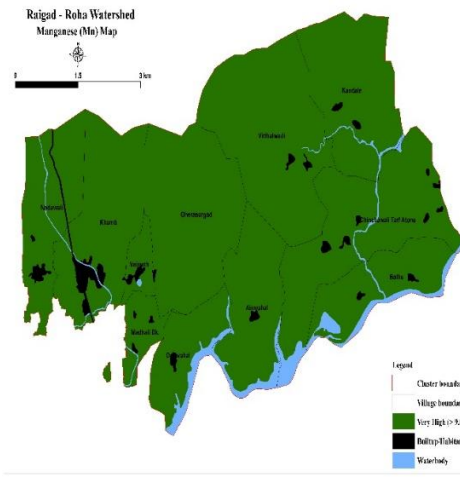
Sr. No.	Available Cu (mg kg <sup>-1</sup> )	Area (ha)	TGA (%)
1	Very High (> 1.0)	4158.1	93.9
2	Built-up/Habitation	94.1	2.1
3	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>

**Table 4.23: Available Zn content in the soils of Raigad-Roha watershed**

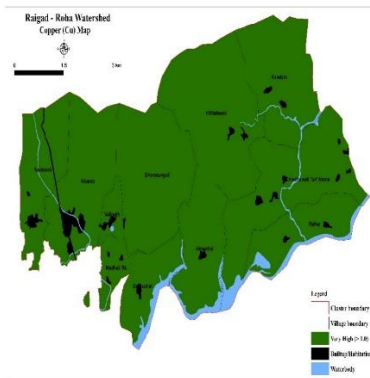
Sr. No.	Available Zn (mg kg <sup>-1</sup> )	Area (ha)	TGA (%)
1	Low (0.3 - 0.6)	3423.1	77.3
2	Medium (0.6 - 0.9)	208.8	4.7
3	Moderately High (0.9 - 1.2)	105.8	2.4
4	High (1.2 - 1.8)	420.6	9.5
5	Built-up/Habitation	94.1	2.1
6	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



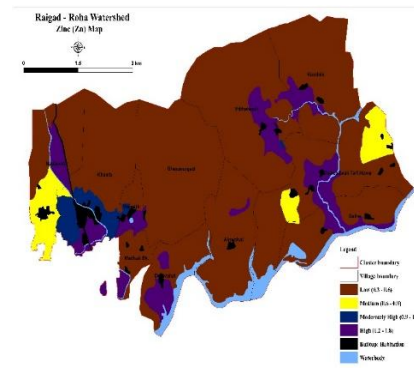
**Fig. 4.15: DTPA-extractable soil Fe map of Raigad-Roha watershed**



**Fig. 4.16: DTPA-extractable soil Mn map of Raigad-Roha watershed**



**Fig. 4.17: DTPA-extractable soil Cu map of Raigad-Roha watershed**



**Fig. 4.18: DTPA-extractable soil Zn map of Raigad-Roha watershed**

#### 4.6 Surface Runoff

Surface runoff plays a critical role in shaping the hydrology and water availability of any watershed, especially in high rainfall, lateritic zones like Roha Taluka villages cluster watershed of Raigad district. Although the region receives over averaging 4294 mm annually over the period 2014 to 2024. The hydrological response across its landscape is highly variable. The 11 study villages are spread across diverse topographic zones, ranging from river-adjacent lowlands to elevated hill slopes with deep soils. General water scarcity is not observed across the entire area. In fact, valley regions and riverside settlements often have sufficient water for domestic and agricultural needs due to better groundwater recharge and surface water access. However, upper hill zones and undulating uplands face frequent challenges such as:

- High surface runoff and limited infiltration
- Seasonal drying of local sources post-monsoon
- Topsoil erosion during high-intensity rain events
- Rapid drainage from unbunded, degraded slopes

These site-specific issues motivated the need for detailed runoff estimation to understand how much rainwater is being lost as direct surface flow especially from the hilly and vulnerable zones and how that water can be better managed through watershed interventions. The primary objective of this exercise was to estimate the annual and seasonal runoff potential over the last decade (2014-24), using the SCS-Curve Number (CN) method, with actual rainfall data, verified land use, and soil profiles. This estimation was critical for identifying the gap between rainfall received and water retained in the landscape, and to guide the design of appropriate water harvesting and recharge interventions. Based on daily rainfall records for the 11-year period was compiled from IMD and verified land conditions. Land use and soil conditions were mapped through satellite imagery, field surveys, and consultation with local farmers.

Based on this, Curve Numbers were assigned and runoff estimated for each monsoon season, adjusted for antecedent moisture based on rainfall distribution patterns.

Runoff generation was typically highest in July and August, with peaks occurring during short, intense rain spells. Most villages have dominant rice cultivation on gentle slopes, which showed relatively high surface runoff due to temporary water retention and slower flow, attributed to a high Curve Number (CN=95) for paddy fields. Such a high CN value represents low infiltration and high runoff potential because paddy fields are intentionally kept saturated or ponded during cultivation, reducing the soil’s capacity to absorb additional rainfall. Under the SCS-CN approach, this condition results in the estimation of very high potential runoff, as the method assumes uniform rainfall and direct response from the catchment without accounting for field-level water management practices. In actual field conditions, however, the magnitude of surface runoff is considerably lower than the theoretical estimates. Paddy cultivation areas are typically surrounded by small bunds and field boundaries that temporarily retain water, allowing gradual infiltration and percolation into the soil profile. In such landscapes, a significant proportion of the rainfall contributes to soil moisture replenishment and subsurface flow rather than immediate surface discharge. Moreover, part of the rainfall is utilized for crop water requirements during the growing period, reducing the amount of water available for direct runoff. Given that the study area covers relatively small agricultural catchments, even with high rainfall, complete transformation of rainfall into surface runoff is hydrologically unrealistic. The estimated values, therefore, represent potential runoff capacity rather than actual flow volumes observed in the field. If the estimated runoff were to occur in full measure, it would imply flood-like conditions within small cultivated patches, which is not the case in reality. The difference arises primarily due to localized retention, infiltration, and storage processes that moderate the hydrological response.

Hence, while the SCS-CN method provides a valuable upper limit for assessing runoff potential and planning water conservation structures, the interpretation must consider on-ground factors such as land management practices, field bunding, crop type, and soil permeability. This understanding ensures that proposed watershed interventions under the project are appropriately scaled, economically viable, and hydrologically balanced to capture excess runoff without overdesigning storage or drainage systems.

Table 4.24. Details of monthly (June-Oct) runoff (mm) for the period 2014-2024

Year/Month	June		July		Aug		Sept		Oct	
	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)
<b>2014</b>	214.2	33.7	2024.0	1111.3	1117.7	446.9	730.2	309.7	66.4	0.0
<b>2015</b>	1036.3	486.8	823.5	293.9	507.4	73.4	396.7	74.0	151.3	1.1
<b>2016</b>	622.9	241.9	1971.3	1052.2	1409.7	670.8	721.9	288.1	124.6	3.3

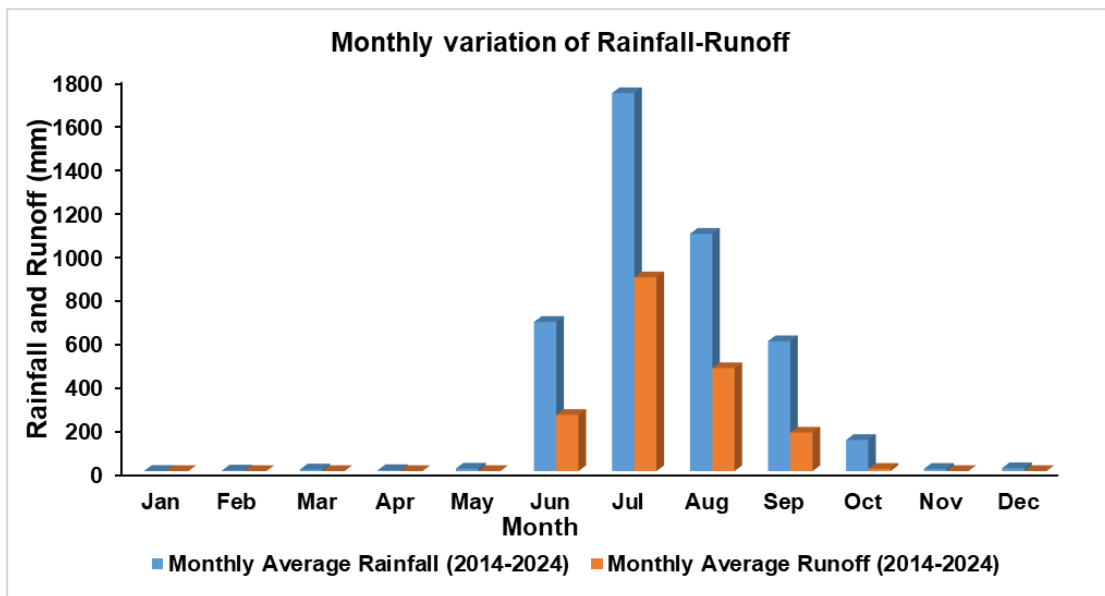
<b>2017</b>	1004.4	479.2	1750.4	847.0	1215.4	536.3	604.0	219.8	126.6	0.0
<b>2018</b>	863.3	341.6	1851.1	984.8	1043.3	315.7	138.3	5.1	95.0	0.0
<b>2019</b>	675.9	302.4	2069.5	1128.4	1656.0	939.0	1379.7	626.6	213.0	15.8
<b>2020</b>	734.5	200.3	1239.5	478.2	2581.7	1595.8	474.8	91.0	289.7	25.1
<b>2021</b>	926.1	317.1	1661.3	865.6	351.8	20.1	559.6	58.7	124.2	15.4
<b>2022</b>	309.7	61.3	1581.1	797.5	928.4	333.0	520.1	132.3	122.0	0.0
<b>2023</b>	477.0	181.9	1985.5	1046.3	375.8	26.9	591.3	86.5	118.7	51.5
<b>2024</b>	657.8	188.3	2105.6	1164.0	780.1	231.8	434.8	48.7	135.2	0.0
<b>Average</b>	<b>683.8</b>	<b>257.7</b>	<b>1733.0</b>	<b>888.1</b>	<b>1087.9</b>	<b>471.8</b>	<b>595.6</b>	<b>176.4</b>	<b>142.4</b>	<b>10.2</b>

As shown above Table 1, runoff peaks in July, with an average of 888.1 mm, which alone contributes nearly half of the total seasonal runoff. Conversely, October runoff is negligible, and even in June, much of the early rain is absorbed by dry soils, resulting in lower runoff. From year to year, the runoff ranged from 929 mm (2015) to as high as 3012 mm (2019), depending on total rainfall and its intensity.

