

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

**(WDC-2.0)3/2021-22: Tuljapur, Dist - Dharashiv**



**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)	Smt. Nisha A. Lade
Dr. Sirisha Adamala (Co-PI)	Sh. J.B. Padole
Dr. P.C. Moharana (Co-PI)	Dr. P.S. Butte
Dr. Jyotiprava Dash (Co-PI)	Sh. Abhishek Meshram
Dr. R.K. Naitam (Co-PI)	Sh. Anmol Ukey
Dr. A.O. Shirale (Co-PI)	Sh. Shyam Bhoyar
Dr. B. Dash (Co-PI)	<b>Cover page design and Layout</b>
Dr. M.S. Raghuvanshi (Co-PI)	Sh. Prakash V. Ambekar
Sh. H.L. Kharbikar (Co-PI)	
Dr. U. Surendran (Co-PI)	
<b>Contractual Project Staff (field and laboratory)</b>	
Er. Aniket Rajput	Dr. Snehalata Chaware
Dr. Abhay Gedam	Ms. Babali Mange
Sh. Anantraj Jadhav	Ms. Kalpana Ghate
Sh. Bhushan Deshkar	Ms. Vishakha Thakre
Sh. Prashant Pakhare	Ms. Shabana Sheikh
Sh. Nihal Uike	Ms. Chetana Thawale
Sh. Ravi Warhade	
Sh. Dinesh Sawale	
Sh. Pratik Borkar	
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 Dharashiv (WDC-2.0)3/2021-22 watershed located within the Tuljapur Taluka of Dharashiv District, Maharashtra, underlain with the characteristic basaltic terrain of the Deccan Plateau, with a non-perineal tributary of Bor river flowing through 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 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 Tuljapur 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 Dharashiv (WDC-2.0 3/2021-22) sub-watershed of Tuljapur taluka 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
Dharashiv	Dharashiv (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	Dodamarga	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

### TULJAPUR WATERSHED AT A GLANCE

#### 2.1 Location and Extent

The village cluster watershed is located in Tuljapur Taluka which is part of the administrative subdivisions of Dharashiv District, within the Marathwada Region of Maharashtra and the taluka is famous for Tuljabhavani temple at Tuljapur. Geographically the cluster area lies in between 17.764698° to 17.898385° N latitude and 76.043201° to 76.198396° E longitude. The Taluka falls under semi-arid region with agriculture largely dependent on monsoon rainfall. The villages in the cluster primarily rely on rainfed cultivation, with limited irrigation supported by surface and groundwater resources.

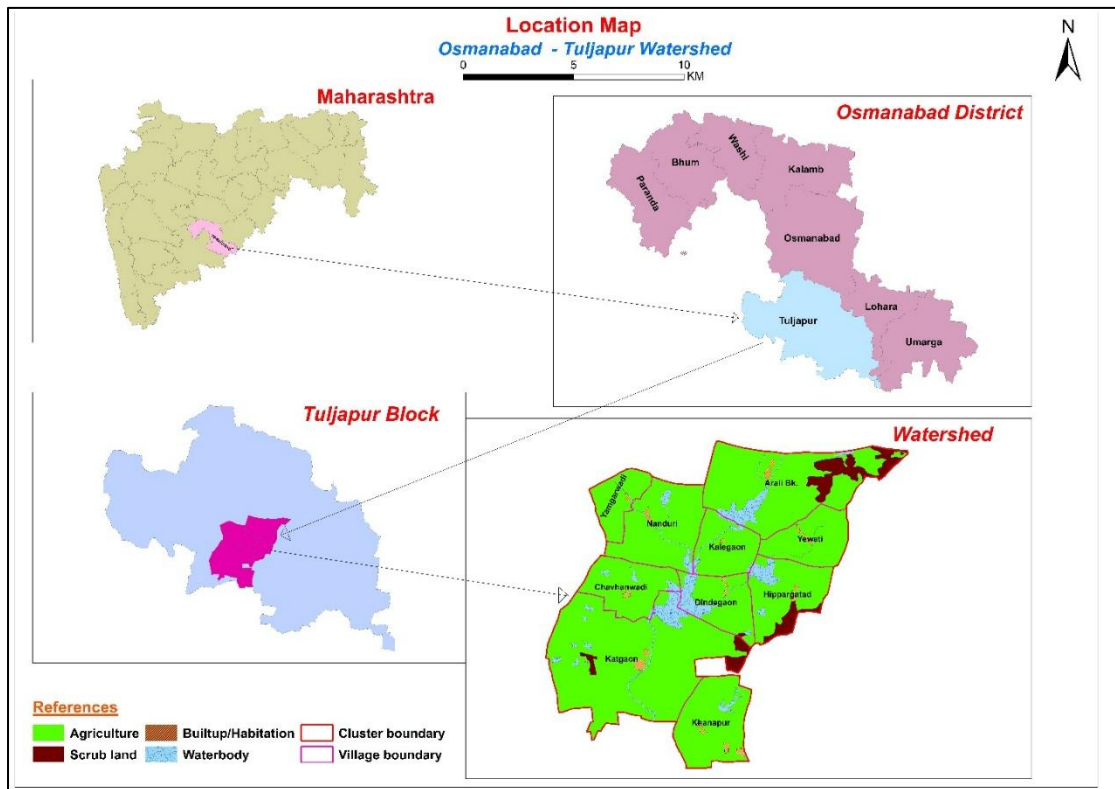


Fig. 2.1. Location map of the Tuljapur watershed

Tuljapur Taluka is predominantly rural, comprising dispersed villages with an agrarian economy largely dependent on rainfed agriculture. The landscape varies from gentle slopes in most areas to moderate relief in hill and ridge zones. 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	Dharashiv
2	Taluka	<b>Tuljapur</b>
3	Revenue Division	Aurangabad
4	Total sub-watershed Area	Approx. 12874 ha
6	Villages	10 (Arali Bk., Chavhanwadi, Dindegaoon, Hippargatad, Katgaon, Katgaon, Khanapur, Nanduri, Yamgarwadi, Yewati)
7	Major River	Local non perennial River which is tributary of Bori River
8	Climate	Semi-arid
9	Average annual Rainfall	653 mm

## 2.2 Geology

Geologically, the Tuljapur watershed is predominantly underlain by the Deccan Trap basalt, which forms the major rock formation of the district. Most parts of the area consist of basaltic lava flows, while alluvial deposits occur along the major drainage channels. In some locations, laterite occurs as small isolated capping over the basalt flows, particularly in the south-eastern part of the district. The Deccan Trap flows generally occur in horizontal layers over a wide area, giving rise to the typical plateau topography of the region. These flows occur in a layered sequence with thickness ranging from a few centimeters to several meters. Each individual flow typically shows massive basalt at the bottom and vesicular or amygdaloidal basalt towards the top, and the flows are often separated by a marker horizon known as bole beds.

## 2.3 Geomorphology

The geomorphology of the Tuljapur watershed reflects the typical landscape developed over the Deccan Plateau region of Dharashiv district. The area forms part of the Balaghat Plateau, which generally slopes towards the south and southwest. The terrain shows a mixture of plateau surfaces, gently sloping areas and undulating landforms that have developed due to long-term weathering and erosion of basaltic rocks. The district lies within the Godavari and Krishna River basins, and the regional drainage pattern is influenced by these major river systems. In the Tuljapur area, the Bori River, which later joins the Sina River, forms an important drainage course. Over time, natural processes such as erosion, weathering and runoff have shaped the present landscape, resulting in a range of landform features across the watershed.

## 2.4 Physiography and Soil

The village cluster watershed in Tuljapur Taluka exhibits elevation ranging from 490 m to 630 m above mean sea level. The terrain comprises distinct geomorphic units including escarpment plateau, pediment, pediplain, hills, and valley landforms. Slope within the watershed varies from nearly level (0%) to steep slopes of about 43%, with higher slopes associated with hill and escarpment areas, and lower slopes occurring in pediplain and valley portions. Soils in the watershed have developed over basaltic lithology and show

variation in texture across different landforms. The dominant soil textures identified in the watershed include silty clay loam, sandy clay loam, silty clay, and clay. These soil types occur in different proportions across the watershed and reflect local topographic and geomorphic conditions.

## **2.5 Climate**

The watershed falls under Tuljapur taluka of Dharashiv district, which experiences a hot and dry climate typical of the Marathwada region of Maharashtra. The area remains dry for most of the year except during the south-west monsoon season from June to September, which contributes the major share of the annual rainfall. The average annual rainfall in Tuljapur is about 650 mm, though it varies from year to year. Summers are generally hot and dry, while winters are comparatively cooler. The mean maximum temperature may rise to around 42 °C during summer, whereas the mean minimum temperature during winter may fall close to about 8 to 10 °C. Rainfall in the region is often irregular and unevenly distributed, and the area frequently experiences dry spells due to the variability of the monsoon.

## **2.6 Drainage**

The drainage of the watershed in Tuljapur taluka is mainly controlled by a local non-perennial river, which is a tributary of the Bori River. The drainage network consists of several seasonal streams and natural nalas that carry runoff during the monsoon season. These streams generally flow only during periods of rainfall and remain dry during the rest of the year due to the semi-arid climatic conditions of the region. The surface runoff generated during the monsoon is conveyed through these drainage lines and ultimately joins the Bori River system. The drainage pattern is mainly influenced by the natural slope and terrain of the watershed, which directs runoff towards the main river channel. Thus, the drainage network plays an important role in draining monsoonal runoff from the watershed area.

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

### **2.7.1 Cropping Pattern**

The cropping pattern in the watershed villages of Tuljapur taluka is predominantly rainfed, with cereals and pulses cultivated mainly during the kharif season. Major kharif crops include jowar, bajra, tur, moong, urad, soybean, and groundnut. Rabi cropping is largely confined to rabi jowar and gram, practiced on a limited scale in areas having access to groundwater or surface water support from watershed structures such as check dams and farm ponds. Overall, agriculture in the watershed reflects low irrigation intensity and strong dependence on monsoonal rainfall, with irrigated cropping restricted to small pockets. In these irrigated zones, commercial crops like sugarcane and grapes are also cultivated, though their area remains limited compared to cereals and pulses.

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

Tuljapur taluka is characterized by a predominantly rural population. The social composition is marked by a significant representation of marginalized communities,

notably Scheduled Castes and Scheduled Tribes. The district's overall literacy rate stands at 77.5%. The local economy demonstrates a high degree of dependency and is overwhelmingly agrarian, with nearly half of the populace categorized as non-workers. Within the active workforce, the economy exhibits high vulnerability to climatic conditions, as over one-third of the workforce relies directly on agriculture, functioning either as wage-earning agricultural laborers or as land-owning cultivators.

## **2.8 Water Resources**

### **2.8.1 Surface Water**

Surface water resources in the cluster watershed are seasonal and monsoon-dependent, controlled by a local river system and associated seasonal nala streams. In the upper reaches, a storage structure near Arali Bk. village intercepts runoff from a local stream, and its overflow joins the main river channel. Along this river, the Harni Dam at Katgaon has been constructed and serves as the principal surface water reservoir in the watershed. Downstream of Harni Dam, the river continues to drain the watershed, receiving additional inflow from seasonal nalas during periods of rainfall. Other surface water bodies, including Pajar Talav and Chilim Khada Lake, are located along secondary drainage lines and function as seasonal storages, along with several smaller water bodies that provide localized, short-term storage. Overall, due to their non-perennial nature, surface water bodies provide limited and variable availability, serving mainly to regulate monsoonal runoff and offer supplementary water support within the watershed.

### **2.8.2 Groundwater**

Groundwater occurs mostly in weathered and fractured zones of basalt rock. According to the Dynamic Ground Water Resources of Dharashiv District (CGWB), 2024, annual extractable ground water resources place the region under the “safe” category, with the groundwater extraction level is 50%.

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

Agricultural lands in the region are heavily dependent on variable rainfall, so water scarcity constitutes a persistent challenge, with groundwater and wells serving as the primary sources of irrigation. It is essential to prioritize micro-irrigation techniques and comprehensive water conservation strategies for the optimal management of these finite resources. Structures like check dams and percolation tanks, spread across the district, offer relief to most villages in the Tuljapur.

## **2.9 Constraints**

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

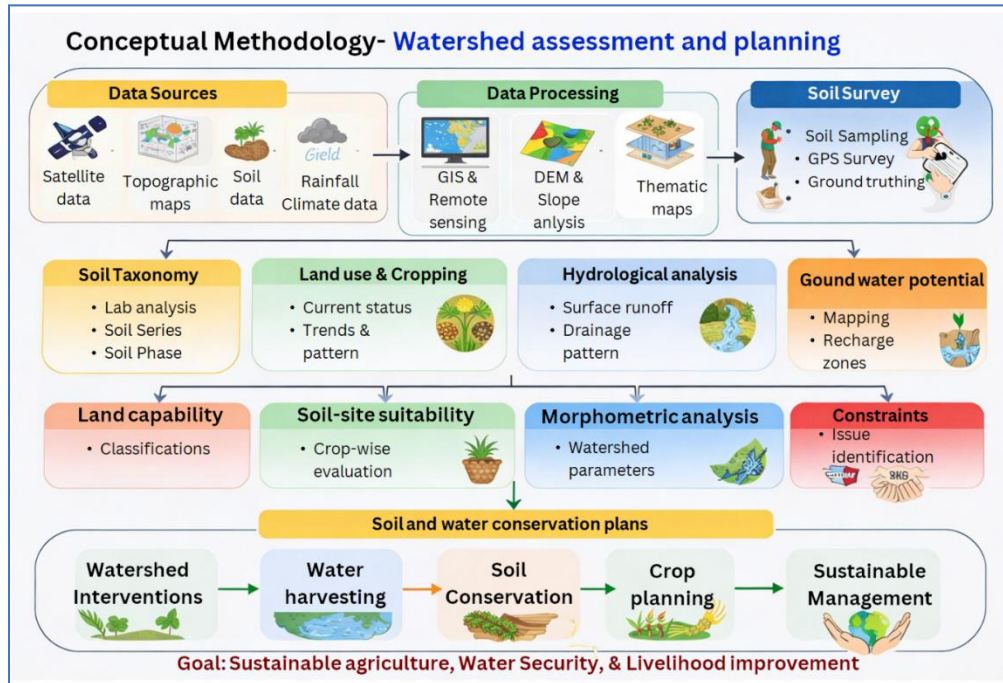
- a. Declining groundwater level trends both pre-monsoon and post-monsoon.
- b. Low and declining rainfall with frequent moderate drought condition

## 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)] was 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 Tuljapur 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 Tuljapur 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.

### **3.9 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 Tuljapur 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 Tuljapur watershed is presented in Table 4.1. It is observed that wells contribute the largest source of irrigation, having 82.6% of the total irrigated area indicates that groundwater extracted through wells is the important irrigation source in the watershed. Ponds contribute 11.4% of the total seasonal irrigation, indicating its importance of small water storage structures in providing supplemental irrigation during critical crop growth stages. Borewells have 5.4% of the total seasonal irrigation. Lift irrigation through rivers contributes 0.6% of the total seasonal irrigation, indicating that lift irrigation is practiced. The irrigation system of the watershed is highly dependent on groundwater sources, emphasizing the need for strengthening water harvesting structures, groundwater recharge measures, and efficient water management practices to ensure the long-term sustainability of agricultural production.