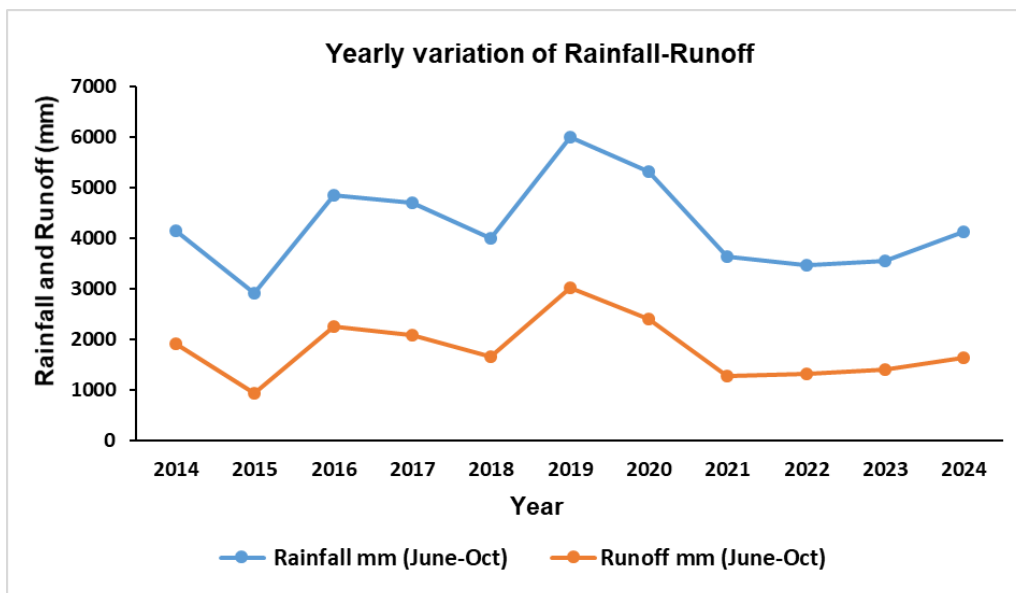
The study revealed that on average, 1804 mm of water is lost as surface runoff each year which is about 41.1% of the total annual rainfall. The rest is absorbed by the soil, used by crops, or lost to evaporation. Runoff is highly seasonal over 75% of the runoff occurs during July and August, when soils are saturated and rainfall intensity is at its peak. Over the 11-year analysis period, it became evident that while rainfall quantity remained relatively stable, the intensity and concentration of rain events had same, leading to flashier runoff patterns. This shift reinforces the need for landscape-level treatment, combining both water harvesting and vegetative measures, to control runoff and improve soil moisture retention.

Table 4.25. Relationship between rainfall and runoff

<b>Year</b>	<b>Rainfall mm</b>	<b>Runoff mm</b>	<b>No. of Runoff Events</b>	<b>Runoff (%)</b>
<b>2014</b>	4244.6	1901.5	59	44.8
<b>2015</b>	3029.9	929.1	45	30.7
<b>2016</b>	4853.5	2256.2	67	46.5
<b>2017</b>	4743.3	2082.3	70	43.9
<b>2018</b>	4059.9	1647.2	59	40.6
<b>2019</b>	6012.8	3012.1	79	50.1
<b>2020</b>	5337.0	2390.4	76	44.8
<b>2021</b>	3775.7	1276.9	56	33.8
<b>2022</b>	3467.0	1324.1	55	38.2
<b>2023</b>	3585.1	1393.0	53	38.9
<b>2024</b>	4128.1	1632.7	62	39.6
<b>Average</b>	<b>4294.3</b>	<b>1804.1</b>	<b>62</b>	<b>41.1</b>



**Fig 4.20: Monthly variation of rainfall-runoff in Raigad-Roha watershed**



**Fig 4.20: Yearly variation of rainfall-runoff in Raigad-Roha watershed**

#### 4.7 Mapping of Groundwater Potential Zones

Groundwater serves as a critical source of water for drinking, domestic use, and irrigation in Roha Taluka, particularly in upland and non-command areas where surface water availability is limited or seasonal. The region experiences a high average annual rainfall of 4294.3 mm, which theoretically should provide abundant recharge. However, the actual availability of groundwater is uneven across the landscape due to factors such as variability in recharge processes and the complex hydrogeological framework of the

area. These spatial disparities in groundwater availability pose challenges to sustainable water resource management and necessitate detailed assessment and mapping of groundwater potential zones.

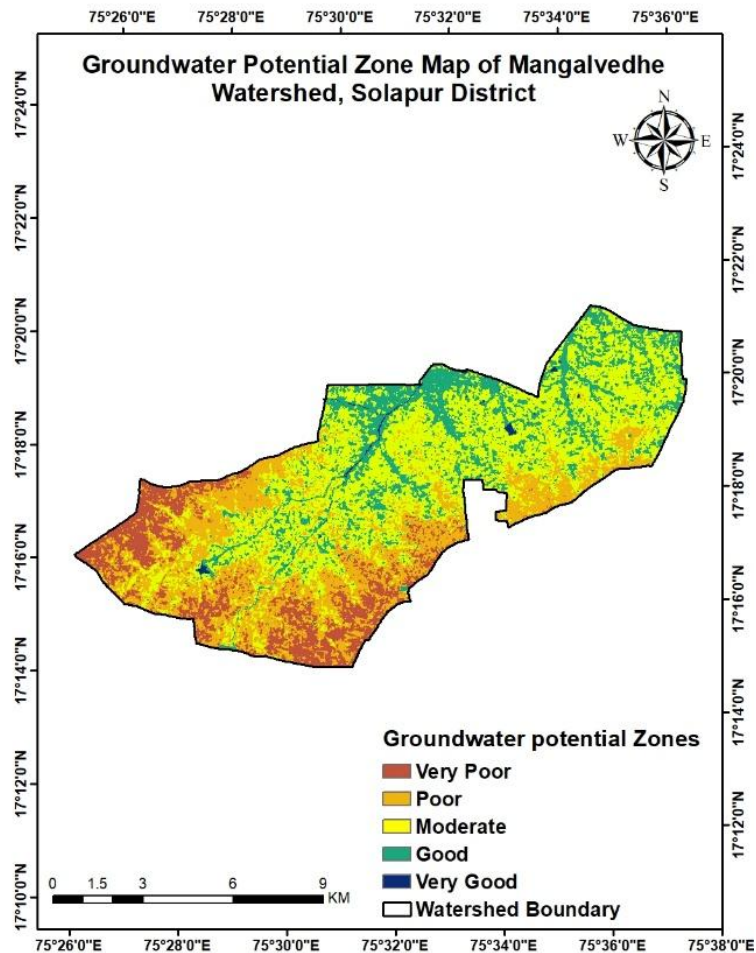
To address these challenges, a comprehensive Groundwater Potential Zonation (GWPZ) map was developed for 11 villages cluster watershed within Roha Taluka. This map was created using a multi-criteria spatial analysis approach that integrates eight thematic layers known to influence groundwater occurrence and movement. These layers include lithology, land use/land cover (LULC), drainage density, soil characteristics, slope, elevation, landform, and rainfall distribution. Each of these thematic factors plays a vital role in determining the recharge capacity and storage potential of groundwater in the region. The integration of these weighted thematic layers produced a detailed Groundwater Potential Zonation map that classifies the cluster watershed into five distinct categories: Very Good, Good, Moderate, Poor, and Very Poor groundwater potential zones. This classification provides a clear spatial understanding of areas with varying groundwater recharge potential and availability.

According to the final groundwater potential map, 23.2% of the area falls under the “Very Poor” potential category, indicating regions with the least favorable conditions for groundwater recharge and storage. These zones typically correspond to steep slopes, rocky terrain, and areas with poor soil cover. The “Poor” potential zones cover 18.6% of the watershed and are characterized by limited infiltration capacity and high runoff potential. “Moderate” potential zones make up the largest portion, at 39.9%, and represent undulating terrain with moderate recharge capabilities. Only 8.4% and 9.9% of the area fall under the “Good” and “Very Good” groundwater potential categories respectively. Collectively, only 18.3% of the Roha watershed is classified as having good to very good groundwater potential, emphasizing the limited areas suitable for high groundwater yield. Conversely, the majority of the landscape (81.7%) ranges from moderate to very poor potential, underscoring the need for targeted management interventions.

The delineation of groundwater potential zones in watershed offers critical spatial insights that can inform and enhance watershed management strategies under the Pradhan Mantri Krishi Sinchayee Yojana – Watershed Development Component 2.0 (PMKSY-WDC 2.0). This information supports data-driven decision-making for the design and implementation of groundwater recharge structures, soil moisture conservation techniques, and land treatment measures. It also aids in identifying priority micro-watersheds that require urgent conservation efforts to improve groundwater availability. Moreover, the map highlights areas where alternative water supply strategies may be necessary due to poor groundwater potential.