**Table 4.1. Seasonal Distribution of Irrigation Sources in the Tuljapur Watershed**

Sr. No.	Number of Farmers Interviewed (n)	Irrigation Source	Seasonal Water Availability	Contribution to Season's Total Irrigation (%)
1	7	Borewell	Kharif & Rabi	5.4
2	27	Pond	Kharif & Rabi	11.4
3	5	Lift irrigation	Kharif & Rabi	0.6
4	137	Well	Kharif & Rabi	82.6

##### 4.1.2 Cropping Pattern

The cropping pattern of the Tuljapur watershed is presented in Table 4.2. The gross cropped area is 580.5 ha, while the net sown area is 379.5 ha.

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

$$\text{Cropping intensity}(\%) = \frac{580.5}{379.5} \times 100 = 152.9\%$$

The cropping intensity of the area is calculated as 152.9%, indicating that a significant area of agricultural land is cultivated more than once during the year. In the Kharif season, soybean cultivated in 43.5% of the total cropped area, with a productivity of 1775.7 kg/ha, making it the important crop of the watershed. Black gram occupies 5.7% of the total cropped area with a productivity of 1249.9 kg/ha, and onion occupies 2.6% of the total cropped area with a productivity of 9835.7 kg/ha. Tur is cultivated under rainfed conditions on 2.4% of the cropped area with a productivity of 568.0 kg/ha, while gram occupies 0.9% of the cropped area with a productivity of 589.0 kg/ha.

In the Rabi season, sorghum occupies 22.1% of the total cropped area with a productivity of 864.1 kg/ha indicating its importance in the Rabi season. Wheat covers 7.2% of the cropped area with a productivity of 1168.1 kg/ha, while gram occupies 4.3% of the total cropped area with a productivity of 682.1 kg/ha. The cropping pattern of the watershed shows a dominance of soybean cultivation during Kharif and sorghum during Rabi. The high cropping intensity indicates efficient utilization of agricultural land through multiple cropping under available irrigation resources.

**Table 4.2. Crop-wise Distribution in the Tuljapur watershed**

Sr. No.	Season	Crop	No. of Farmers Interviewed (n)	Irrigation Type	Total Cropped Area (%)	Productivity (kg/ha)
1	Kharif	Soybean	220	Irrigated	43.5	1775.7
2	Rabi	Sorghum	173	Irrigated	22.1	864.1
3	Rabi	Wheat	92	Irrigated	7.2	1168.1
4	Kharif	Black gram	61	Irrigated	5.7	1249.9
5	Rabi	Gram	58	Irrigated	4.3	682.1
6	Kharif	Onion	26	Irrigated	2.6	9835.7
7	Kharif	Tur	25	Rainfed	2.4	568.0
8	Rabi	Onion	13	Rainfed	1.2	12450.2
9	Kharif	Gram	11	Irrigated	0.9	589.0

### 4.1.3 Socioeconomic Status

#### 4.1.3.1 Land holding pattern

The landholding pattern of farmers in the Tuljapur watershed is presented in the Table 4.3. From the table it was observed that small farmers (1–2 ha) constitute the larger population, 41.4% of the total farmers, having an average landholding of 1.4 ha. This is followed by semi-medium farmers (2–4 ha) accounting for 28.8% with an average landholding of 2.6 ha. Marginal farmers (<1 ha) constitute 23.9% of the farmers with an average landholding of 0.6 ha. Medium farmers (4–10 ha) account for 5.9% with an average landholding of 4.1 ha, while no farmers were recorded under the large farmer category (>10 ha). Average landholding size was found to be 1.7 ha, indicating that agriculture in the watershed cluster is characterized by small landholdings. The small and marginal farm sizes may limit farm mechanization, capital investment capacity, irrigation development, and adoption of improved agricultural technologies.

**Table 4.3. Land holding pattern in Tuljapur watershed**

Category	Criteria Land (ha)	No. of Farmers Interviewed (n)	Farmers (%)	Average Land Holding (ha)
Marginal Farmers	<1	53	23.9	0.6
Small Farmers	1-2	92	41.4	1.4
Semi-Medium Farmers	2-4	64	28.8	2.6
Medium Farmers	4-10	13	5.9	4.1
Large Farmers	>10	0	0.0	0.0
<b>Average land holding</b>				<b>1.7</b>

#### 4.1.3.2 Income distribution

The income from different crops in the Tuljapur watershed is presented in Table 4.4. Soybean occupies the largest share of the cropped area (47.2%) with an average income of 83,048 Rs, indicating that the major income-contributing crop. Sorghum is the second most important crop covering 24.5% of the cropped area with an average income of 26,349 Rs, while wheat occupies 7.8% of the cropped area with an average income of 13,324 Rs. Gram covers 5.8% of the cropped area with an average income of 24,469 Rs, whereas tur occupies 2.7% of the cropped area with an average income of 27,888 Rs. Onion cultivated on 4.1% of the area with average income of 76,200 Rs, indicating importance as a commercial crop in the watershed. Grapes occupy 0.7% of the cropped area with average income of 8,20,000 Rs. The results indicate that soybeans and sorghum dominate the cropped area, horticultural crops like grapes contribute significantly higher income. Economic importance of high-value horticultural crops in enhancing farmers' income and improving livelihood opportunities in the watershed.

**Table 4.4. Average annual income of farmers in Tuljapur watershed**

Name of Crops	No. of Farmers Interviewed (n)	Crop Area (%)	Average Income (Rs.)
Soybean	215	47.2	83048
Sorghum	135	24.5	26349
Wheat	76	7.8	13324
Gram	41	5.8	24469
Onion	32	4.1	76200
Tur	20	2.7	27888
Grapes	5	0.7	820000
<b>Total</b>	<b>524</b>		

#### 4.1.3.3 Education

The educational profile of the Tuljapur watershed is presented in Table 4.5. Kalegaon and Katgaon recorded the highest illiteracy rate (100%), where the respondents reported no formal education, indicating extremely poor educational status in these villages. Dindegaon also shows a high illiteracy rate (67%). Moderate levels of illiteracy were observed in Yamgarwadi (38%) and Chavhanwadi (22%), while comparatively lower illiteracy was

recorded in Arali and Nanduri (14% each), Khanapur (8%), Hippergatad (7%), and Yevati (5%).

With respect to primary education, Nanduri recorded the highest population (43%), followed by Hippergatad (30%), Yamgarwadi (21%), and Chavhanwadi (17%). With respect to secondary education level, the highest population was recorded in Hippergatad (48%), followed by Arali (47%), Yevati (45%), Chavhanwadi (43%), and Khanapur (40%) indicating moderate to good educational attainment in these villages. With respect to higher secondary education, Khanapur recorded the highest proportion (28%), followed by Yamgarwadi (17%), Arali (14%), and Chavhanwadi (13%). Yevati recorded the highest population (27%) with respect to Higher studies, followed by Khanapur (20%) and Arali (17%). The results indicate significant disparities in educational attainment across the villages, with some villages showing relatively better levels of secondary and higher education, while others have very high illiteracy. This educational scenario influences awareness levels, decision-making capacity and adoption of improved agricultural practices in the watershed area.

**Table 4.5. Education profile of villages in Tuljapur watershed by population**

Village	No Education (%)	Primary (%)	Secondary (%)	Higher Secondary (%)	Higher Studies (%)
Arali	14.0	8.0	47.0	14.0	17.0
Chavhanwadi	22.0	17.0	43.0	13.0	4.0
Dindegaon	67.0	5.0	24.0	0.0	5.0
Hippergatad	7.0	30.0	48.0	11.0	4.0
Kalegaon	100.0	0.0	0.0	0.0	0.0
Katgaon	100.0	0.0	0.0	0.0	0.0
Khanapur	8.0	4.0	40.0	28.0	20.0
Nanduri	14.0	43.0	29.0	4.0	11.0
Yamgarwadi	38.0	21.0	21.0	17.0	4.0
Yevati	5.0	14.0	45.0	9.0	27.0

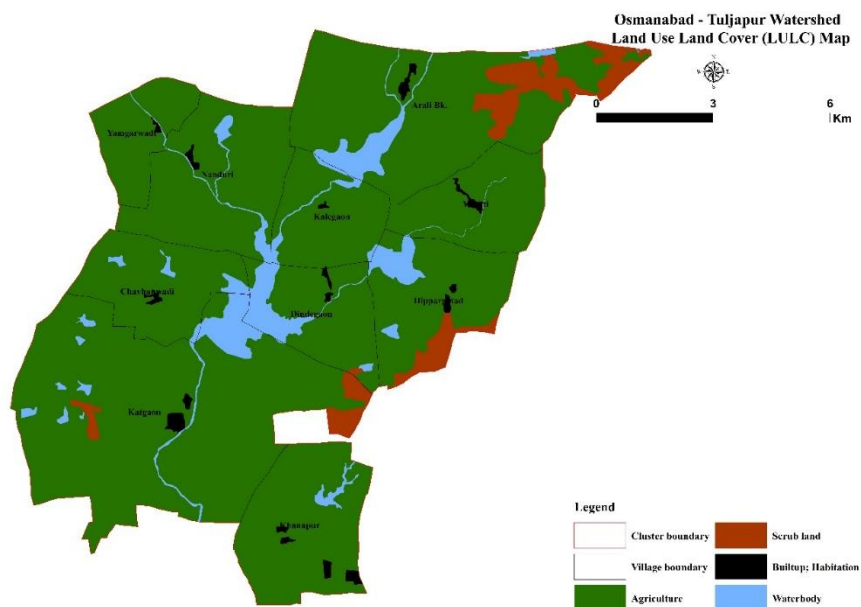
#### 4.2 Land-use/Land-cover

LULC classification is undertaken to quantify how the watershed area is distributed among different land use categories. This helps in identifying the dominance of agriculture, the extent of wastelands, and the presence of water bodies and built-up areas. Such classification provides a scientific basis for watershed planning, resource management, and prioritization of conservation measures. The classification of the area reveals that agriculture is the predominant land use type, occupying 11340 ha, and constitutes approximately 88% of the total area (Table 4.6 and Fig. 4.1). Scrub lands represent 4.5% of the area, which may indicate land degradation or areas unsuitable for cultivation. Waterbodies are limited to 821 ha, making up 6.4% of the total area, reflecting the presence

of scattered and useable surface water resources in the region. This LULC distribution highlights the dominance of agricultural activities in the area.

**Table 4.6. Land-use/land-cover statistics of Tuljapur watershed**

Land use	Area(ha)	Percent (%)
Agriculture	11339.4	88.1
Waterbody	820.8	6.4
Scrub land	581.8	4.5
Habitation	131.9	1.0
<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



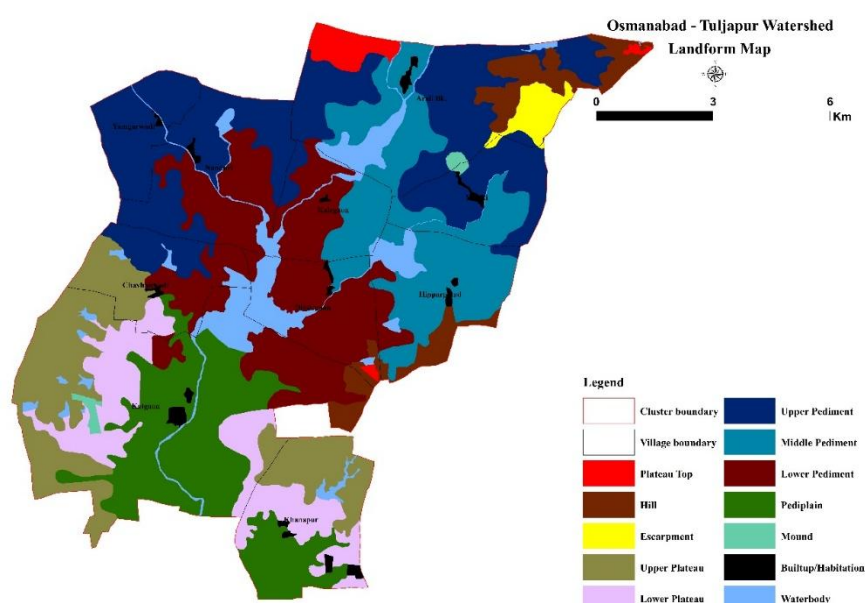
**Fig. 4.1. Land-use/land-cover map**

### 4.3 Landform Delineation

The landform pattern of the Tuljapur watershed, Dharashiv district, shows a mixed landscape with noticeable variation in surface form and relief. Large stretches of gently rolling midland and lowland areas define the general terrain, giving some parts of the watershed its characteristic undulating appearance. Alluvial and plain landforms are mainly observed along valley floors and drainage lines, forming relatively flat stretches within the watershed. The upland areas represent higher ground with gentle to moderate undulations. Overall, the watershed presents a diverse mix of landforms, reflecting a naturally varied geomorphic setting. The landform map of the watershed is presented in Fig. 4.2. The descriptions of each landform are presented in Table 4.7.

**Table 4.7. Landform features existing in Tuljapur watershed**

Sr. no	Landform	Area(ha)	Percent (%)
1	Upper Pediment	2910.8	22.6
2	Lower Pediment	2121.1	16.5
3	Middle Pediment	1700.3	13.2
4	Pediplain	1673.1	13.0
5	Upper Plateau	1502.1	11.7
6	Lower Plateau	1013.8	7.9
7	Waterbody	820.8	6.4
8	Hill	586.5	4.6
9	Plateau Top	192.4	1.5
10	Escarpment	166.8	1.3
11	Habitation/Builtup	131.9	1.0
12	Mound	54.3	0.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



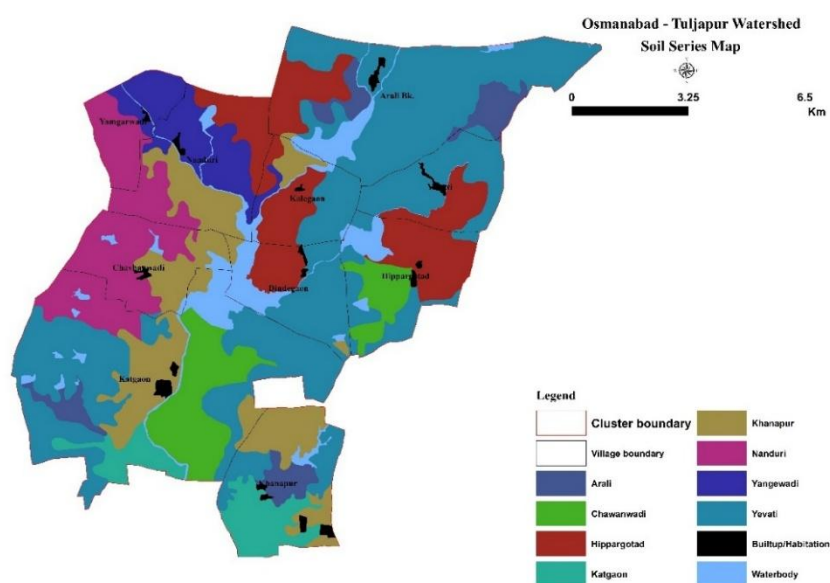
**Fig. 4.2. Landform map of Tuljapur watershed**

#### 4.4 Soil Series and Phases

Eight soil series have been identified and mapped with 27 soil mapping units (phases of series) (Fig 4.3). The taxonomic classification and mapping legend of the soil series are shown in Table 4.8. The detailed descriptions of each phase are provided in Table 4.9 and Fig 4.4.