Given the complex hydrogeological setting of the Konkan region, this integrated assessment of groundwater potential is an essential tool for sustainable groundwater

management. It facilitates the judicious utilization and augmentation of groundwater resources in Roha Taluka, particularly within the cluster of 11 villages identified for focused development. The study's outcomes contribute to ensuring long-term water security for domestic, agricultural, and ecological needs, thereby supporting the overall socio-economic development of the region.



**Fig. 4.21. Ground water potential zones in Raigard-Roha watershed**

#### 4.8 Evaluation of Soil-Site Suitability for Crops

Soil and climate are the prime factors governing optimum crop growth. Soil physicochemical properties and crop micro-environment control the availability of water and essential plant nutrients. Therefore, key soil attributes, *viz.* soil depth, texture, fertility status and drainage conditions are carefully assessed during soil-site evaluation. This enables meaningful interpretation of soil maps in terms of their suitability for field and horticultural crops and contributes to the formulation of scientific land-use plans for watershed development.

The suitability of soils for crop cultivation was determined based on the criteria proposed by Naidu et al. (2006). The concept of land utilization types and the classification system for land evaluation categorizes land into different hierarchical levels, namely orders, classes, sub-classes, and units. Two major orders are recognized: ‘S’ (Suitable) and ‘N’ (Not

suitable), representing the general suitability status of land. Under the suitable order (S), three classes S1, S2, and S3 indicate high, moderate, and marginal suitability, respectively, while the not suitable order (N) includes two classes N1 and N2 representing current and permanent unsuitability. The assignment of these classes is based on the degree of land limitations affecting crop production.

The major land limitations considered in this evaluation exercise include those imposed by climate (c), topography (t), wetness (w), soil fertility (f), and physical soil constraints (s). These limitations were graded on a scale from 0 to 4, where 0 indicates no limitation and optimal conditions for crop growth; 1 denotes slight limitation with nearly optimal conditions; 2 indicates moderate limitation with noticeable effects on crop performance; 3 represents severe limitation rendering the land uneconomical for the proposed use; and 4 reflects very severe limitation, where crop yields fall below economically viable levels, making the land unsuitable for the intended use.

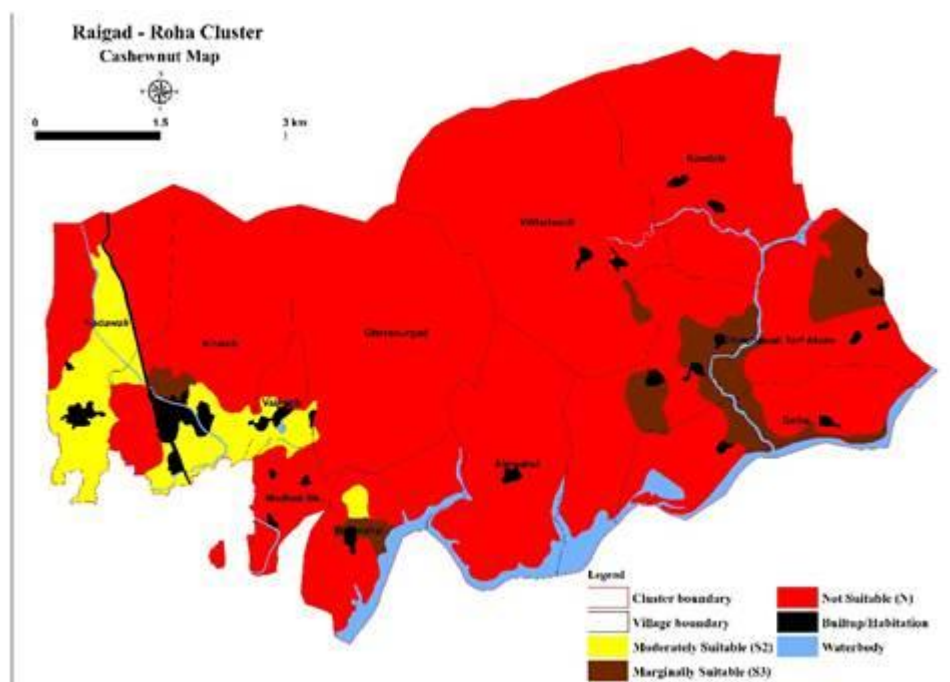
Several soil-site parameters, including climatic variables (rainfall, temperature); topographic features (slope, landscape position, and erosion susceptibility); wetness conditions (drainage, flooding risk and soil aeration); physical soil properties (texture, depth, structure and available soil moisture); fertility attributes (soil pH, nutrient availability, organic matter content, cation exchange capacity, base saturation) and groundwater table were examined to determine land suitability for agricultural crops and other land uses. Based on the integration of these parameters, the watershed area was evaluated for its suitability for the following commonly cultivated and potential-for-introduction crops.

#### 4.8.1 Soil-Site Suitability for Cashewnut Cultivation

The soil-site evaluation for Cashewnut cultivation shows areas categorized as moderately suitable (S2) which covering 261.9 ha (5.9%) of the total geographical area is classified, these areas provide acceptable conditions for Cashewnut cultivation, though certain soil and site constraints may affect crop performance. A portion of the watershed, covering 251.9 ha (5.7%), falls under the marginally suitable (S3) category (Table 4.26, Fig. 4.22), indicating the presence of moderate limitations that may restrict yield potential. About, 3644.3 ha (82.3%) of the area is categorized as not suitable (N) for Cashewnut cultivation due to severe soil and site-related constraints.

**Table 4.26 Area under suitability sub-classes for Cashewnut cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Marginally Suitable (S2)	261.9	5.9
2	Moderately Suitable (S3)	251.9	5.7
3	Not Suitable (N)	3644.3	82.3
4	Habitation/Built up	94.1	2.1
5	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



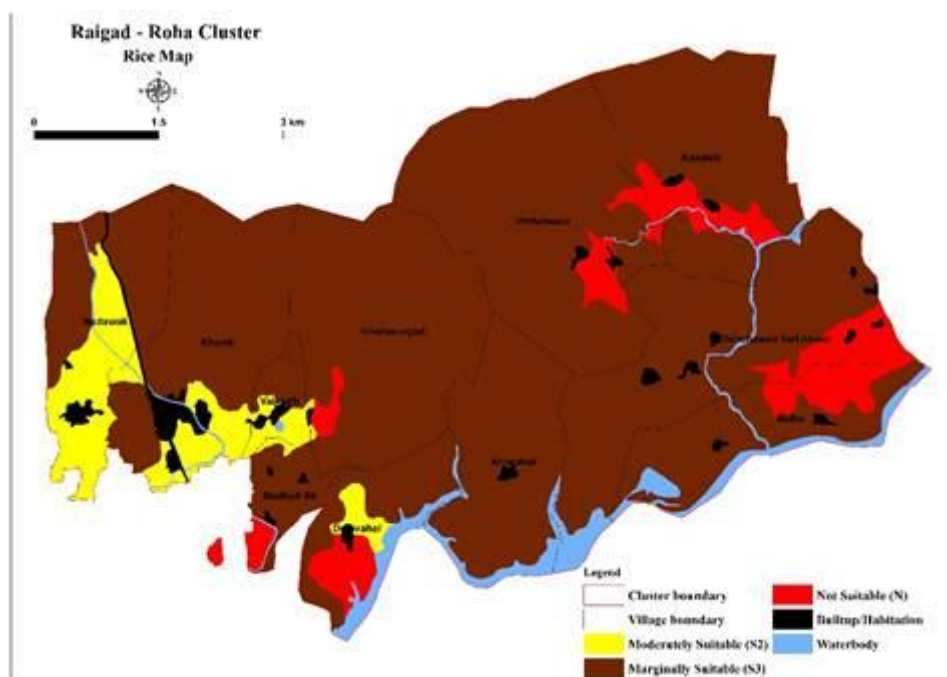
**Fig. 4.22 Soil site suitability map for Cashewnut cultivation**

#### 4.8.2 Area under suitability sub-classes for Rice Cultivation

Soil-site evaluation results for Rice show a varied distribution of suitability classes across the watershed (Table 4.27, Fig. 4.23). Areas categorized as moderately suitable (S2) cover 277.1 ha, accounting for about 6.3% of the total geographical area, representing zones where Rice cultivation is feasible, although certain soil or site constraints may influence yield levels. The marginally suitable (S3) category extends over 3570.9 ha (or 80.6%), suggesting the presence of noticeable limitations that may restrict optimum crop growth. About 7.0% of the watershed is not suitable (N) for Rice cultivation. These results most favorable for Rice cultivation in the Raigad-Roha watershed by following recommended package of practices.

**Table 4.27 Area under suitability sub-classes for Rice cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Marginally Suitable (S2)	277.1	6.3
2	Moderately Suitable (S3)	3570.9	80.6
3	Not Suitable (N)	310.1	7.0
4	Habitation/Built up	94.1	2.1
5	Waterbody	176.8	4.0
<b>Total</b>		<b>4429.0</b>	<b>100.0</b>



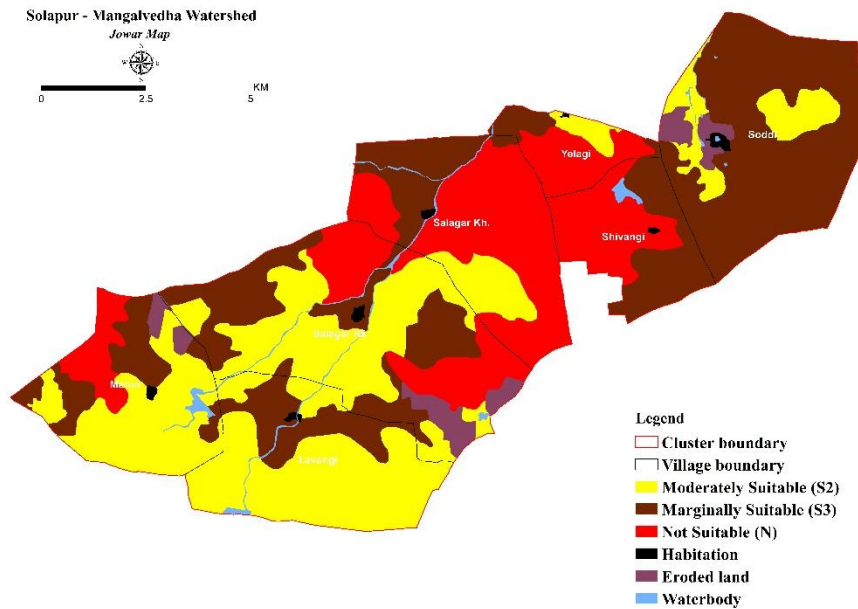
**Fig. 4.23 Soil site suitability map for Rice cultivation**

#### 4.8.3 Soil-Site Suitability for Arecanut Cultivation

Only 79.9 ha (1.8%) of the watershed area was found to be highly suitable (S1) and 5.9% area was moderately (S2) suitable for arecanut, providing optimal and/or manageable conditions for crop growth and productivity. Approximately 3.9% of the watershed can only marginally suitable arecanut crop, indicating moderate to severe soil, terrain and environmental constraints limiting crop productivity. An additional 3644.3 ha (82.3%) of the area is unsuitable for the crop, suggesting that arecanut may not be the best bet for Raigad-Roha watershed, or needs to be cultivated by strictly following the recommended package of practices (Table 4.28, Fig. 4.24).

**Table 4.28 Area under different suitability sub-classes for Arecanut cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	79.9	1.8
2	Marginally Suitable (S3)	259.5	5.9
3	Not Suitable (N)	174.4	3.9
4	Eroded land	3644.3	82.3
5	Habitation	94.1	2.1
6	Waterbody	176.8	4.0
<b>Total</b>		<b>4429.0</b>	<b>4429.0</b>



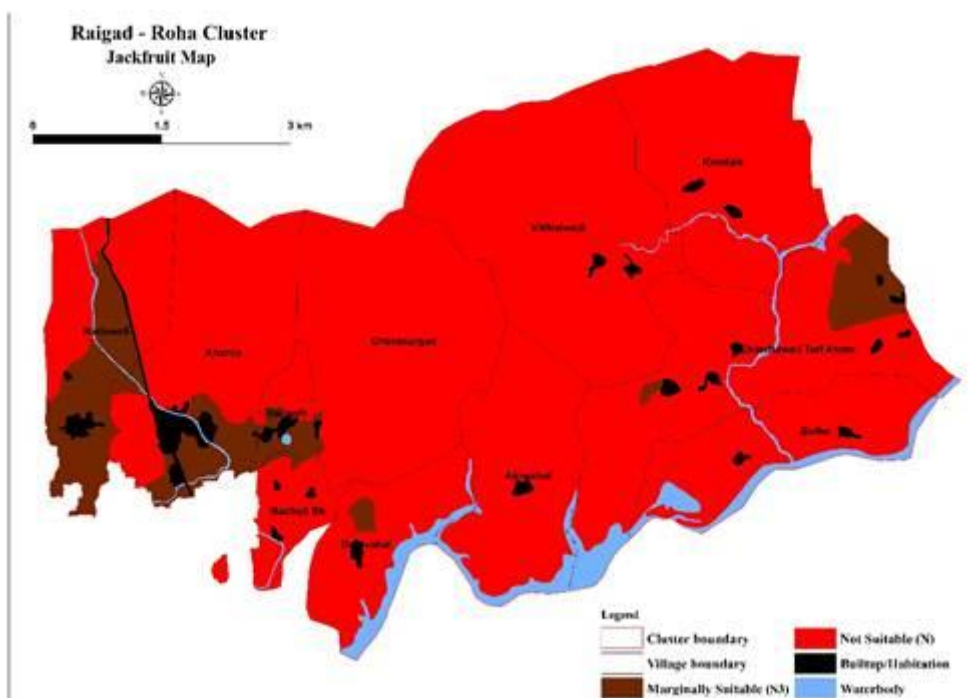
**Fig. 4.24 Soil site suitability map for Arecanut cultivation**

#### 4.8.4 Soil-Site Suitability for Jackfruit Cultivation

About 339.4 ha (7.7%) of the watershed area is marginally suitable(S3) for Jackfruit cultivation. While the former class represents areas with more acceptable conditions for crop growth, the latter would permit cultivation after following recommended conservation or ameliorative measures. About 86.2% of the watersheds was identified as not suitable (N) for jackfruit cultivation due to severe soil and site limitations (Table 4.29, Fig. 4.25).

**Table 4.29 Area under suitability sub-classes for Jackfruit cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S3)	339.4	7.7
2	Not Suitable (N)	3818.7	86.2
3	Habitation/Built up	94.1	2.1
4	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



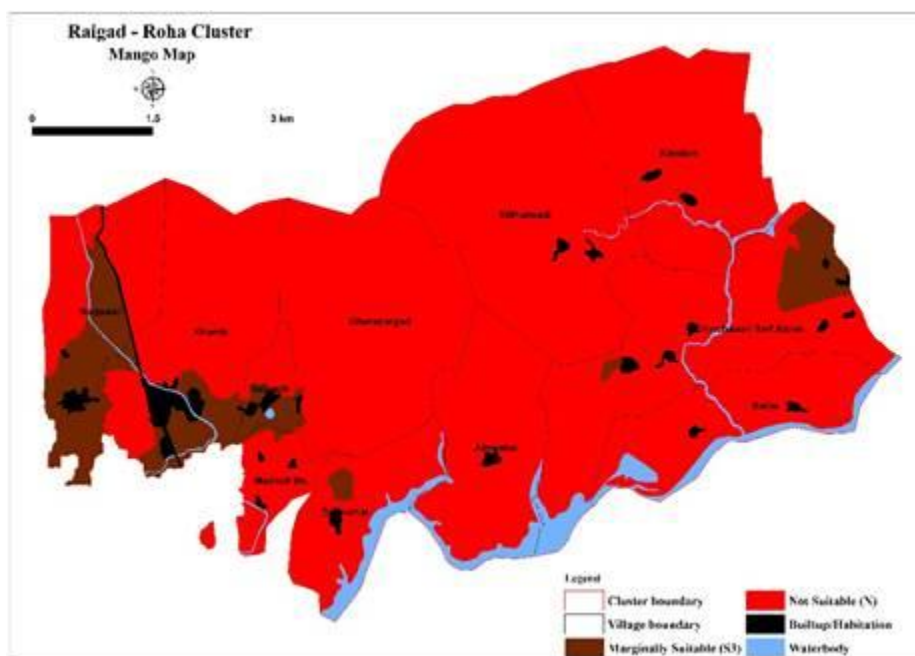
**Fig. 4.25 Soil site suitability map for Jackfruit cultivation**

#### **4.8.5 Soil-Site Suitability for Mango Cultivation**

The soils of the watershed were evaluated for mango cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.31. The results indicate that about 339.4 ha (7.7%) of the watershed area is found to be marginally suitable (S3) for the crop, reflecting moderate to severe limitations related to soil and terrain parameters that may restrict yield potential unless appropriate agronomic management practices are adopted. Approximately, 86.2% of the watershed area is not suitable (N) for mango cultivation due to severe soil and site constraints. (Table 4.30, Fig. 4.26).

**Table 4.30 Area under suitability sub-classes for Mango cultivation**

<b>Sr. No.</b>	<b>Suitability class</b>	<b>Area (ha)</b>	<b>Percent (%)</b>
1	Marginally Suitable (S3)	339.4	7.7
2	Not Suitable (N)	3818.7	86.2
3	Habitation/Built up	94.1	2.1
4	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



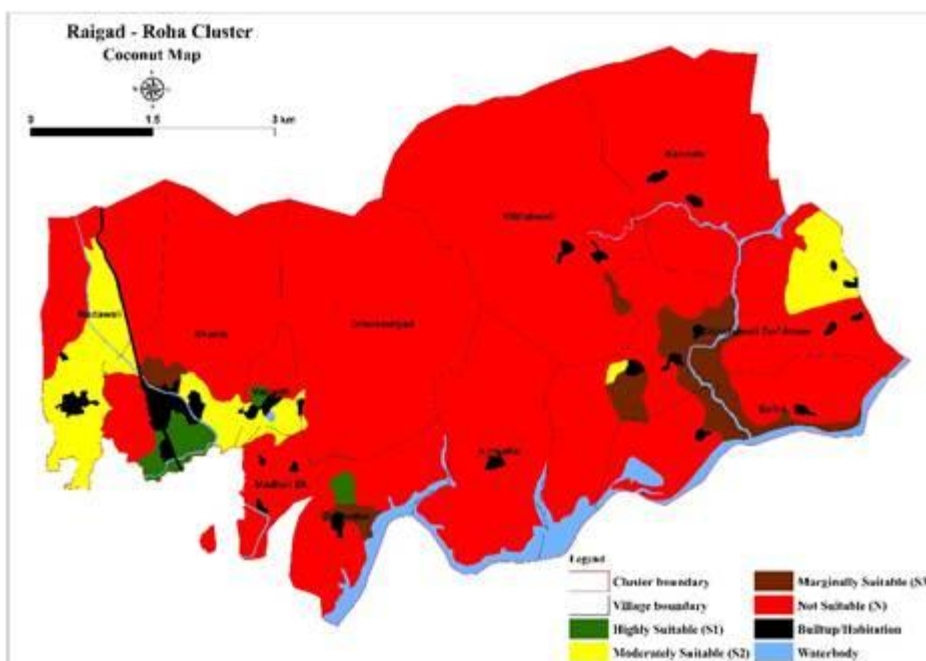
**Fig. 4.26 Soil site suitability map for Mango cultivation**

#### 4.8.6 Soil-Site Suitability for Coconut Cultivation

The soils of the watershed were evaluated for coconut cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.32. The results indicate that only 50.0 ha (1.1%) of the watershed area provides favorable soil and site conditions for optimal crop growth and is highly suitable (S1) for coconut. Areas categorized as moderately suitable (S2) cover 289.4 ha, accounting for about 6.5% of the total geographical area, representing zones where Coconut cultivation is feasible, although certain soil or site constraints may influence yield levels. Around 3.9% of the watershed was found to be marginally suitable (S3) for the crop, reflecting moderate to severe limitations related to soil and terrain parameters that may restrict yield potential unless appropriate agronomic management practices are adopted. About 82.3% of the watershed area is not suitable (N) for rice cultivation due to severe soil and site constraints (Table 4.31, Fig. 4.27).