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

Sr. No.	Series	Area (ha)	Percent (%)
1	Arali	510.3	4.0
2	Chawanwadi	914.4	7.1
3	Hippargotad	1593.1	12.4
4	Katgaon	579.8	4.5
5	Khanapur	1487.3	11.6
6	Nanduri	1322.2	10.3
7	Yangewadi	684.0	5.3
8	Yevati	4830.0	37.5
9	Habitation/Built-up	131.9	1.0
10	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



**Fig. 4.3. Soil series map of Tuljapur watershed**

**Table 4.9. Soil phases existing in Tuljapur watershed**

Sr. No.	Phase	Area(ha)	Percent (%)
1	Ara2gC2	236.8	1.8
2	Ara2hB1	106.8	0.8
3	Ara2hD2	166.8	1.3
4	Builtup	20.5	0.2
5	Cha3gB1	242.8	1.9
6	Cha4kB1	671.6	5.2
7	Hip5gB1	1593.1	12.4
8	Kat3gB1	223.2	1.7
9	Kat3mB1	356.6	2.8
10	Kha2gB1	585.7	4.6
11	Kha2hC1	10.5	0.1
12	Kha2kB1	421.6	3.3

13	Kha2kC2	87.4	0.7
14	Nan2gB1	286.3	2.2
15	Nan3gC1	434.0	3.4
16	Nan3hB1	166.5	1.3
17	Nan3kC1	721.6	5.6
18	Yan3gB1	83.6	0.7
19	Yan3gC2	254.6	2.0
20	Yan3kD2	345.8	2.7
21	Yev1gC2	594.9	4.6
22	Yev1gD2	110.3	0.9
23	Yev1hB1	1625.2	12.6
24	Yev1hC2	1809.9	14.1
25	Yev1hD3	273.3	2.1
26	Yev1kB1	455.0	3.5
27	Yev2hB1	57.3	0.5
28	Habitation	111.4	0.9
29	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>

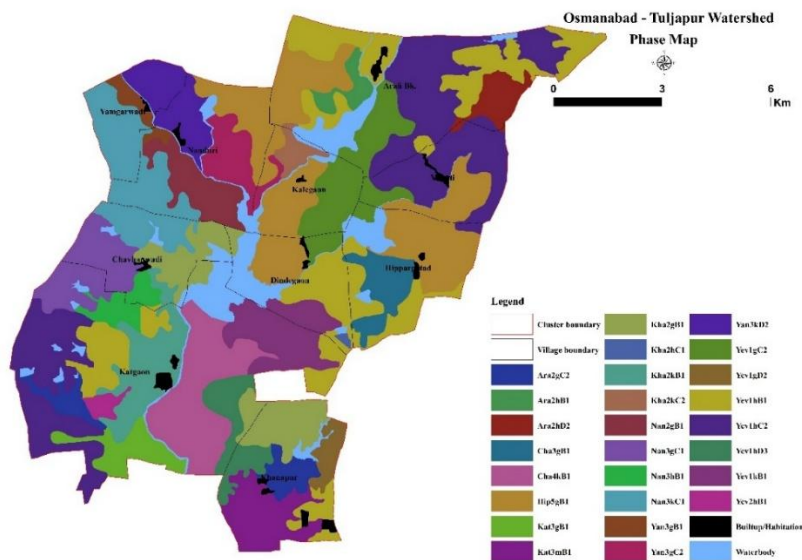


Fig. 4.4. Soil Phase map of Tuljapur watershed

## 4.5 Soil Survey Interpretation

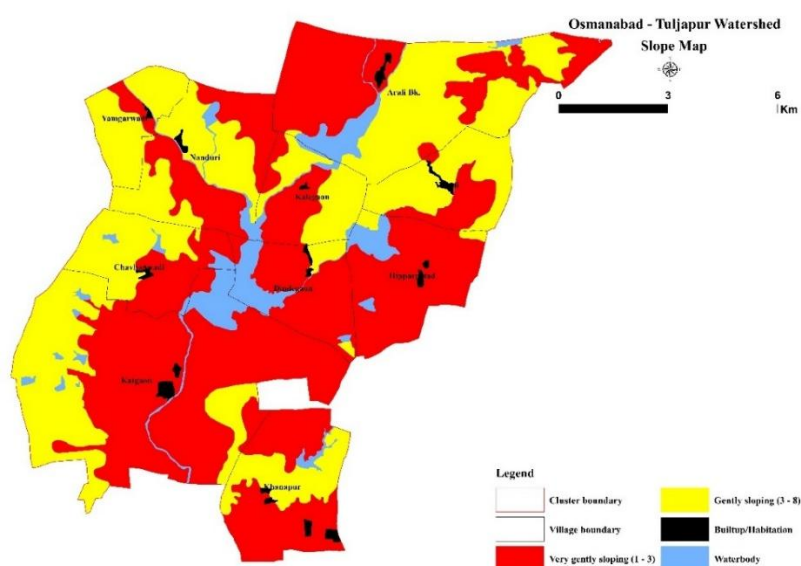
### 4.5.1 Slope

Land slope plays a crucial role in agriculture, as it affects water drainage, soil erosion, and the ease with which crops can be cultivated. Steep slopes tend 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, flat or 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, ensuring more sustainable agricultural practices. Among the two slope classes (Table 4.10, Fig. 4.5) prevailing in the watershed, very gently sloping (1-3%) covers about 53% of the area followed by gently sloping (3-8%), with an area coverage of about 40%.

**Table: 4.10. Land slope classes in Tuljapur watershed**

Sr. No.	Slope Class (%)	Area (ha)	TGA (%)
1	Very gently sloping (1 - 3)	6875.3	53.4
2	Gently sloping (3 - 8)	5045.9	39.2
3	Habitation/Built-up	131.9	1.0
4	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



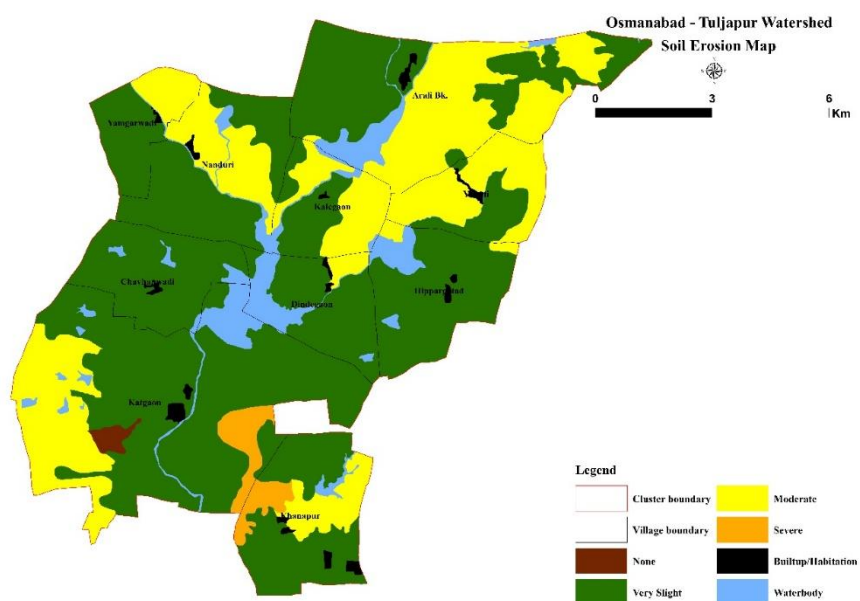
**Fig. 4.5. Slope map of Tuljapur watershed**

#### 4.5.2 Soil Erosion

More than 90% of the watershed exhibits very slow to moderate rates of soil erosion based on local terrain and land conditions (Table 4.11 and Fig 4.6). This indicates that the erosion could be managed in one-third of the area through appropriate conservation practices.

**Table 4.11. Soil erosion status in Tuljapur watershed**

Sr. No.	Erosion class	Area (ha)	Percent (%)
1	Very Slight	7984.2	62.5
2	Moderate	3606.4	28.0
3	Severe	273.3	2.1
4	Habitation/Built-up	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



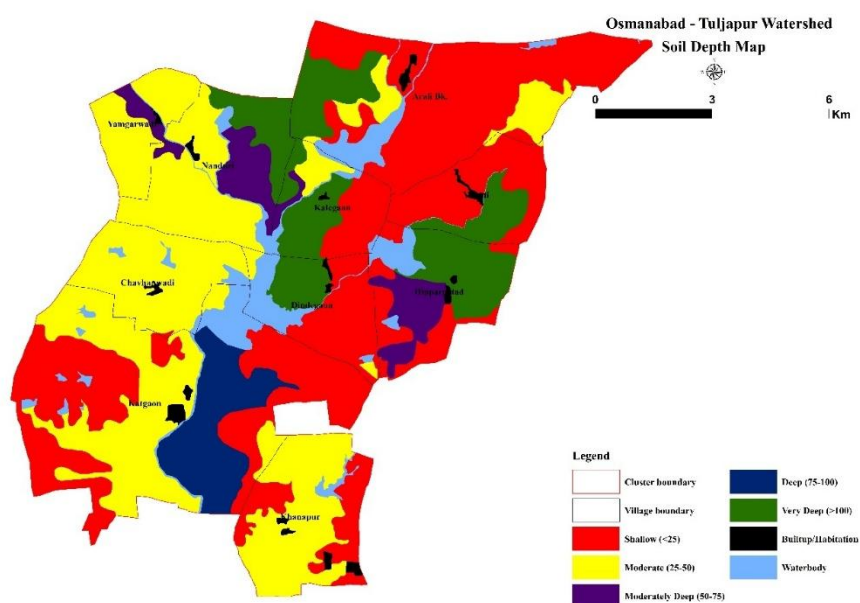
**Fig. 4.6. Erosion map of Tuljapur watershed**

### 4.5.3 Soil Depth

Soil depth acts as an integrative proxy for several other soil properties and functions, including soil moisture retention, organic carbon storage, effective rooting depth, nutrient availability, and overall profile development. These properties are intrinsically linked to pedogenic processes such as weathering, translocation, erosion-deposition dynamics, and biological activity, all of which are strongly modulated by landscape position and hydrological regime. Thus, spatial variability in soil depth reflects not only physical soil thickness but also broader gradients in soil fertility, water holding capacity, and ecosystem functioning across the terrain. Deeper soils generally provide more space for roots to penetrate, access water, and take up essential nutrients, which supports healthier plant growth and higher crop yields. Shallow soils, on the other hand, can restrict root development and limit the availability of nutrients and moisture, especially during dry periods. This can result in stunted plant growth, lower productivity, and increased vulnerability to drought stress. In regions with shallow soils, farmers may need to implement practices such as deep ploughing, irrigation, or the addition of organic matter to improve soil depth and enhance crop performance. Understanding soil depth helps farmers make better decisions on crop selection, irrigation, and soil management, promoting more efficient and sustainable agricultural practices. The soil depth in the watershed (Fig. 4.7) varies from shallow (<25 cm) to very deep (>100 cm). Area wise distribution of the data (Table 4.12) shows that maximum area was under shallow to moderate (~70%) followed by very deep (12%) soils.

**Table 4.12. Soil depth classes in Tuljapur watershed**

Sr. No.	Depth Class (cm)	Area (ha)	TGA (%)
1	Shallow (< 25)	4868.5	37.8
2	Moderate (25 - 50)	4206.9	32.7
3	Moderately Deep (50 - 75)	581.0	4.5
4	Deep (75 - 100)	671.6	5.2
5	Very Deep (> 100)	1593.1	12.4
6	Habitation/Built-up	131.9	1.0
7	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



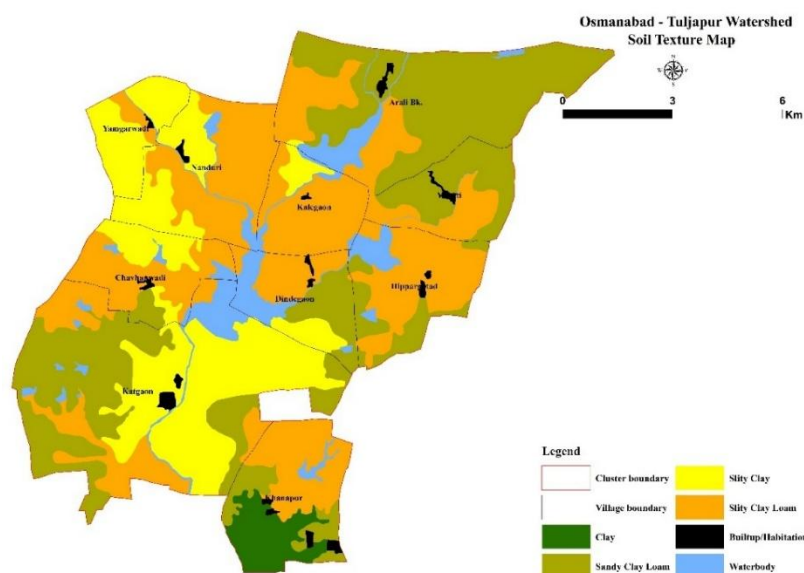
**Fig. 4.7. Depth map of Tuljapur watershed**

#### 4.5.4 Surface texture

Soil texture plays a vital role in agriculture by directly influencing water retention, root development, and nutrient availability to plants. Soils with a balanced texture, such as loam, provide optimal conditions for plant growth by allowing good water drainage while retaining enough moisture for the roots. Clay soils, though rich in nutrients, can become compacted and poorly drained, while sandy soils may drain too quickly and lack essential nutrients. Understanding soil texture helps farmers make informed decisions about irrigation practices, crop selection, and the appropriate use of soil amendments. The texture of the watershed area soils was grouped into five classes (Table 4.13, Fig. 4.8). The loamy classes, viz. sandy clay loam and silty clay loam account for nearly 70% of the soil texture. Based on the texture, the soils of the watershed, particularly the moderately deep to deep soils are expected to be fertile and produce good crops.

**Table 4.13. Soil texture distribution in Tuljapur watershed**

Sr. No.	Texture	Area (ha)	TGA (%)
1	Clay	356.6	2.8
2	Sandy Clay Loam	4216.2	32.8
3	Silty Clay	2703.0	21.0
4	Silty Clay Loam	4645.3	36.1
5	Habitation/Built-up	131.9	1.0
6	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



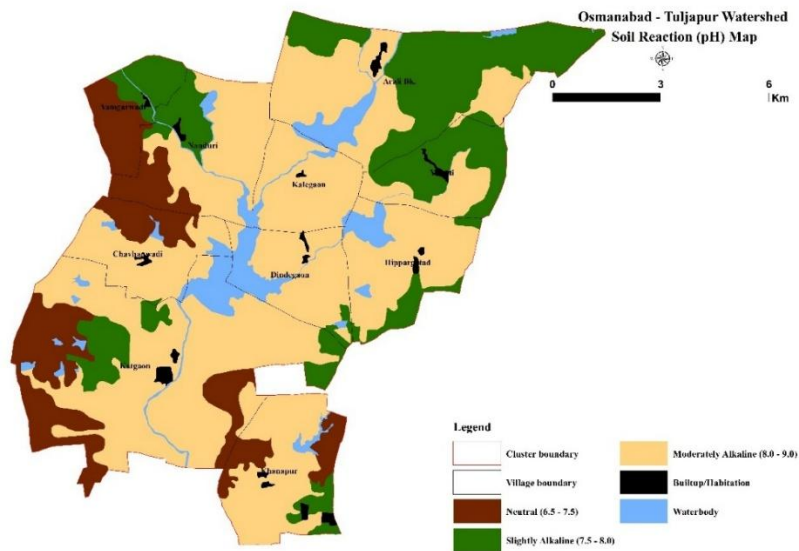
**Fig. 4.8. Soil texture map of Tuljapur watershed**

#### 4.5.5 Soil reaction

Soil reaction or pH, a measure of acidity or alkalinity, is crucial for plant health and growth because it directly impacts nutrient availability, microbial activity, and overall soil health, influencing crop yields and suitability. The pH value also helps to determine the quantity of various amendments to be added to the soils for ameliorating acidity or alkalinity. Soils of the watershed have been grouped into four soil reaction classes (Table 4.14, Fig. 4.9). The data revealed that soils in watershed are predominantly moderately alkaline in reaction (pH 8.0-9.0) covering an area of about 58% followed by slightly alkaline (7.5-8.0) and neutral (pH 6.5-7.5). The high pH soils could pose problems in nutrient bioavailability, particularly those of the micronutrients and phosphorus.

**Table 4.14. Soil pH distribution in Tuljapur watershed**

Sr. No.	Soil pH	Area (ha)	TGA (%)
1	Neutral (6.5 - 7.5)	1754.4	13.6
2	Slightly Alkaline (7.5 - 8.0)	2747.0	21.3
3	Moderately Alkaline (8.0 - 9.0)	7419.8	57.6
4	Habitation/Built-up	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



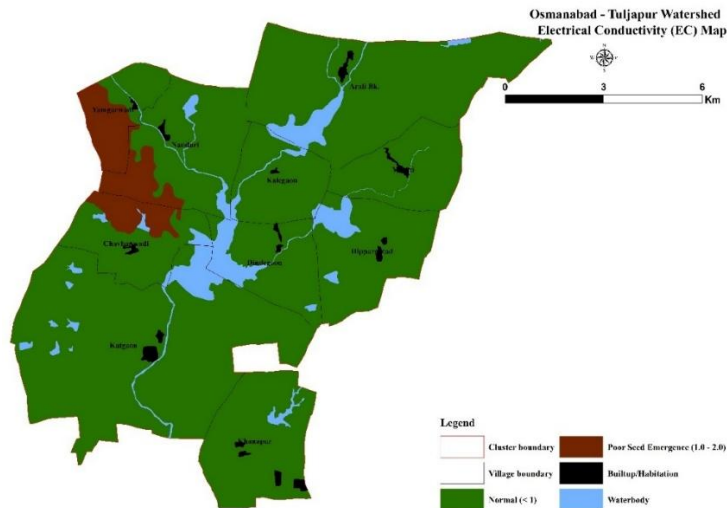
**Fig. 4.9. Soil pH map of Tuljapur watershed**

#### 4.5.6 Soil salinity

Soil salinity, measured through the electrical conductivity of a solution within a unit distance, represents the content of soluble salts in the matrix. Soil conductivity is an index to measure soil water-soluble salt, which is an important indicator of mineral nutrients in the topsoil that can be quickly utilized by plants and is a factor to determine whether salt ions in soil limit crop growth. The EC of the soils of the watershed were well within the permissible limit of salinity (Table 4.15, Fig 4.10) and will not affect to crop growth.

**Table 4.15. Soil salinity classes in Tuljapur watershed**

Sr. No.	Electrical conductivity (dSm <sup>-1</sup> )	Area (ha)	TGA (%)
1	Normal (< 1)	11199.6	87.0
2	Poor Seed Emergence (1.0 - 2.0)	721.6	5.6
3	Habitation/Built-up	131.9	1.0
4	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



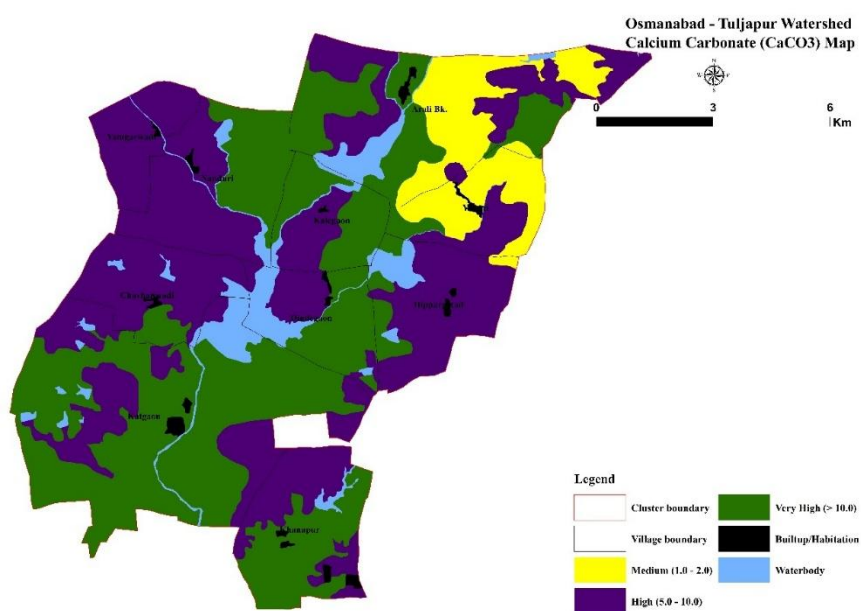
**Fig. 4.10. Soil EC map of Tuljapur watershed**

#### 4.5.7 Calcium carbonate (CaCO<sub>3</sub>) content

The soils of the watershed are generally calcareous in nature with the CaCO<sub>3</sub> content ranging from moderate to very high (>10%). Semi-arid climatic features with low rainfall and high PET favour release of substantial amount of alkali bicarbonates and carbonates into the soil solution, thereby rendering the soils calcareous. As can be inferred from Table 4.16 and Fig. 4.11, more than 41% of the watershed area contains more than 10% CaCO<sub>3</sub> in soil, which could pose problems to normal crop growth.

**Table 4.16. Extent of calcareousness in soils of Tuljapur watershed**

Sr. No.	CaCO <sub>3</sub> content (%)	Area (ha)	TGA (%)
1	Moderate (1.0 - 2.0)	1160.8	9.0
2	High (5.0 - 10.0)	5407.7	42.0
3	Very High (> 10.0)	5352.8	41.6
4	Habitation/Built-up	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



**Fig. 4.11. Status of soil calcareousness in Tuljapur watershed**

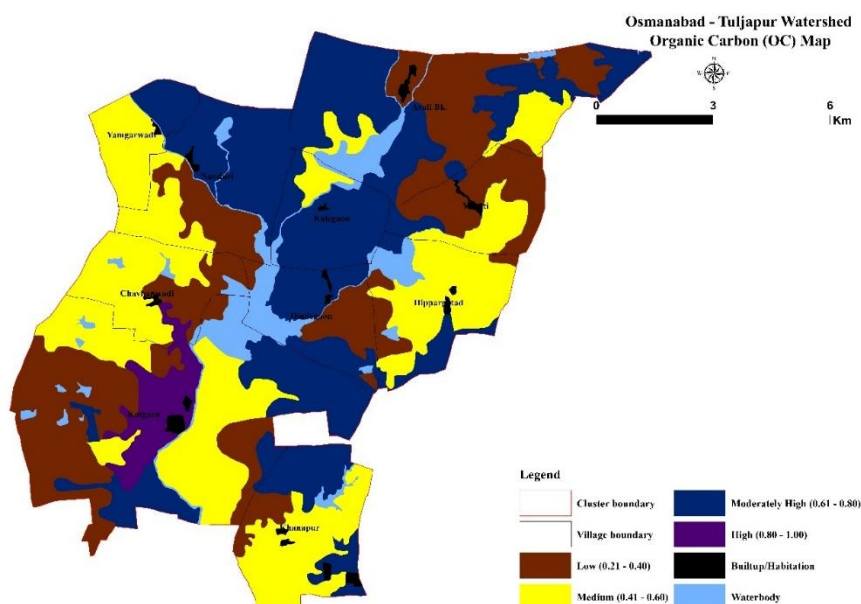
#### 4.5.8 Soil organic carbon

The soil organic carbon (SOC) is a critical component to several ecological processes and is primarily derived from plant decomposition and animal residues, like leaves, roots, and dead organisms. It serves as a significant indicator of soil health and fertility. The SOC influences the soil's ability to retain and release essential nutrients, regulate water-holding capacity and support microbial activity. It also acts as a reservoir for carbon sequestration, helping mitigate climate change by removing carbon dioxide from the atmosphere. Monitoring SOC levels is crucial for sustainable land use and management. The loss of

SOC through practices like deforestation and intensive agriculture can result in degraded soils leading to reduced agricultural productivity and enhanced greenhouse gas emissions. Promotion of climate-smart practices that increase SOC can ensure healthier and productive soils. Soils of Dharashiv-Tuljapur watershed supported low to moderately high SOC content, which can be inferred from Table 4.17 and Fig. 4.12. This is also indicated by the loamy texture prevalent in the watershed. However, there is an immense need for application of organic manures by the farmers in the watershed area in general, and in about one-fourth of the area exhibiting low SOC. High SOC content was found to occur in approximately 400 ha of the watershed.

**Table 4.17. Soil organic carbon status of Tuljapur watershed**

Sr. No.	Organic carbon (%)	Area (ha)	TGA (%)
1	Low (0.21 - 0.40)	3390.0	26.3
2	Medium (0.41 - 0.60)	3904.9	30.3
3	Moderately High (0.61 - 0.80)	4204.7	32.7
4	High (0.80 - 1.00)	421.6	3.3
5	Habitation/Built-up	131.9	1.0
6	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



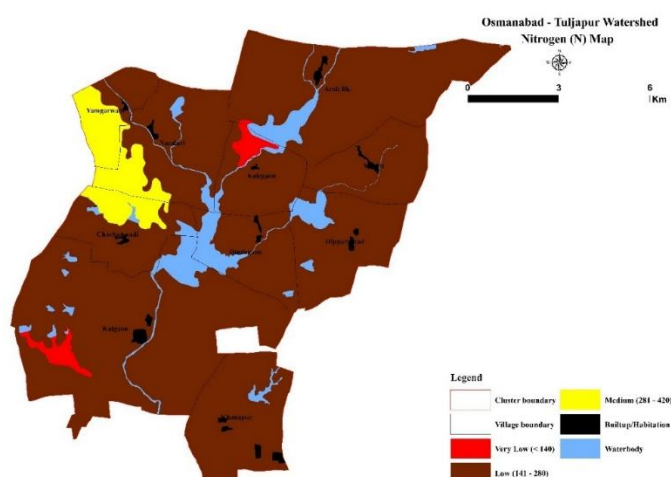
**Fig. 4.12. Soil organic carbon map of Tuljapur watershed**

#### 4.5.9 Available Nitrogen (N)

Available nitrogen content in soils is crucial as it forms the primary building block for plant growth, is essential for producing proteins, amino acids, and chlorophyll to support photosynthesis, plant health and yield. The agricultural soils of watershed are inherently deficient in available N content. As seen from Table 4.18 and Fig. 4.13. More than 85% of the soils of Dharashiv-Tuljapur watershed area are inherently low in available N ( $<140 \text{ kg ha}^{-1}$ ), which needs to be looked into. It is advocated to apply the nitrogenous fertilizers as per crop needs to maximize yields in the watershed area.

**Table 4.18. Available N content in soils of Tuljapur watershed**

Sr. No.	Available N (kg ha <sup>-1</sup> )	Area (ha)	TGA (%)
1	Very Low (< 140)	188.9	1.5
2	Low (141 - 280)	11010.6	85.5
3	Medium (281 - 420)	721.6	5.6
4	Habitation/Built-up	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



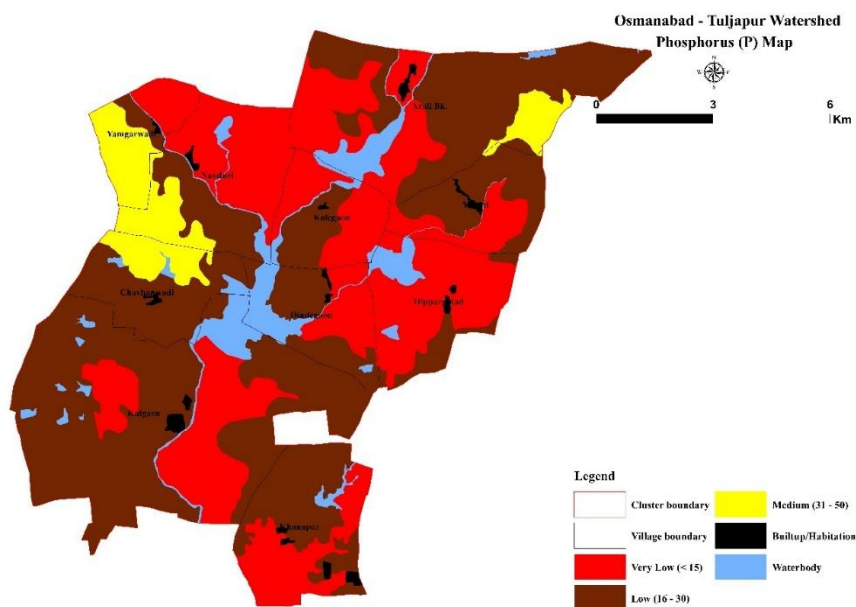
**Fig. 4.13. Available soil Nitrogen map of Tuljapur watershed**

#### 4.5.10 Available Phosphorous (P)

Among the three major nutrients, phosphorus (P) plays an important role to complete the life cycle of a plant; its functions start right from the stimulation of root growth to proper seed filling and seed setting. It also plays a vital role in photosynthesis, carbohydrate breakdown and transfer of energy in the form of ATP and ADP compounds in various metabolic processes. Similar to nitrogen, available P content of the agricultural soils of the watershed (Table 4.19, Fig. 4.14) ranged from very low (<15 kg ha<sup>-1</sup>) to low (16-30 kg ha<sup>-1</sup>) in 85% of the watershed area, which could be attributed to the high pH and calcareousness of the soils leading to its fixation. Further, the very low to low status indicates that the farmers are not adequately applying phosphatic fertilizers to soils.