**Table 4.31 Area under suitability sub-classes for Coconut cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Highly Suitable (S1)	50.0	1.1
2	Moderately Suitable (S2)	289.4	6.5
3	Marginally Suitable (S3)	174.4	3.9
4	Not Suitable (N)	3644.3	82.3
5	Habitation/Built up	94.1	2.1
6	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



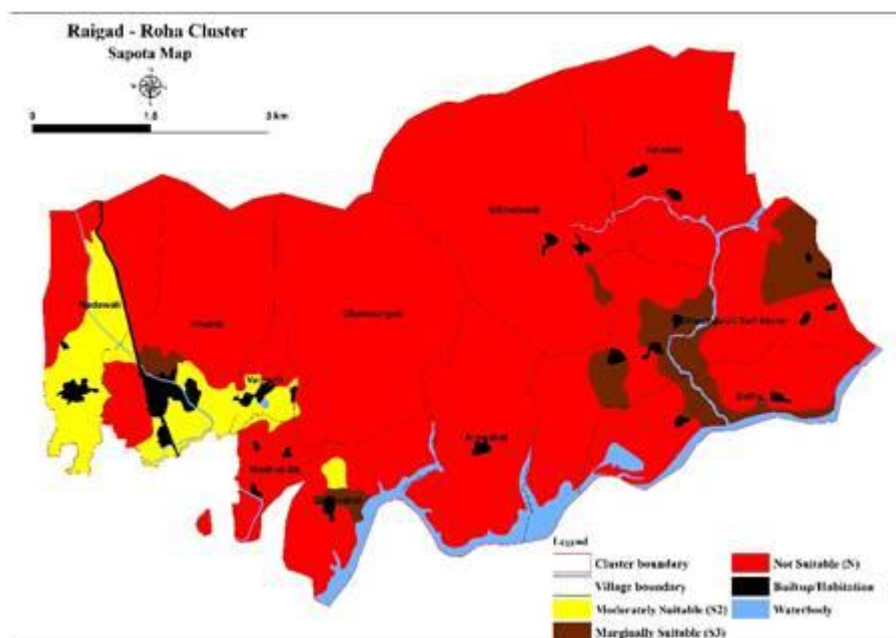
**Fig. 4.27 Soil site suitability map for Coconut cultivation**

#### 4.8.7 Soil-Site Suitability for Sapota Cultivation

The suitability assessment for sapota cultivation across the watershed reveals a broad range of suitability classes (Table 4.32, Fig. 4.28). Areas covering 261.9 ha (5.9%) and 251.9 ha (5.7%) have been classified under moderately suitable (S2) and marginally suitable (S3) categories, respectively. In contrast, 3644.3 ha (82.3%) of the area is classified as not suitable (N) for sapota cultivation due to severe soil and environmental limitations. The evaluation therefore points at about most of the watershed being conducive for sapota cultivation for obtaining desired yield levels, although the marginally suitable land could be productive, albeit after incurring soil restorative costs (appropriate land-use planning and targeted management interventions).

**Table 4.32 Area under suitability sub-classes for Sapota cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Marginally Suitable (S2)	261.9	5.9
2	Moderately Suitable (S3)	251.9	5.7
3	Not Suitable (N)	3644.3	82.3
4	Habitation/Built up	94.1	2.1
5	Waterbody	176.8	4.0
	<b>Total</b>	<b>4429.0</b>	<b>100.0</b>



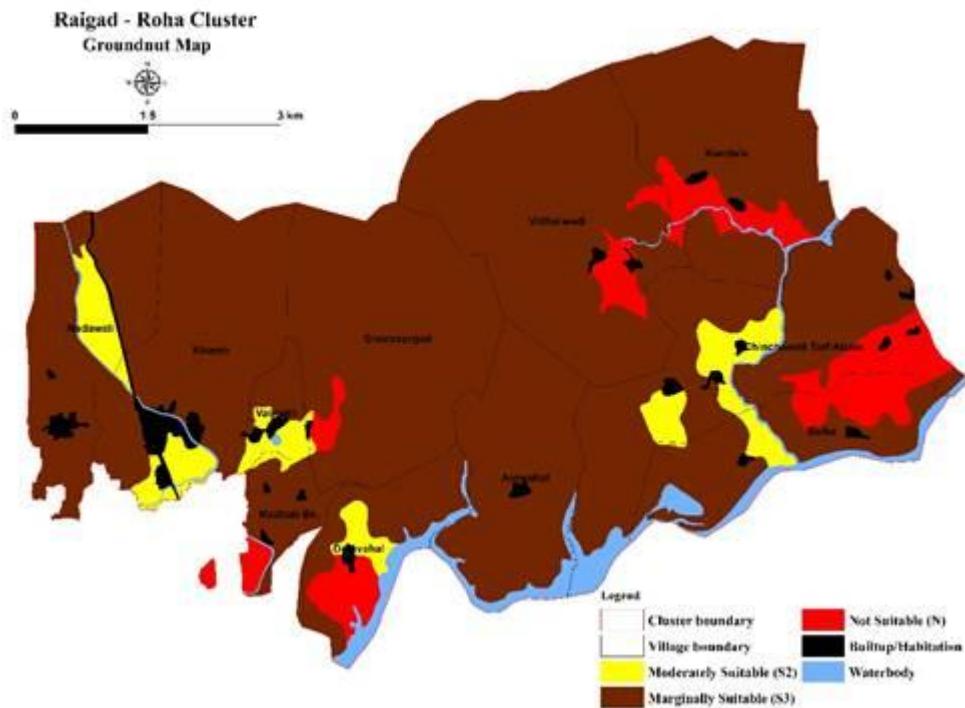
**Fig. 4.28 Soil site suitability map for Sapota cultivation**

#### 4.8.8 Soil-Site Suitability for Groundnut Cultivation

The soils of the watershed were evaluated for groundnut cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.34. The results indicate that only 229.10 ha (5.2%) of the watershed area with certain soil limitation for crop cultivation is under moderately suitable (S2) for groundnut. Around 81.7% of the watershed was found to be marginally suitable (S3) for the crop, reflecting moderate to severe limitations related to soil and terrain parameters that may restrict yield potential unless appropriate agronomic management practices are adopted. Around 7.0% of the watershed area is not suitable (N) for rice cultivation due to severe soil and site constraints. Therefore, it is suggested that more than four-fifth of the watershed may be put under groundnut cultivation, and in marginally suitable areas, appropriate agronomic and soil and water management interventions may be adopted (Table 4.33, Fig. 4.29).

**Table 4.33 Area under suitability sub-classes for Groundnut cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	229.10	5.2
2	Marginally Suitable (S3)	3618.94	81.7
3	Not Suitable (N)	310.08	7.0
4	Habitation/Built up	94.05	2.1
5	Waterbody	176.78	4.0
	<b>Total</b>	<b>4428.96</b>	<b>100.0</b>



**Fig. 4.29 Soil site suitability map for Groundnut cultivation**

#### 4.10 Soil and Water Conservation Measures

Soil and water conservation is crucial for maintaining land productivity, controlling erosion, and optimizing water retention across different landforms and land use types. In the study area, the SWC plan has been prepared to address the specific conditions of cultivable lands, forests, degraded forests, open scrub, plantation fallow, wastelands, riverbanks, and water bodies. The interventions have been designed according to slope, soil depth, soil texture, landform, and land use to ensure effective management of runoff and soil stabilization. In hilly terrain, which is characterized by shallow clay soils, cultivable lands are treated with field bunds, contour bunds, and conservation bench terraces, including the strengthening of existing bunds to ensure safe disposal of runoff water. These measures are applied across slopes ranging from 0–20%, covering small to medium-sized cultivable areas. Degraded forest patches are addressed with afforestation, contour trenches, and silt detention trenches in downstream locations, while forested areas receive silt detention trenches to stabilize soil and prevent sediment movement. Open scrub areas have been treated with afforestation and in-situ moisture conservation measures and vegetation cover.