**Table 4.19. Available P content in soils of Tuljapur watershed**

Sr. No.	Available P (kg ha <sup>-1</sup> )	Area (ha)	TGA (%)
1	Very Low (< 15)	4511.2	35.0
2	Low (16 - 30)	6521.5	50.7
3	Medium (31 - 50)	888.5	6.9
4	Habitation/Built-up	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



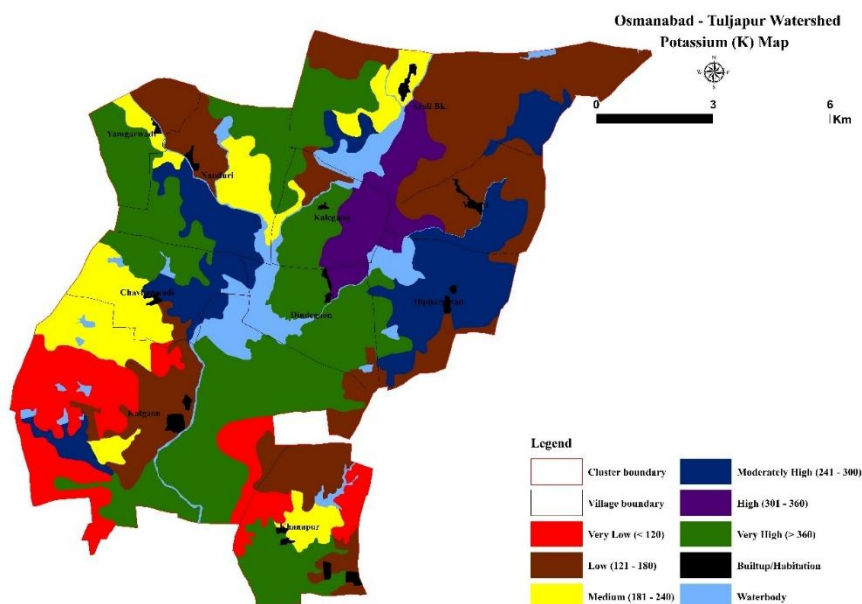
**Fig.4.14. Available soil Phosphorus map of Tuljapur watershed**

#### 4.5.11 Available Potassium (K)

Exchangeable or available K is widely used to evaluate the soil K status and to predict the crop K requirements. Six classes of available K (Table 4.20, Fig. 4.15) were observed in the watershed soils. About one-third of the watershed exhibits a low K content necessitating external addition through potassic fertilizers.

**Table 4.20. Available K content of soils of Tuljapur watershed**

Sr. No.	Available K (kg ha <sup>-1</sup> )	Area (ha)	TGA (%)
1	Very Low (< 120)	1271.0	9.9
2	Low (121 - 180)	3253.2	25.3
3	Medium (181 - 240)	1322.7	10.3
4	Moderately High (241 - 300)	1745.6	13.6
5	High (301 - 360)	594.9	4.6
6	Very High (> 360)	3733.8	29.0
7	Habitation/Builtup	131.9	1.0
8	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



**Fig. 4.15. Available soil Potassium map of Tuljapur watershed**

#### 4.5.12 Micronutrient status of soils

Although required in small quantities, the DTPA-extractable micronutrients, are involved in vital plant processes like photosynthesis, enzyme activation, and nitrogen fixation. Deficiencies in any of these micronutrients can lead to poor plant development, reduced yields, and lower quality crops. Table 4.21 through 4.24, and Fig. 4.16 through 4.19 indicate that a majority of the watershed soils are adequately supplied with micronutrients, hinting at the possible organic-micronutrient chelation in the soils.

**Table 4.21. Available Fe content in the soils of Tuljapur watershed**

Sr. No.	Available Fe ( $\text{mg kg}^{-1}$ )	Area (ha)	TGA (%)
1	Moderately High (6.5 - 8.5)	57.3	0.5
2	High (8.5 - 10.5)	220.7	1.7
3	Very High (> 10.5)	11643.2	90.4
4	Habitation/Built-up	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>

**Table 4.22. Available Mn content in the soils of Tuljapur watershed**

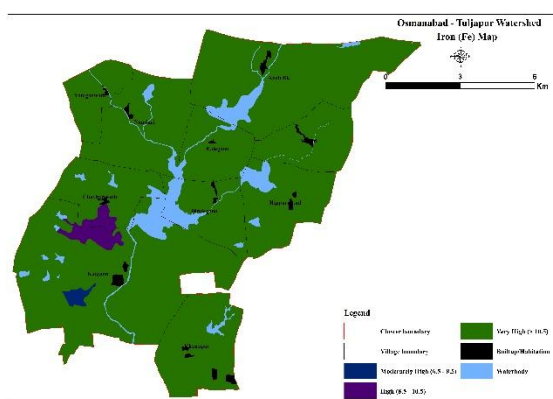
Sr. No.	Available Mn ( $\text{mg kg}^{-1}$ )	Area (ha)	TGA (%)
1	Medium (1.3 - 5.0)	75.2	0.6
2	High (7.0 - 9.0)	106.8	0.8
3	Very High (> 9.0)	11739.2	91.2
4	Habitation/Built-up	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>

**Table 4.23. Available Cu content in the soils of Tuljapur watershed**

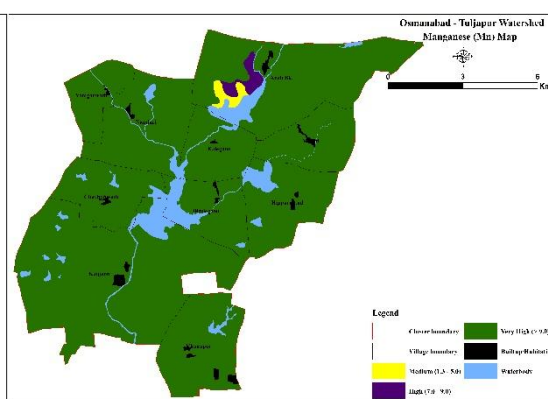
Sr. No.	Available Cu (mg kg <sup>-1</sup> )	Area (ha)	TGA (%)
1	Very High (> 1.0)	11921.2	92.6
2	Habitation/Builtup	131.9	1.0
3	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>

**Table 4.24. Available Zn content in the soils of Tuljapur watershed**

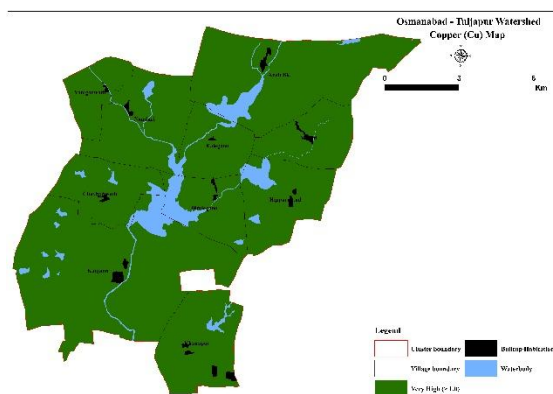
Sr. No.	Available Zn (mg kg <sup>-1</sup> )	Area (ha)	TGA (%)
1	Very High (> 1.0)	11921.2	92.6
2	Habitation/Builtup	131.9	1.0
3	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



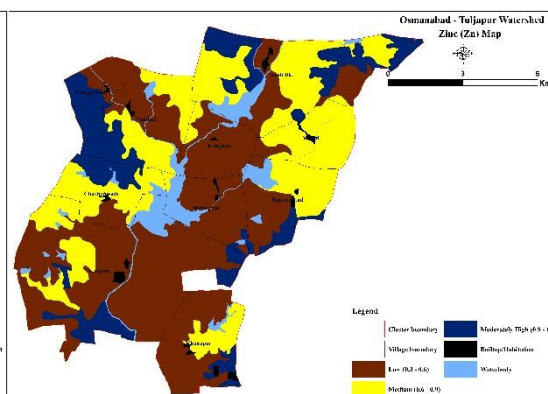
**Fig. 4.16. DTPA-extractable soil Fe map of Tuljapur watershed**



**Fig. 4.17. DTPA-extractable soil Mn map of Tuljapur watershed**



**Fig. 4.18. DTPA-extractable soil Cu map of Tuljapur watershed**



**Fig. 4.19. DTPA-extractable soil Zn map of Tuljapur watershed**

## **4.6 Surface Runoff**

Runoff estimation is a critical step in understanding the hydrological behavior of Tuljapur Taluka, which lies in the drought-prone Marathwada region of Maharashtra. The taluka experiences highly variable monsoon rainfall, and the conversion of rainfall into surface runoff determines the availability of water for storage, recharge, and irrigation. The analysis of rainfall and runoff data for the period 2014 to 2024 provides valuable insights into the seasonal and annual dynamics of water resources in this semi-arid environment.

Runoff quantifies the portion of rainfall that is lost as direct surface flow rather than infiltrating into the soil or recharging aquifers. In basaltic semi-arid regions such as Tuljapur, where water scarcity is a recurring issue, understanding runoff behavior is essential for designing interventions that conserve rainwater, reduce erosion, and improve groundwater recharge. Rainfall data alone cannot explain why communities face shortages despite receiving adequate precipitation; runoff analysis bridges this gap by showing how much water escapes the landscape and how much can potentially be retained through management measures.

The importance of runoff estimation lies in its ability to guide practical watershed planning. High runoff percentages indicate zones where rainwater harvesting structures are urgently needed, while low runoff values highlight areas with better infiltration capacity that can be enhanced further. By identifying seasonal peaks and inter-annual variability, planners can prioritize interventions during critical months such as September, which consistently produces the highest runoff, and during intense storm periods when maximum losses occur. Runoff estimation also helps assess erosion risk, since high quickflow events often coincide with topsoil loss and land degradation. Thus, the exercise is not only about water budgeting but also about sustaining soil health and long-term agricultural productivity.

For this study, the Daily rainfall records for 11 years (2014-2024) were compiled and aggregated into storm events. Land use and soil profiles were mapped using satellite imagery, field surveys, and farmer consultations. Curve Numbers were then assigned to each land cover-soil combination, adjusted for antecedent moisture conditions to reflect seasonal saturation. Using the SCS equation, runoff depth was calculated for each storm, aggregated monthly, and then summarized annually. This allowed the estimation of both seasonal peaks and long-term averages, providing a comprehensive picture of runoff dynamics across the decade.

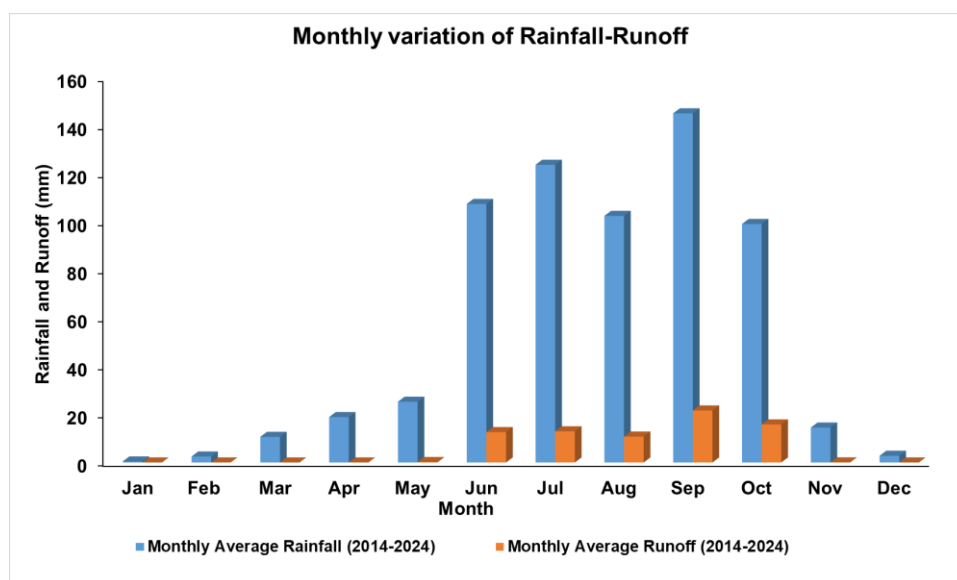
### **Monthly Rainfall-Runoff Characteristics**

The monthly rainfall and runoff values for the monsoon months (June to October) during the period 2014-2024 are presented in Table 4.25. The table indicates considerable variation in both rainfall and runoff across months and years.

**Table 4.25. Details of monthly (June-Oct) runoff (mm) for the period 2014-24**

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)
2014	24.6	0.0	94.5	0.0	223.4	63.5	66.2	0.9	33.7	0.0
2015	42.1	0.0	12.4	0.0	71.3	0.0	119.6	20.6	57.0	0.1
2016	96.8	0.9	233.8	59.6	30.9	0.0	250.8	69.8	73.8	10.2
2017	217.7	61.6	20.1	0.0	174.7	28.1	135.4	10.0	128.5	19.3
2018	191.2	24.6	71.2	0.0	107.5	15.7	47.7	0.0	50.9	0.7
2019	71.5	0.1	79.2	0.0	86.8	0.0	227.1	69.5	272.7	57.2
2020	108.2	0.0	186.8	7.5	99.8	0.0	124.4	6.3	202.6	84.3
2021	100.2	2.0	165.9	20.6	71.9	0.0	225.4	39.9	65.0	1.3
2022	93.9	0.2	197.0	51.1	124.5	9.7	139.2	8.8	105.5	0.0
2023	31.4	0.2	185.6	3.8	15.0	0.0	101.5	0.0	24.3	0.0
2024	204.7	49.3	114.9	0.0	122.2	1.4	159.6	12.0	76.6	0.9
<b>Average</b>	<b>107.5</b>	<b>12.6</b>	<b>123.8</b>	<b>13.0</b>	<b>102.5</b>	<b>10.8</b>	<b>145.2</b>	<b>21.6</b>	<b>99.1</b>	<b>15.8</b>

Analysis of Table 4.25 shows that September consistently emerges as the most significant month for runoff generation. With an average rainfall of 145.2 mm, September produced an average runoff of 21.6 mm, contributing the highest share to annual runoff. June and July, despite receiving moderate to high rainfall in certain years, generally recorded low runoff, suggesting that early monsoon rainfall was largely absorbed by dry soils and vegetation. August exhibited moderate runoff, while October showed late-season runoff peaks in selected years, particularly during 2019 and 2020 when high-intensity rainfall events occurred. The monthly variation in rainfall and runoff is illustrated in Fig 4.20, which clearly shows the dominance of September in runoff generation and the comparatively low runoff during the early monsoon period.



**Fig 4.20. Monthly variation of rainfall-runoff in Tuljapur watershed**

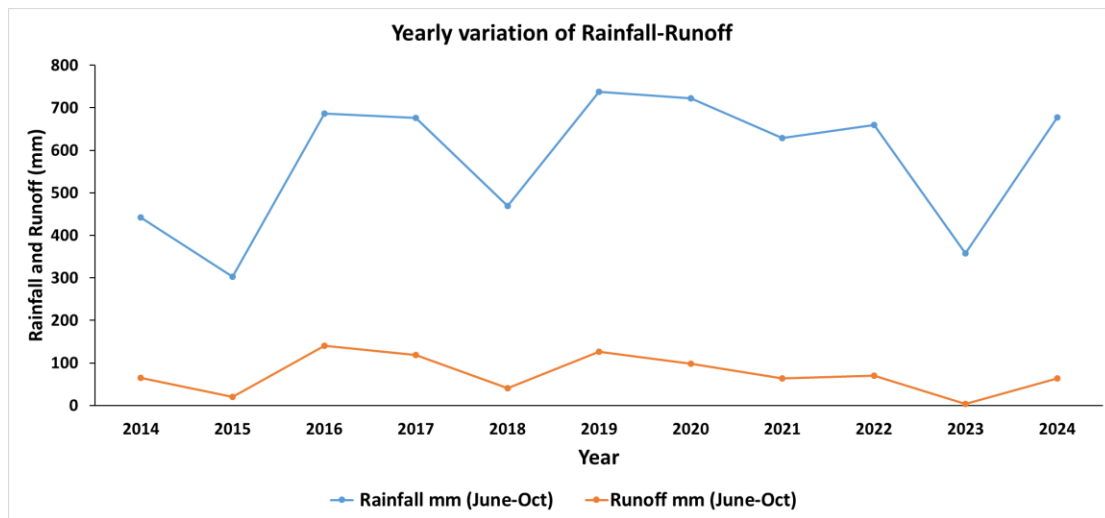
### Annual Rainfall-Runoff Relationship

Annual rainfall, runoff depth, number of runoff events, and runoff percentage for the study period are summarized in Table 4.26.