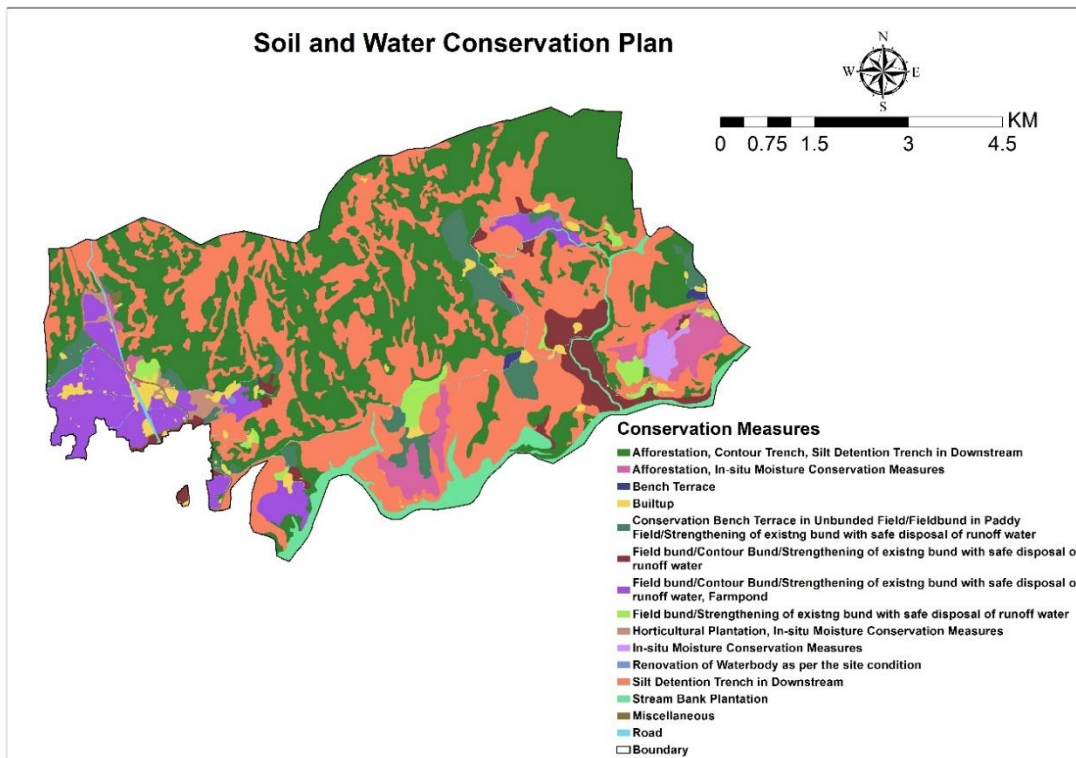
Similarly, lower pediment areas, consisting of clay and clay loam soils, employ conservation bench terraces, field bunds, contour bunds, and farm ponds for cultivable lands, with the choice of measure depending on soil depth and slope. Degraded forests are addressed with afforestation and contour trenching, while open scrub areas are designated for horticultural plantation combined with in-situ moisture conservation

measures. Upper pediments feature deeper soils supporting cultivable lands, where bench terraces, conservation bench terraces, and field bunds, sometimes combined with farm ponds, have been applied. Degraded forests are treated with afforestation, contour trenches, and silt detention trenches, while open scrub areas are addressed with horticultural plantation and in-situ moisture conservation measures. Forested areas are managed with silt detention trenches to prevent downstream sedimentation.

In plateau regions, cultivable lands are protected using bench terraces and conservation bench terraces, while degraded forests are treated with afforestation, contour trenches, and silt detention trenches. Open scrub areas receive afforestation and in-situ moisture conservation measures, and forests are managed with silt detention trenches. Other landforms have specific interventions: mounds with forest areas use silt detention trenches, valleys employ field bunds, contour bunds, strengthening of existing bunds, and farm ponds for cultivable lands, rivers use stream bank plantation, and water bodies are treated with renovation as per site condition. Built-up areas, roads, and canals are generally not assigned structural conservation measures. At the time of execution of conservation measures, farmers' opinion may be opted and appropriate design may be done. If the site condition is not appropriate for suggested measures, alternative measures may be opted.

**Table 4.34 Proposed soil and water conservation (SWC) plan for Raigad-Roha watershed**

Sr. No.	Proposed SWC Plan
1	Afforestation, Contour Trench, Silt Detention Trench in Downstream
2	Silt Detention Trench in Downstream
3	Field bund/Contour Bund/Strengthening of existing bund with safe disposal of runoff water, Farm pond
4	Conservation Bench Terrace in Unbundled Field/Field bund in Paddy Field/Strengthening of existing bund with safe disposal of runoff water
5	Stream Bank Plantation
6	Field bund/Contour Bund/Strengthening of existing bund with safe disposal of runoff water
7	Afforestation, In-situ Moisture Conservation Measures
8	Built-up
9	Field bund/Strengthening of existing bund with safe disposal of runoff water
10	In-situ Moisture Conservation Measures
11	Horticultural Plantation, In-situ Moisture Conservation Measures
12	Road
13	Canal
14	Bench Terrace
15	Miscellaneous
16	Renovation of Waterbody as per the site condition



**Fig. 4.30: Soil and water conservation measures proposed for Raigad-Roha watershed**

## CHAPTER 5

### SUMMARY AND CONCLUSION

#### 5.1 SUMMARY

- The Roha watershed of Raigad District representing a predominantly rural landscape where agriculture and forest resources together support local livelihoods. The Kundalika River is the major river traversing the watershed and serves as an important source of water for irrigation, domestic use, and other socio-economic activities in the region.
- The watershed experiences a humid tropical monsoon climate typical of the Konkan region, receiving high annual rainfall mainly during the southwest monsoon (June-September). The intense concentration of rainfall during the monsoon period leads to significant surface runoff and comparatively limited water availability during the post-monsoon months.
- Geologically, the watershed is underlain by Deccan Trap basalt formations, which form the dominant geological base of the region. Geomorphologically, the landscape is largely hilly and dissected, consisting of hills, pediments, plateaus, valleys, and minor mound features, reflecting the influence of weathering and erosion processes acting on basaltic terrain.
- The hilly landform dominates the watershed, occupying about 73.9% of the total area, followed by pediments, plateau regions, valleys, and water bodies. This heterogeneous terrain influences drainage patterns, soil development, and land-use distribution within the watershed.
- The slope analysis indicates that the watershed is mainly characterized by gently sloping terrain (3-8%), covering about 83.4% of the total area, followed by very gently sloping and moderately sloping lands. The predominance of gentle slopes provides relatively favorable conditions for agricultural activities and reduces the risk of severe soil erosion.
- The soils of the watershed vary from shallow (<25 cm) to very deep (>100 cm), with moderately deep soils (25–50 cm) covering the largest proportion of the area. These soils generally possess moderate rooting depth and water holding capacity, supporting agricultural production in suitable areas.
- In terms of soil texture, clay soils dominate the watershed, covering about 80.8% of the area, followed by clay loam and silty clay loam soils. These soils have high moisture retention capacity but require appropriate management practices to ensure proper aeration and crop productivity.
- Soil chemical analysis indicates that slightly acidic soils (pH 6.0–6.5) dominate the watershed. Electrical conductivity values are generally within the normal salinity range, indicating that the soils are non-saline and suitable for agricultural use.
- The soils exhibit very high organic carbon content across most of the watershed, suggesting favorable soil health conditions. However, the nutrient analysis reveals low nitrogen and phosphorus levels, while potassium is generally high. Among

micronutrients, iron, manganese, and copper are sufficiently available, whereas zinc deficiency is widespread in many parts of the watershed.

- The LULC analysis shows that forest land dominates the watershed, covering 76.7% of the total area, while agriculture occupies about 17.1%.
- The cropping pattern is dominated by rice cultivation, which occupies about 73.5% of the cropped area across both Kharif and Rabi seasons. Other crops include finger millet (Nachani), green gram, and mango plantations, which contribute to crop diversification and household income.
- Crop productivity analysis indicates that Rabi rice yields are higher than Kharif rice, while green gram and mango provide comparatively higher economic returns, contributing to improved farm income in the watershed.
- The landholding pattern is dominated by marginal farmers, accounting for 88.14% of the total farmers, with an average holding size of only 0.54 ha. This indicates that agriculture in the watershed is characterized by small and fragmented landholdings, which limits large-scale mechanization and advanced agricultural practices.
- The educational profile of the villages shows moderate levels of literacy, with primary and secondary education dominating across most villages. However, some villages still show relatively high illiteracy rates, which may affect awareness and adoption of improved agricultural technologies.
- Runoff analysis indicates that a significant portion of rainfall is lost as surface runoff, with an average annual runoff of about 1804 mm, representing approximately 41.1% of the total rainfall. Most of the runoff occurs during July and August, when rainfall intensity is highest and soil saturation levels increase.
- The groundwater potential zone analysis reveals that only 18.3% of the watershed falls under good to very good groundwater potential, while the remaining 81.7% falls under moderate to very poor potential zones, highlighting the limited groundwater availability in the region.
- Soil-site suitability analysis indicates that most of the watershed area is marginally suitable or unsuitable for several horticultural crops such as mango, cashew, coconut, sapota, and jackfruit due to soil depth, slope, and terrain limitations. Rice cultivation shows comparatively better suitability in low-lying areas.
- A comprehensive soil and water conservation plan includes structural and vegetative measures such as field bunds, contour bunds, bench terraces, farm ponds, afforestation, contour trenches, silt detention trenches, and stream bank plantation to reduce runoff, control soil erosion, enhance groundwater recharge, and improve agricultural sustainability.

## **5.2 CONCLUSION**

The present study demonstrates the effective use of integrated geospatial techniques along with field-based observations for comprehensive watershed assessment and planning in the Roha watershed of Raigad district under the framework of the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). The systematic analysis of terrain characteristics, drainage pattern, slope distribution, soil resources, LULC, and hydrological behavior has provided a detailed understanding of the natural resource base of the watershed. Although the region

receives high rainfall under humid tropical climatic conditions of the Konkan belt, a considerable portion of this rainfall is lost as surface runoff due to the predominance of hilly terrain, moderately sloping landscapes, and limited water harvesting structures. Consequently, water availability during the post-monsoon period becomes constrained, which may affect crop productivity and groundwater recharge in the watershed. The soil resource assessment indicates noticeable spatial variability in soil depth, texture, and fertility across the watershed. The soils are predominantly clayey, slightly acidic, and non-saline with generally high organic carbon content, which provides favorable conditions for crop growth. However, deficiencies of essential nutrients such as nitrogen and phosphorus, along with widespread zinc deficiency, may limit crop productivity if appropriate nutrient management practices are not adopted. The predominance of moderately deep soils combined with the presence of shallow soils in upland areas highlights the need for effective soil conservation measures to minimize erosion and improve moisture retention. Runoff analysis further reveals that a significant proportion of rainfall occurs within a short monsoon period, leading to substantial runoff losses. Groundwater potential assessment indicates that only a limited portion of the watershed has good to very good groundwater potential, emphasizing the need for improved water conservation and recharge measures. The evaluation of soil-site suitability for different crops indicates that rice remains the principal crop cultivated in low-lying areas, while upland areas show limited suitability for horticultural crops such as mango, cashew, coconut, and sapota due to constraints related to soil depth, slope, and terrain conditions. Nevertheless, crop diversification and improved management practices can enhance farm income and strengthen the agricultural system in the watershed. Overall, the Land Resource Inventory (LRI) study of the Roha watershed provides a scientific basis for sustainable watershed management. The proposed soil and water conservation interventions, including structural measures such as field bunds, contour bunds, bench terraces, farm ponds, and vegetative measures like afforestation, contour trenching, and stream bank stabilization, will help reduce runoff, control soil erosion, improve groundwater recharge, and enhance soil moisture availability. The implementation of these integrated watershed management strategies will promote sustainable land use planning, improved agricultural productivity, enhanced water resource management, and better livelihood opportunities for farming communities in the Roha watershed of Raigad district.

## ANNEXURE - 1

### **Morphometric Analysis**

Morphometric analysis was carried out to understand the drainage characteristics and hydrological behaviour of the study area. A Digital Elevation Model (DEM) was used as the primary dataset to derive terrain and drainage information. The DEM was processed in a Geographic Information System (GIS) environment to remove sinks and generate flow direction and flow accumulation grids. Based on the flow accumulation threshold, the drainage network was extracted and stream orders were assigned using the Strahler stream ordering method.

Using the derived drainage network and flow direction layers, watershed and sub-watershed boundaries were delineated by identifying outlet points along the main drainage channels. The resulting hydrologically closed units were used as the basis for morphometric analysis. Linear, areal, and relief morphometric parameters were computed using standard equations widely adopted in geomorphological studies (e.g., Horton, 1945; Strahler, 1964; Schumm, 1956). Linear parameters such as number of streams, stream length, bifurcation ratio, channel length, and basin perimeter were calculated from the extracted stream network. Areal parameters including basin area, drainage density, stream frequency, form factor, elongation ratio, circularity ratio, compactness coefficient, and length of overland flow were derived to evaluate watershed shape, drainage efficiency, and runoff potential. Relief parameters such as basin relief, relief ratio, ruggedness number, and Melton ruggedness number were estimated using elevation data from the DEM to assess terrain characteristics and erosion susceptibility.

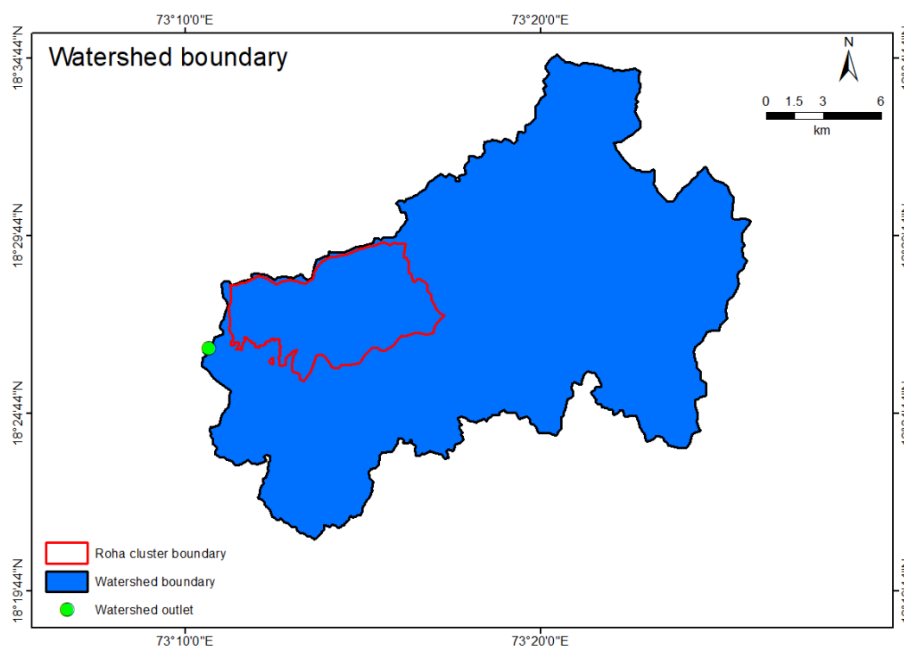
The morphometric analysis was conducted at the watershed and sub-watershed scale, as these parameters depend on natural drainage boundaries rather than administrative limits. The derived indices were subsequently interpreted to understand runoff generation, erosion susceptibility, and groundwater recharge potential within the watershed system. The results were further used to support soil and water conservation planning and watershed management strategies for the study area.

### **Morphometric analysis of Roha cluster, Raigad**

The runoff estimation, groundwater potential zone (GWPZ) mapping, and soil and water conservation (SWC) planning were performed at the village-cluster level to facilitate site-specific evaluation and practical implementation. In contrast, morphometric analysis was carried out at the watershed level because morphometric parameters are governed by natural drainage boundaries rather than administrative limits. Morphometric analysis involves the quantitative assessment of drainage network characteristics, basin geometry, slope, and relief, all of which directly influence runoff generation, soil erosion, and groundwater recharge. These parameters must be derived

from a hydrologically closed unit defined by natural divides. A watershed represents such a unit, where streams develop in a hierarchical order and converge toward a common outlet, enabling accurate computation of indices such as drainage density, bifurcation ratio, stream frequency, form factor, and relief ratio.

Village clusters, being administrative units, do not correspond to complete drainage systems. As streams frequently traverse village boundaries, conducting morphometric analysis at the cluster level would produce truncated stream networks and distorted basin geometry, thereby leading to unreliable hydrological interpretation. Therefore, morphometric analysis was intentionally performed at the watershed level to maintain hydrological accuracy, while runoff estimation, GWPZ mapping, and SWC planning were undertaken at the village cluster level for effective local implementation. This integrated framework links natural hydrological processes with decentralized planning for sustainable water resource management. The Roha cluster, Raigad, Maharashtra, comprises 11 villages. Together, these villages constitute the study cluster having one sub-watershed Fig. 1.

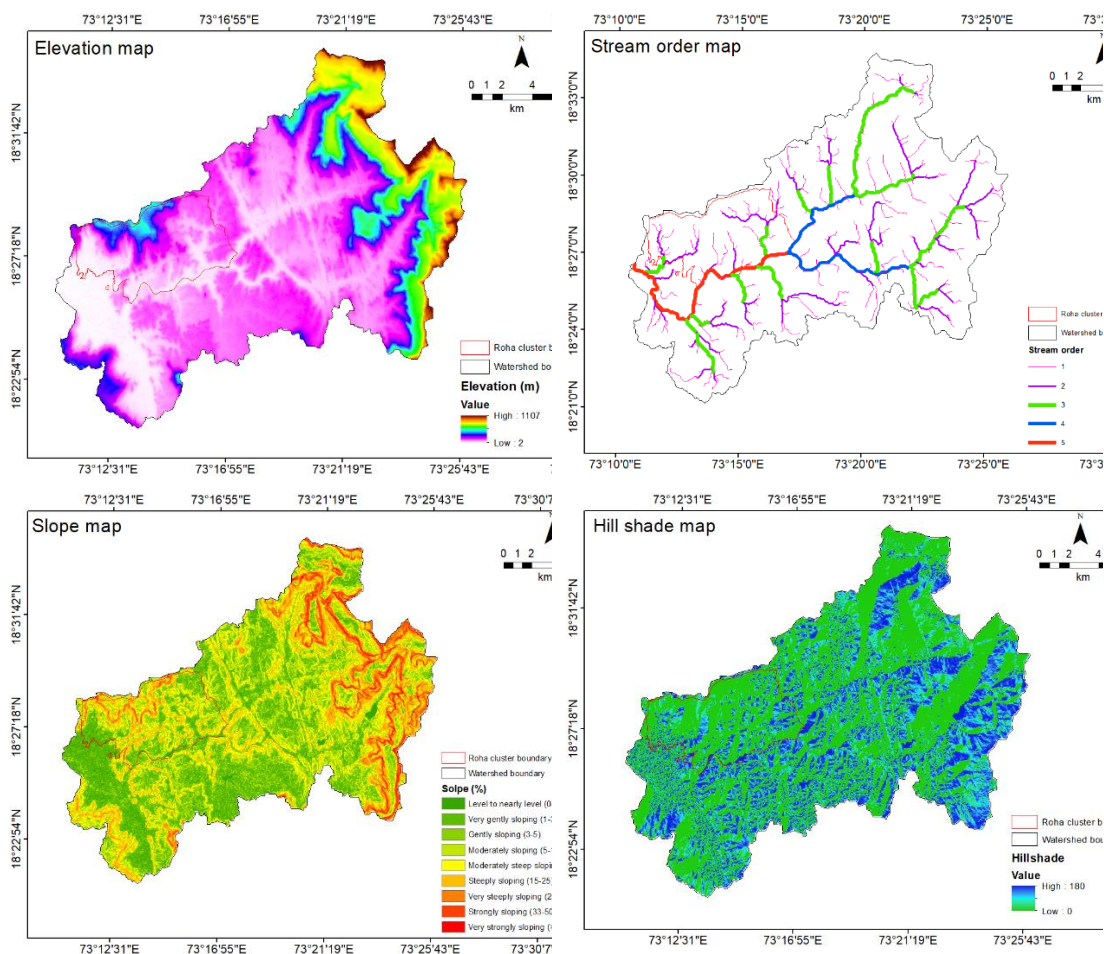


**Fig. 1. Map of Raigad-Roha Cluster depicted through sub-watershed**

**Table 1. Distribution of area under different sub-watershed, Raigad-Roha**

Sl. No.	Sub-watershed name	Sub-watershed order	Elevation (m)	Area (km <sup>2</sup> )	Flow origination
1	W1	5 <sup>th</sup>	2 - 1107	345.82	East to west
			<b>Total</b>	<b>345.82</b>	

The watershed wise area, their order, elevation range and drainage network are presented in Table 1 and in Fig 1. The morphometric characteristics of sub-watershed are analysed under three aspects: linear, areal, and relief.