**Table 4.26. Relationship between rainfall and runoff**

Year	Rainfall (mm)	Runoff (mm)	No. of Runoff Events	Runoff (%)
2014	639.9	64.4	9	10.1
2015	383.0	20.8	6	5.4
2016	725.8	140.5	15	19.4
2017	698.2	118.8	18	17.0
2018	558.1	41.0	7	7.3
2019	758.2	126.8	15	16.7
2020	767.6	98.1	11	12.8
2021	794.4	65.7	14	8.3
2022	686.7	69.8	15	10.2
2023	431.6	4.1	4	1.0
2024	739.8	63.6	12	8.6
<b>Average</b>	<b>653.0</b>	<b>74.0</b>	<b>11</b>	<b>11.3</b>

As shown in Table 4.26, the average annual rainfall during the study period was 653 mm, while the average annual runoff was 74 mm, corresponding to approximately 11.3 percent of rainfall. The number of runoff-generating events averaged 11 per year, but ranged from as few as 4 events in 2023 to as many as 18 events in 2017, indicating strong inter-annual variability in rainfall distribution and runoff response. Inter-annual variability in runoff is pronounced. Years such as 2016, 2017, and 2019 recorded high annual runoff values of 140.5 mm, 118.8 mm, and 126.8 mm respectively, with runoff coefficients ranging from 16 to 19 percent. These years were characterized by multiple high-intensity rainfall events resulting in higher runoff generation. In contrast, years such as 2015, 2018, and particularly 2023 recorded very low runoff, with runoff coefficients below 7 percent and only about 1 percent in 2023, highlighting the sensitivity of surface water availability to rainfall distribution. The year-to-year variation in rainfall and runoff is depicted in Fig 4.21, which demonstrates the lack of a linear relationship between total rainfall and runoff and emphasizes the role of rainfall intensity and distribution.



**Fig 4.21. Yearly variation of rainfall-runoff in Tuljapur watershed**

In conclusion, the runoff estimation for Tuljapur taluka over the period 2014 to 2024 establishes that the region generates an average of 74 mm runoff annually, equivalent to 11.3 percent of rainfall. The variability across years underscores the importance of adaptive water management strategies. This study provides a scientific reference for future watershed development and irrigation planning in Dharashiv district, and it can serve as a model for other talukas with similar semi-arid conditions. By combining runoff analysis with conservation planning, the resilience of agriculture and rural livelihoods can be strengthened, ensuring sustainable water use in line with the objectives of PMKSY.

#### 4.7 Mapping of Groundwater Potential Zones

Groundwater plays a vital role in sustaining agriculture and domestic supply in Tuljapur taluka of Dharashiv district, situated in the semi-arid Marathwada region of Maharashtra. Marathwada is widely recognized as one of the most drought-prone belts of India, where rainfall is highly variable and surface water resources are limited. In this semi-arid climate, coupled with basaltic geology of the Deccan Traps, groundwater serves as the most dependable source of water for farming and drinking purposes. In this fragile environment, the importance of groundwater is magnified, as it serves as the backbone of socio-economic stability and resilience against recurring droughts, while the current scenario reflects both challenges and opportunities. Declining rainfall and increasing demand have placed stress on aquifers.

The watershed contains small reservoirs and waterbodies, mainly seasonal which store seasonal runoff and provide supplemental water for nearby agricultural fields. Seepage from these reservoirs contributes to localized groundwater recharge in their immediate vicinity. However, the influence of reservoirs is limited spatially and temporally, as it depends on rainfall, reservoir storage levels, and the hydrogeological characteristics of the basaltic terrain. The reservoirs support localized water availability

but do not uniformly alter groundwater potential across the watershed.

The study area, comprising an eight-village cluster watershed, benefits from these waterbodies. Field observations and hydrological analysis indicate that reservoirs provide supplemental irrigation and contribute to localized groundwater recharge. However, their effectiveness is closely tied to rainfall variability. In years of low precipitation, storage levels decline, reducing both irrigation support and localized recharge. This variability underscores the importance of integrated planning that accounts for both surface and subsurface water dynamics.

The study area, comprising an eight-village cluster watershed, benefits directly from these waterbodies. Field observations and hydrological analysis indicate that the reservoirs and waterbodies provide supplemental irrigation in adjacent areas, supporting local water availability. However, the effectiveness of these reservoirs is closely tied to rainfall variability. In years of low precipitation, storage levels decline, and some water bodies fail to perform at full capacity, reducing both irrigation support and recharge contribution. This variability underscores the importance of integrated planning that accounts for both surface and subsurface water dynamics.

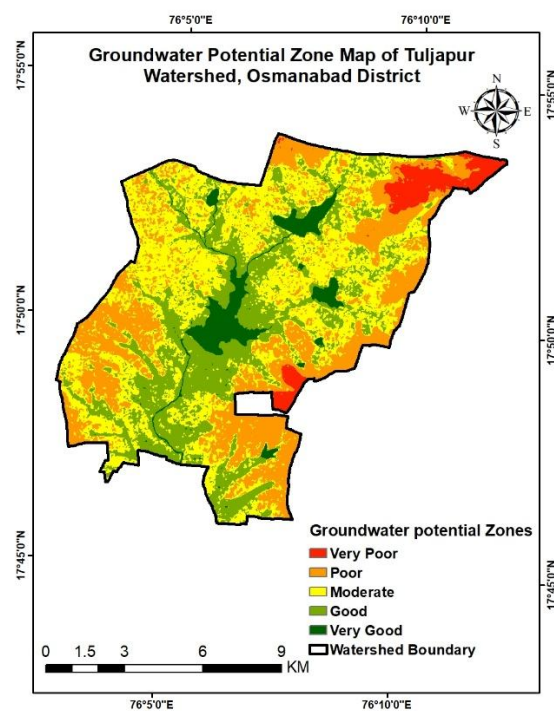
To assess groundwater potential, the study employed eight thematic factors: lithology, land use and land cover, rainfall, landform, soil, slope, drainage density, and elevation. Each factor was analyzed for its influence on groundwater occurrence, and the Analytical Hierarchy Process (AHP) combined with weighted overlay was used to integrate these factors into a composite groundwater potential map. The map classifies the watershed into five categories: very poor, poor, moderate, good, and very good groundwater potential. These categories indicate relative groundwater potential and are intended to support planning for water resource management, recharge structures, and sustainable agricultural interventions.

The results of the study indicate that the groundwater potential in the cluster watershed varies significantly across the region. According to the final groundwater potential map, 4.4 % of the region is classified as “very poor groundwater potential”, 28.6 % as “poor groundwater potential”, 36.4 % percent as “moderate groundwater potential”, 25.4 % as “good groundwater potential” and 5.2 % as “very good groundwater potential”. Approximately 30.6 % of the watershed area have good to very good groundwater potential. The presence of reservoirs shifted the balance in favor of good and very good zones within their command areas, demonstrating the critical role of surface water bodies in enhancing groundwater potential.

This exercise under PMKSY holds significant importance. By identifying recharge-prone areas and zones of limited potential, the study provides a scientific basis for targeted investment in water conservation structures. It highlights the dual role of reservoirs as both irrigation sources and recharge bodies, emphasizing the need to maintain and expand such infrastructure. The mapping results also guide crop planning, encouraging water-efficient practices in stressed zones and supporting sustainable cultivation in favorable areas. Reservoirs, while limited in influence, contribute to

supplemental irrigation and localized recharge, emphasizing the importance of maintaining and rehabilitating such infrastructure.

The study establishes a reference for future development activities in Dharashiv district. It demonstrates that integrating groundwater potential mapping with an understanding of reservoir dynamics provides a more accurate picture of water availability. This approach can serve as a model for other drought-prone regions with similar conditions, ensuring that interventions are evidence-based, region-specific, and aligned with ecological realities. By combining scientific analysis with policy objectives, the exercise strengthens resilience against drought, supports agricultural productivity, and secures livelihoods, fulfilling the goals of PMKSY in ensuring water for every farm and household.



**Fig. 4.22. Ground water potential zones in Tuljapur watershed**

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

Crop growth primarily depends on soil and climate. Evaluating soil-site suitability for crops requires a careful assessment of key soil attributes including soil depth, texture, fertility status, and drainage conditions. This is important because a soil's physicochemical properties and the crop's micro-environment directly influence the availability of water and essential nutrients. The evaluation process helps in the interpretation of soil maps to assess their suitability for various field and horticultural crops, thereby supporting the development of scientific land-use plans for watershed management.

The suitability of soils for crop cultivation was assessed using the criteria proposed by Naidu et al. (2006), employing a hierarchical land evaluation classification system based on land utilization types with a structure of orders, classes, subclasses, and units. This

system recognizes two primary orders: Suitable (S), which is subdivided into three classes S1 (High suitability), S2 (Moderate suitability), and S3 (Marginal suitability) and Not Suitable (N),

Soil-site suitability was evaluated by assessing limitations across five key categories: climate (c), topography (t), wetness (w), soil fertility (f), and physical soil constraints (s) using a grading scale from 0 to 4, where Grade 0 signifies no limitation and optimal conditions; Grade 1 denotes a slight, nearly optimal limitation; Grade 2 indicates a moderate limitation with noticeable negative effects on crop performance; Grade 3 represents a severe limitation making the land uneconomical; and Grade 4 signifies a very severe limitation where crop yields are below economically viable levels, rendering the land unsuitable for the proposed agricultural use.

To assess the suitability of the land for agricultural crops and other uses, an evaluation was conducted considering a range of soil-site parameters grouped into several key categories: climatic variables (rainfall and temperature), topographic features (slope, landscape position, and susceptibility to erosion), wetness conditions (drainage, risk of flooding, and soil aeration), physical soil properties (texture, soil depth, structure, and available soil moisture), fertility attributes (soil pH, nutrient availability, organic matter content and cation exchange capacity). By integrating these multiple parameters, the watershed area was evaluated to determine its suitability for crops that are either commonly cultivated or possess the potential for introduction.

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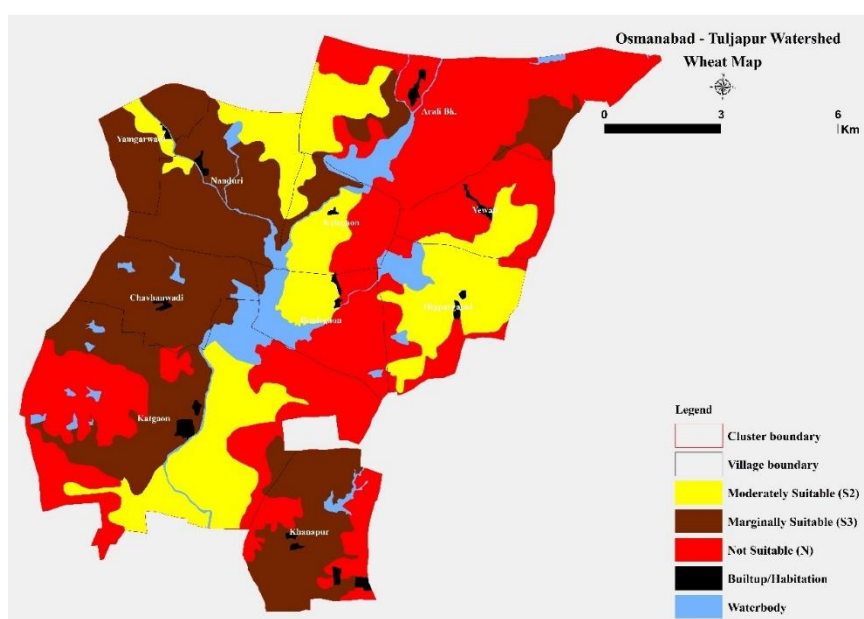
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#### 4.8.1 Soil-Site Suitability for Wheat Cultivation

The soil site suitability carried out for the wheat crop is presented in Table 4.27 and Fig 4.23. It suggests that wheat is moderately suitable for cultivation in about one-fifth of the watershed, indicating that appropriate conservation strategies need to be followed during the crop growth states. Further, about one-third of the watershed is marginally suitable for cultivation suggesting soil and climatic constraints. The patches characterized by low organic content need to be adequately supplied by farmyard manure. Wheat is not suitable for cultivation in about 38% of the watershed area.

**Table 4.27. Area under suitability sub-classes for Wheat cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2814.4	21.9
2	Marginally Suitable (S3)	4227.7	32.8
3	Not Suitable (N)	4879.1	37.9
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



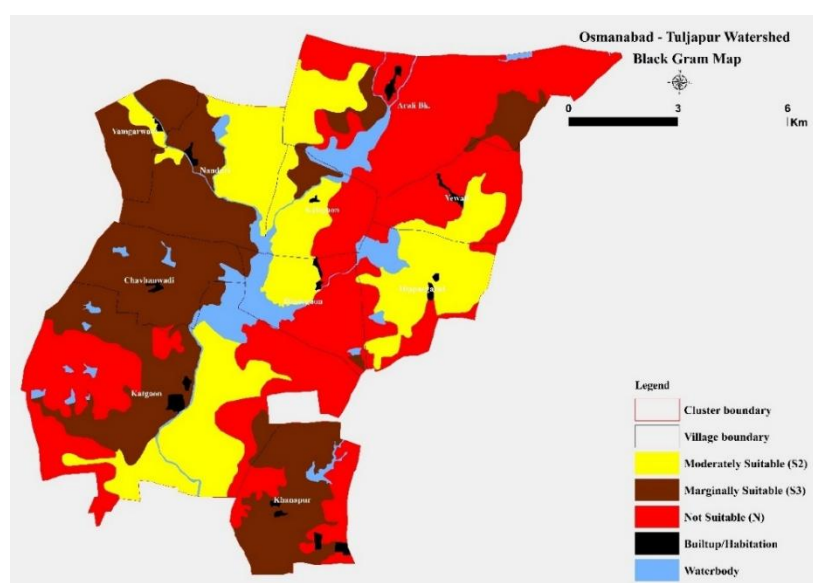
**Fig. 4.23. Soil site suitability map for Wheat cultivation**

#### 4.8.2 Soil-Site Suitability for Black gram Cultivation

Black gram cultivation can be taken up in about one-fourth of the watershed area with reasonable degree of success, while it is marginally suitable in about 31% of the area and not suitable in about 38% of the area. This indicates moderate to severe soil, terrain and environmental constraints limiting crop productivity, and black gram (*urad*) may be cultivated by strictly following the recommended package of practices in Tuljapur watershed (Table 4.28, Fig. 4.24).