**Fig. 2: Elevation, stream network, slope and hill shade map of sub-watershed**

### Linear aspect

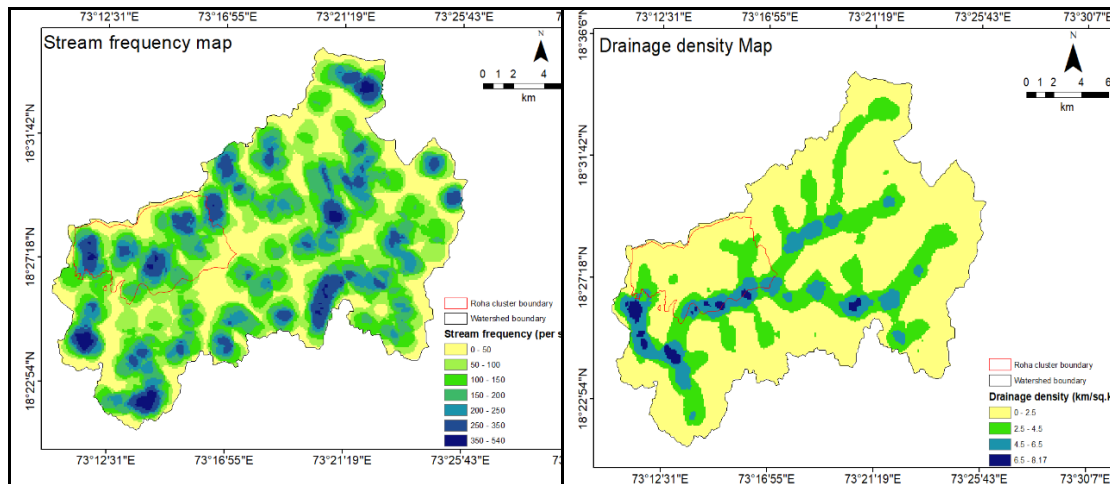
Linear morphometric parameters focus on the stream network characteristics and its influence on runoff and watershed behaviour. The morphometric analysis of the sub-watersheds shows clear variation in drainage characteristics. W1 has the number of streams (286) and total stream length (349.3 km), indicating a well-developed drainage network Table 2. The bifurcation ratio indicated as 4.2, suggesting relatively greater structural influence watershed. Mean channel length and valley length of watershed, reflecting more mature channel development. Channel index of watershed W1 (1.20), indicating greater sinuosity. Basin perimeter of W1 (120 km), confirming it as the most extensive sub-watershed.

**Table 2. Linear morphometric parameters of sub-watersheds, Raigad-Roha cluster**

Sl. No.	Morphometric parameter	Symbol	Unit	W1
1	No. of streams	Nu	No	286
2	Stream length	Lu	km	349.3
3	Bi-furcation ratio	Rb	-	4.2
4	Mean channel length	Cl	km	40.69
5	Valley Length	VI	km	35.28
6	Channel Index	Ci	-	1.20
7	Minimum areal distance	Adm	km	33.19
8	Valley Index	Vi	-	1.06
9	Basin perimeter	P	km	120

### Areal Aspects

Areal parameters describe the two-dimensional properties of the watershed, including shape, size, and drainage efficiency, which directly influence runoff and groundwater recharge. Basin area of watershed W1 (345.82 km<sup>2</sup>) and mean basin width is 8.4 km. Form factor (Ff) and elongation ratio (Re) in W1 (0.20 and 0.51), suggesting a comparatively more circular basin. Circularity ratio (Rc) of W1 is 0.30, while compactness coefficient (Cc) as 1.83, reflecting greater basin irregularity. Standard sinuosity index (Ssi) as 1.15, indicating relatively higher channel sinuosity in W1. Drainage parameters show that stream frequency (Fs) is 0.83 per km<sup>2</sup> and Drainage density (Dd) as 1.0 km/km<sup>2</sup>. Drainage intensity (Di) follows a similar trend, with the highest value as 0.82. Length of overland flow (Lg) as (0.83 km) indicating shorter runoff travel distance in W1.



**Fig. 3: Steam frequency and drainage density map of sub-watershed**

**Table 3. Areal morphometric parameters of sub-watersheds, Raigad-Roha cluster**

Sr. No.	Parameter	Symbol	Method/Formula	Unit	W1
1.	Mean basin width	Wb	$Wb = A/Lb$	km	8.4
2.	Basin area	A	GIS Analysis	km <sup>2</sup>	345.8
3.	Relative perimeter	Pr	$Pr = A/P$	km	2.8
4.	Length area relation	Lar	$Lar = 1.4 * A^{0.6}$	km <sup>2</sup>	46.7
5.	Lemniscate's	k	$K = Lb^2/A$	-	4.9
6.	Form factor	Ff	$Ff = A/Lb^2$	-	0.2

7.	Elongation ratio	Re	$Re = 2/Lb*(A/\pi)^{0.5}$	-	0.5
8.	Circularity ratio	Rc	$Rc = 12.57*(A/P^2)$	-	0.3
9.	Compactness coefficient	Cc	$Cc = 0.2841*P/A^{0.5}$	-	1.8
10.	Standard sinuosity index	Ssi	$Ssi = Ci/Vi$	-	1.1
11.	Stream frequency	Fs	$Fs = Nu/A$	Per km <sup>2</sup>	0.8
12.	Drainage density	Dd	$Dd = Lu/A$	km/km <sup>2</sup>	1.0
13.	Drainage intensity	Di	$Di = Fs/Dd$	-	0.8
14.	Length of overland flow	Lg	$Lg = A/2*Lu$	km	0.8

### Relief Aspects

The maximum basin height (Z) of W1 (1107 m) and total basin relief (H) is also maximum as (1105 m) Table 4. Relief ratio (Rhl) as W1 (26.8), indicating steeper terrain conditions, while Relative relief ratio (Rhp) of W1 (920.4) suggesting higher relief intensity in W1. The ruggedness number (Rn) of watershed W1 (0.90), reflecting more dissected and erosion-prone terrain. Similarly, the Melton ruggedness number (MRn) is shown in W1 (59.4), indicating comparatively higher susceptibility to runoff and erosion processes.

**Table 4. Relief morphometric parameters of sub-watersheds, Raigad-Roha cluster**

Sl. No.	Parameters	Symbol	Methods/Formula	W1
1.	Height of at basin mouth	z	DEM	2.0
2.	Maximum height of the basin	Z	DEM	1107.0
3.	Total basin relief	H	$H = Z - z$	1105.0
4.	Relief ratio	Rhl	$Rhl = H / Lb$	26.8
5.	Relative relief ratio	Rhp	$Rhp = H * 100 / P$	920.4
6.	Ruggedness number	Rn	$Rn = Dd*(H/1000)$	0.90
7.	Melton Ruggedness number	MRn	$MRn = H / A^{0.5}$	59.4

The slope distribution of watershed W1 indicates a predominantly undulating to moderately sloping terrain with the presence of both gentle and steep slopes. The moderately sloping class (5-10%) occupies the largest portion of the watershed, covering 76.47 km<sup>2</sup> (22.11%), indicating that a considerable part of the basin experiences moderate runoff conditions. This is followed by the very gently sloping class (1-3%), which accounts for 65.37 km<sup>2</sup> (18.90%), and the gently sloping class (3-5%) covering 53.61 km<sup>2</sup> (15.50%), representing relatively stable areas suitable for agricultural activities. The moderately steep slopes (10-15%) and steep slopes (15-25%) cover 51.56 km<sup>2</sup> (14.91%) and 49.98 km<sup>2</sup> (14.45%), respectively, indicating the presence of erosion-prone zones within the watershed. In addition, very steep slopes (25-33%) and strongly sloping areas (33–50%) account for 17.91 km<sup>2</sup> (5.18%) and

14.00 km<sup>2</sup> (4.05%), respectively, while very strongly sloping areas (>50%) occupy only 2.25 km<sup>2</sup>, representing a very small portion of the watershed. The level to nearly level class (0–1%) covers 14.67 km<sup>2</sup> (4.24%), indicating limited flat terrain mainly in valley bottoms.

Based on the morphometric characteristics and slope distribution of watershed W1, a suitable soil conservation and land use planning strategy is necessary to reduce soil erosion and manage runoff effectively. The morphometric analysis indicates a well-developed drainage network with considerable stream length, moderate drainage density, and relatively high relief parameters such as basin relief, relief ratio, ruggedness number, and Melton ruggedness number, which together suggest strong runoff generation and a higher susceptibility to erosion. The slope distribution shows that a significant portion of the watershed falls under moderately sloping (5-10%) and steeper slope categories, indicating undulating to rugged terrain conditions. Therefore, land use planning should be based on slope capability and drainage characteristics. In very gently to gently sloping areas (1-5%), agricultural activities can be practiced with conservation measures such as field bunding, graded bunds, mulching, and strip cropping to reduce surface runoff and enhance soil moisture retention. In moderately sloping lands (5–10%), contour farming, terracing, vegetative hedges, and conservation tillage should be implemented to control soil loss and improve water infiltration. In steep and very steep slopes (>15%), which are more prone to erosion, afforestation, agro-forestry, and pasture development are recommended to stabilize the soil and maintain continuous vegetation cover. Additionally, check dams, gully plugs, contour trenches, and percolation tanks should be constructed along drainage lines and lower catchment areas to slow runoff, trap sediments, and enhance groundwater recharge. Thus, integrating morphometric analysis with slope-based land use planning will help identify priority zones for conservation measures, ensuring improved watershed stability, reduced soil degradation, and sustainable management of land and water resources in watershed W1.