**Table 4.28. Area under suitability sub-classes for Black gram cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	3069.0	23.8
2	Marginally Suitable (S3)	3983.7	30.9
3	Not Suitable (N)	4868.5	37.8
4	Builtup/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



**Fig. 4.24. Soil site suitability map for Black gram cultivation**

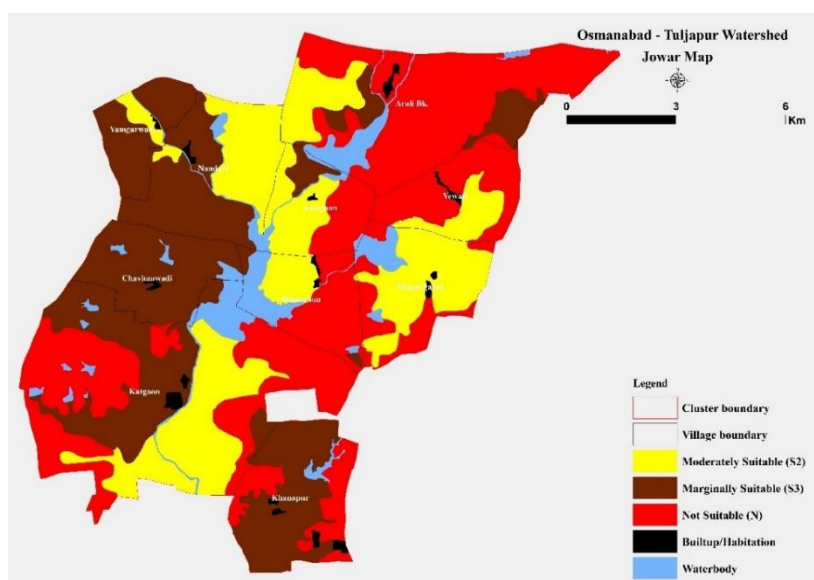
#### 4.8.3 Soil-Site Suitability for Sorghum (Jowar) Cultivation

The soils of the watershed were evaluated for sorghum cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.29. The results indicate that about 24% of the watershed area provides moderately favorable soil and site conditions for optimal crop growth and is moderately suitable (S2) for sorghum due to minor constraints in climate, soil texture, depth and drainage. The marginally suitable (S3) category covers 31%, wherein significant soil and environmental constraints may reduce crop productivity unless appropriate agronomic management practices are adopted. Around 38% of the watershed was found to be unsuitable (N) for the crop (Fig. 4.25). Therefore, it is suggested that *in-situ* soil moisture management interventions such as

alternate ridges and furrows, along with soil test-based nutrient management may be adopted while cultivating sorghum.

**Table 4.29. Area under suitability sub-classes for Sorghum (Jowar) cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	3069.0	23.8
2	Marginally Suitable (S3)	3983.7	30.9
3	Not Suitable (N)	4868.5	37.8
4	Builtup/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



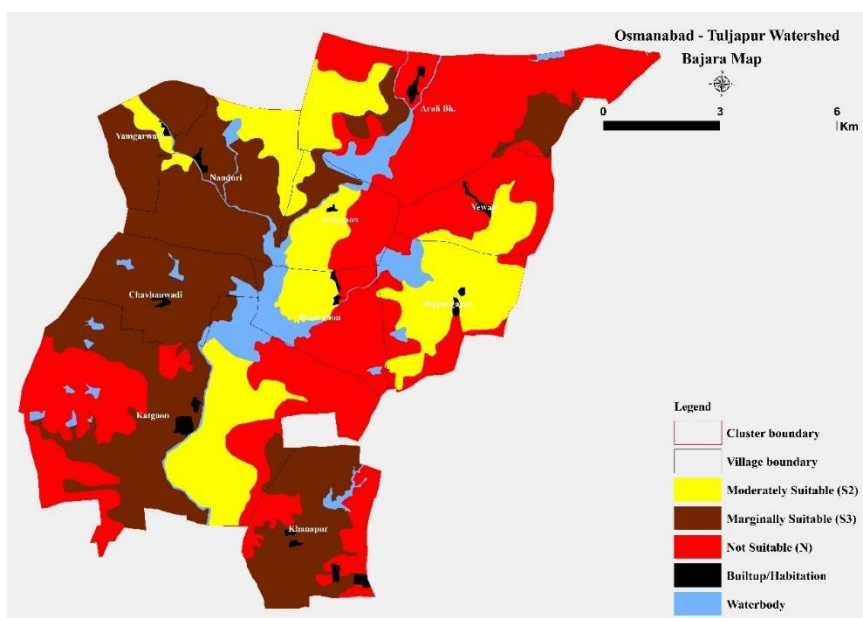
**Fig. 4.25. Soil site suitability map for Sorghum (Jowar) cultivation**

#### 4.8.4 Soil-Site Suitability for Pearl millet (Bajra) Cultivation

Being a relatively hardier crop as compared to sorghum, bajra cultivation is possible on both moderately and marginally suitable lands, existing in about 55% of the watershed (Table 4.30, Fig. 4.26). The crop is expected to perform better if proper *in-situ* soil moisture conservation techniques are adopted, and fertilizer nutrient applications are made according to their bioavailability. Around 38% of the watershed area was found to be not suitable (N) for pearl milled cultivation, reflecting severe constraints primarily associated with stony soil, slope, moisture retention which may not provide economical yields.

**Table 4.30. Area under suitability sub-classes for Pearl millet (Bajra) cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2591.2	20.1
2	Marginally Suitable (S3)	4450.9	34.6
3	Not Suitable (N)	4879.1	37.9
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



**Fig. 4.26. Soil site suitability map for Pearl millet (Bajra) cultivation**

#### 4.8.5 Soil-Site Suitability for Gram Cultivation

Soil site suitability evaluation for gram suggests that 2814 ha (22%) of land is moderately suitable (S2) for cultivation of gram, while another 4238 ha, or 33% of the watershed area is marginally suitable, as shown in Table 4.31 and Fig 4.27. This region has problems of soil depth, texture and low residual soil moisture due to erratic rainfall patterns, or unfavorable temperature during critical crop growth stages. Nearly 38% of the area is not suitable (N) for cultivation due to coarse fragments in the soil. The soils with low organic carbon content may be treated with farmyard manure application, and *in-situ* soil moisture conservation measures may be adopted in areas with shallow soil depths or poor moisture holding capacity.

**Table 4.31. Area under suitability sub-classes for Gram cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2814.4	21.9
2	Marginally Suitable (S3)	4238.3	32.9
3	Not Suitable (N)	4868.5	37.8
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>

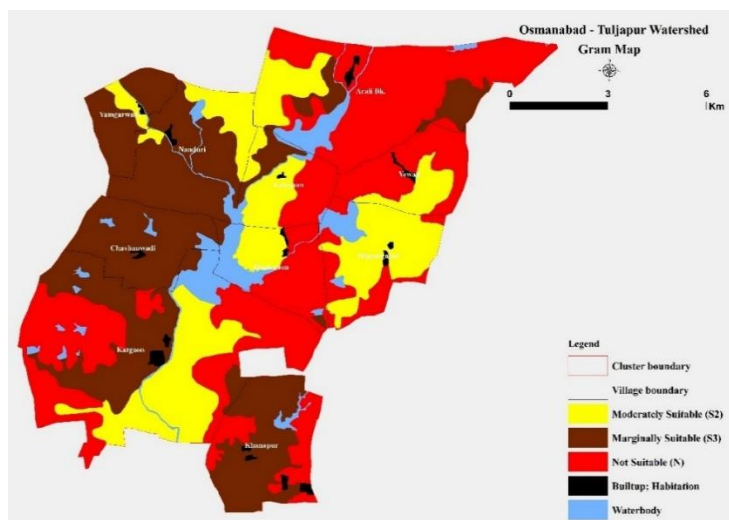


Fig. 4.27. Soil site suitability map for Gram cultivation

#### 4.8.6 Soil-Site Suitability for Pigeon Pea Cultivation

The soil-site suitability analysis (Table 4.32, Fig. 4.28) indicates that the regional rainfall is sufficient for pigeon pea cultivation. However, the land suitability varies significantly: 2265 ha (18%) is considered moderately suitable (S2), 2662 ha (21%) is marginally suitable (S3), and a larger area of 6994 ha (54%) is not Suitable (N), due to inadequate soil depth and/or soil physio-chemical conditions limiting productivity.

Table 4.32. Area under suitability sub-classes for Pigeon Pea cultivation

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2264.8	17.6
2	Marginally Suitable (S3)	2662.3	20.7
3	Not Suitable (N)	6994.1	54.3
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>

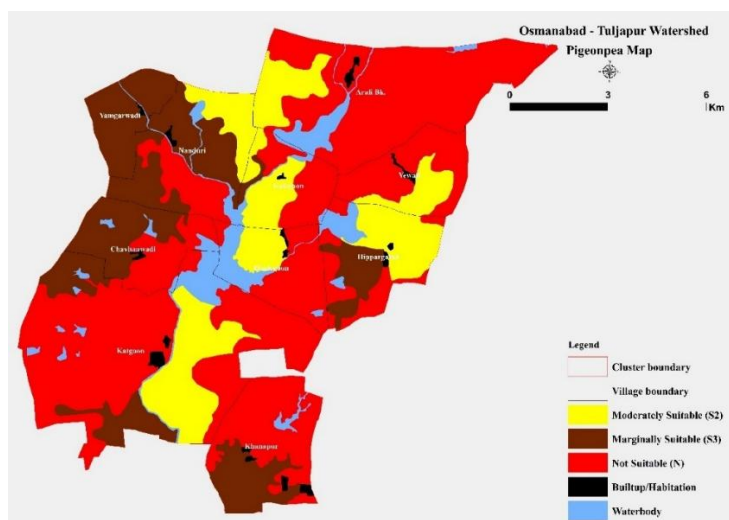


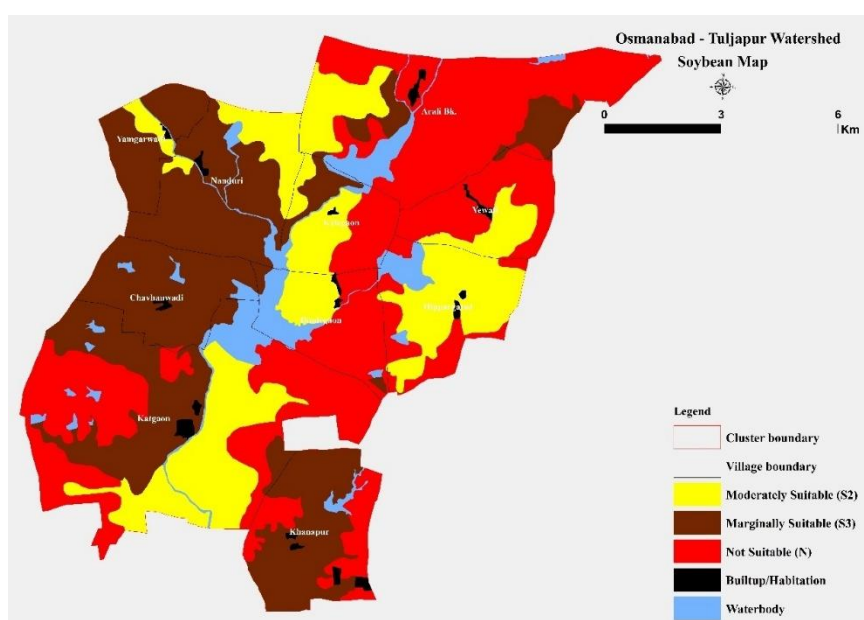
Fig. 4.28. Soil site suitability map for Pigeon Pea cultivation

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

Soil-site evaluation results for soybeans show a varied distribution of suitability classes across the watershed (Table 4.33, Fig. 4.29). Areas categorized as moderately suitable (S2) cover 2814.4 ha, accounting for about 22% of the total geographical area, indicating moderately favorable soil and site conditions for achieving good crop performance. An additional 33 % of the area is occupied under marginally suitable (S3) class, representing zones where soybean cultivation is feasible, although certain soil or site constraints may adversely impact yield levels. More than one-third of the watershed is not suitable (N) for soybean cultivation due to stony soils, shallow depth and other unfavorable soil/climatic conditions. These results mostly favor soybean cultivation in the watershed by following the recommended package of practices and conservation measures.

**Table 4.33. Area under suitability sub-classes for Soybean cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2814.4	21.9
2	Marginally Suitable (S3)	4238.3	32.9
3	Not Suitable (N)	4868.5	37.8
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



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

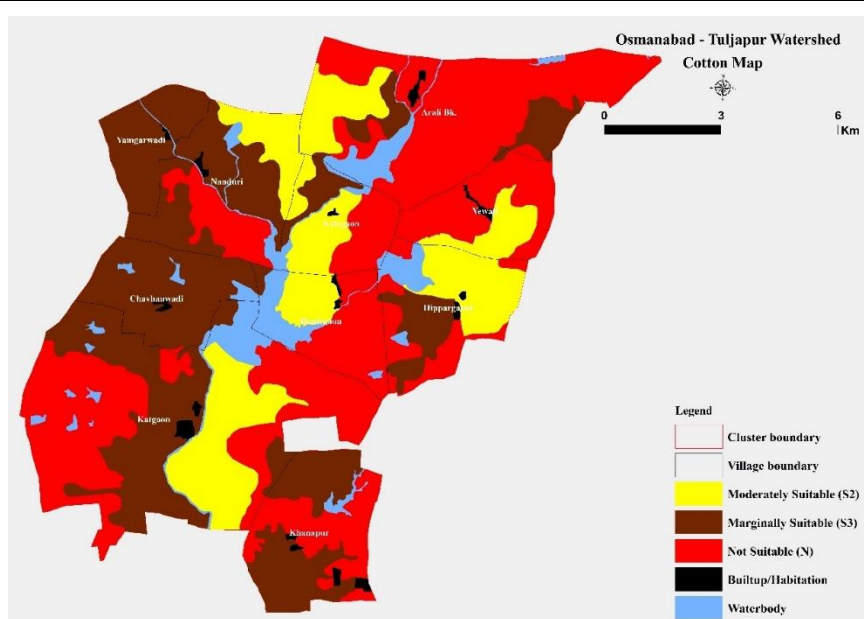
#### 4.8.8 Soil-Site Suitability for Cotton Cultivation

The soil-site evaluation for cotton cultivation shows that 2265 ha (about 18%) of the total watershed area is classified as moderately suitable (S1), these areas provide reasonably favorable conditions for cotton cultivation due to proper drainage, salinity, good soil depth and suitable soil texture, and require soil health and water conservation measures for

optimizing crop yields. About one-third of the Tuljapur watershed is marginally suitable for cotton, indicating the presence of moderate to severe limitations (e.g. moderate slope, low organic carbon and shallow soil depth) that may restrict yield potential. More than 40% of the watershed area is not considered suitable for growing cotton due to severe soil and site-related constraints. (Table 4.34 and Fig. 4.30)

**Table 4.34. Area under suitability sub-classes for Cotton cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2264.8	17.6
2	Marginally Suitable (S3)	4254.3	33.1
3	Not Suitable (N)	5402.2	42.0
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



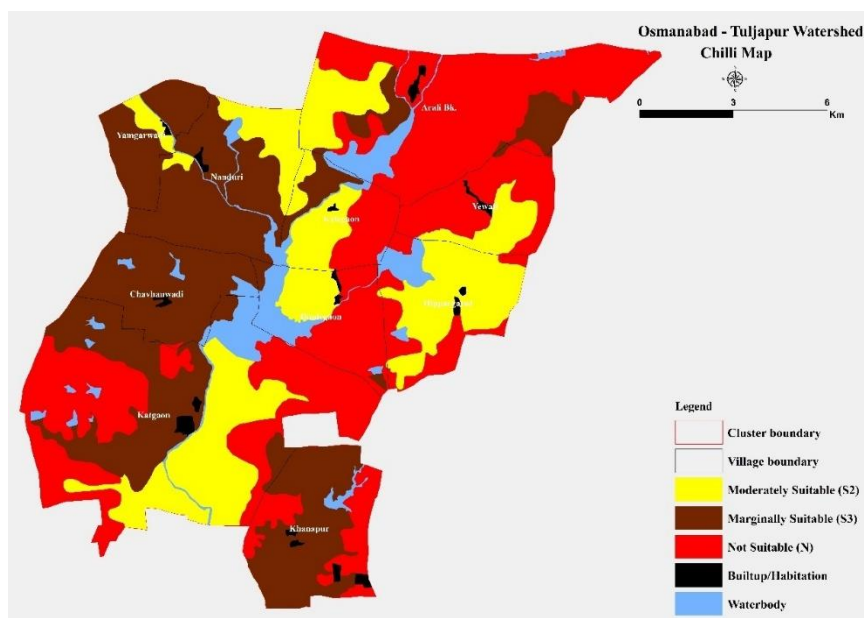
**Fig. 4.30. Soil site suitability map for Cotton cultivation**

#### 4.8.9 Soil-Site Suitability for Chilli Cultivation

The soil site suitability assessment indicates that this region has favorable temperatures for the growth of chili but lacks sufficient rainfall to meet its crop water requirement. Nearly one-third of the area is marginally suitable (S3) as shown in Table 4.35 and Fig. 4.31. Effective irrigation practices that prioritize water conservation are essential for successful crop cultivation. More than one-fifth of land is moderately suitable (S2) for cultivation. Leveling the land and applying farmyard manure will improve productivity of Chillies. About 38% of the watershed is not suitable for Chilli cultivation due to shallow soil depth with coarse fragments.

**Table 4.35. Area under suitability sub-classes for Chilli cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2814.4	21.9
2	Marginally Suitable (S3)	4238.3	32.9
3	Not Suitable (N)	4868.5	37.8
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



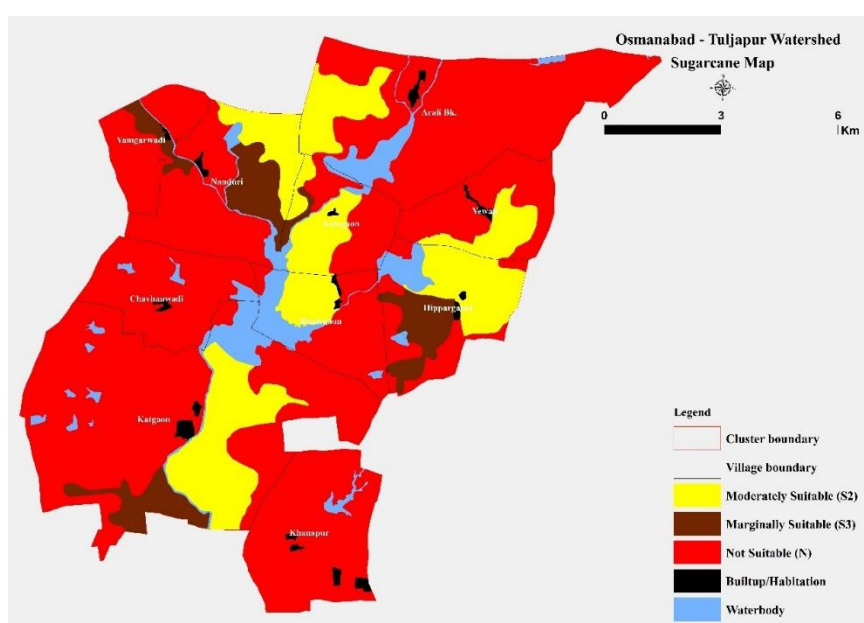
**Fig. 4.31. Soil site suitability map for Chilli cultivation**

#### 4.8.10 Soil-Site Suitability for Sugarcane Cultivation

The spatial distribution of suitability classes for sugarcane is presented in Table 4.36 and the corresponding map, in Fig. 4.32. The results indicate that only about one-fourth of the watershed area (~2265 ha) is marginally to moderately suitable (S2) for sugarcane, reflecting moderate-severe limitations in rainfall, temperature, soil depth, texture, drainage, fertility status, and terrain conditions for optimum sugarcane growth and productivity. Appropriate soil and water management practices, therefore need to be adopted. Conversely, the majority of the watershed, accounting for over 69% (8852 ha) is classified as not suitable (N) for sugarcane cultivation. The detailed evaluation of soil-site parameters indicates that this unsuitability is primarily driven by severe climatic and physical constraints, specifically inadequate rainfall and unfavorable Length of Growing Period (LGP), alongside significant limitations in soil depth across various soil units. It is also worth considering that sugarcane, being a highly water and nutrient intensive crop may be taken up only after ensuring sufficient groundwater availability and site-specific nutrient management.

**Table 4.36. Area under suitability sub-classes for Sugarcane cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2264.8	17.6
2	Marginally Suitable (S3)	804.2	6.3
3	Not Suitable (N)	8852.2	68.8
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



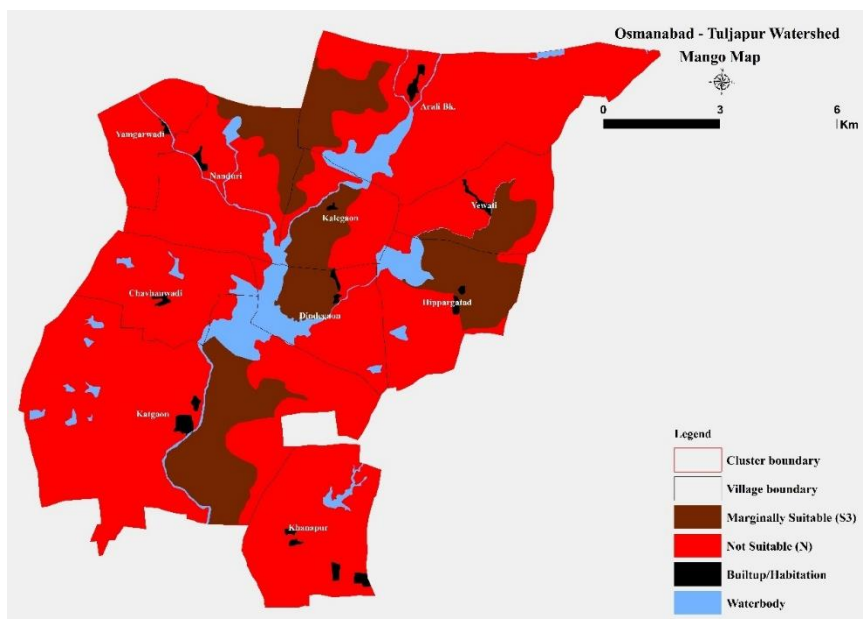
**Fig. 4.32. Soil site suitability map for Sugarcane cultivation**

#### 4.8.11 Soil-Site Suitability for Mango Cultivation

The spatial distribution of suitability classes in respect of mango is presented in Table 4.37 and Fig. 4.33. The results indicate that a major proportion of the total geographical area (TGA) is classified as not suitable (N) for mango cultivation, covering more than 9000 ha (75%) of the watershed. About 2264 ha (18%) of the watershed area is under the marginally (S3) suitable category owing to limitations in soil depth and due to soil calcareousness, suggesting that mango could be cultivated with caution in limited portions of the watershed by following management practices.

**Table 4.37. Area under suitability sub-classes for Mango cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Marginally Suitable (S3)	2264.8	17.6
2	Not Suitable (N)	9656.4	75.0
3	Built-up/Habitation	131.9	1.0
4	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



**Fig. 4.33. Soil site suitability map for Mango cultivation**

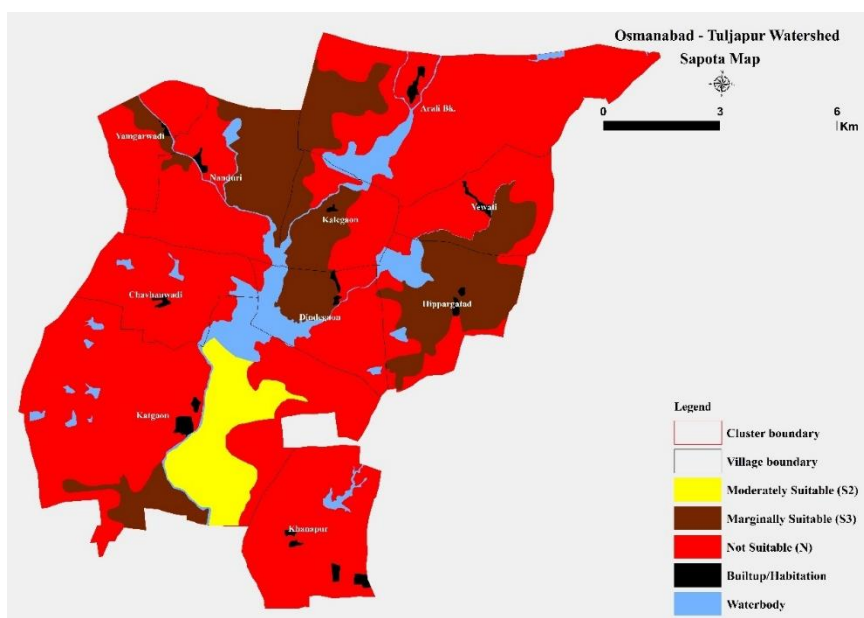
#### 4.8.12 Soil-Site Suitability for Sapota Cultivation

The soils of the watershed were evaluated for sapota cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.38 and Fig. 4.34. The results indicate that about 3000 ha (24% of the total geographical area of the watershed) is classified as moderately (S2) or marginally suitable (S3) for sapota cultivation, reflecting moderate to severe constraints related to soil properties and terrain slope, which may restrict yield potential unless appropriate management practices are adopted.

More than 68% of the watershed area is not suitable (N) for sapota cultivation due to severe limitations associated with rocky soil, topography, steep slope and soil alkalinity. Overall, the evaluation suggests that limited soil types in the watershed are suitable for sapota cultivation.

**Table 4.38. Area under suitability sub-classes for Sapota cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	671.6	5.2
2	Marginally Suitable (S3)	2397.3	18.6
3	Not Suitable (N)	8852.2	68.8
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



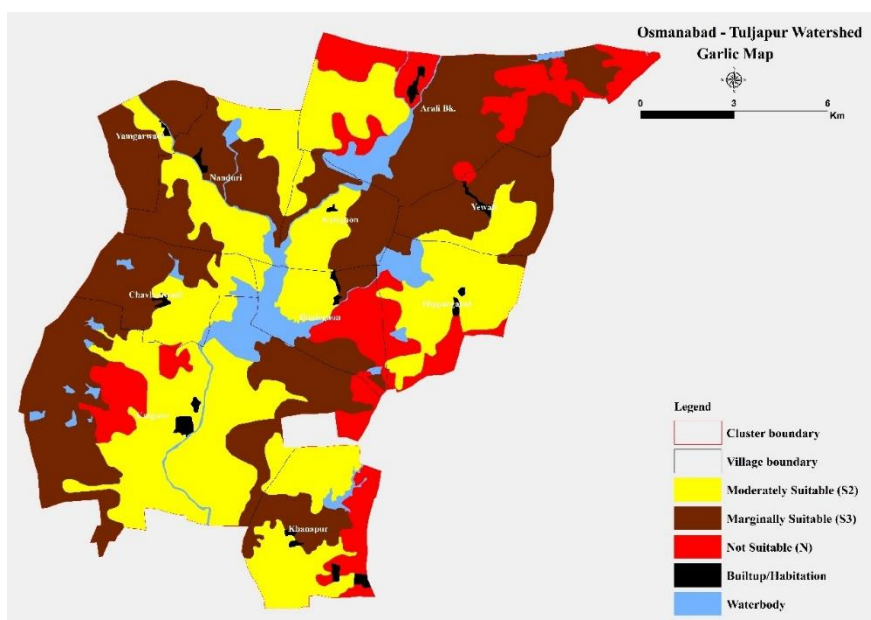
**Fig. 4.34. Soil site suitability map for Sapota cultivation**

#### 4.8.13 Soil-Site Suitability for Garlic Cultivation

The crop suitability assessment for tomato shows that more than 79% of the Tuljapur watershed (Table 4.39 and Fig. 4.35) is suitable for garlic cultivation, albeit after adopting proper conservation practices such as soil moisture and nutrient management.

**Table 4.39. Area under suitability sub-classes for Garlic cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	4795.2	37.3
2	Marginally Suitable (S3)	5390.5	41.9
3	Not Suitable (N)	1735.5	13.5
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



**Fig. 4.35. Soil site suitability map for Garlic cultivation**

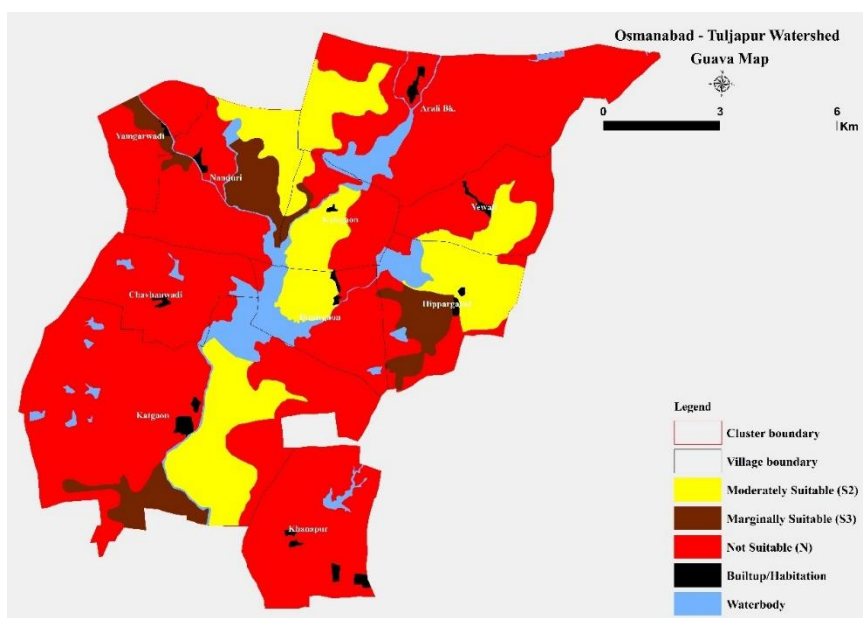
#### 4.8.14 Soil-Site Suitability for Guava Cultivation

The soils of the watershed were evaluated for Guava cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.40 and Fig. 4.36. The results indicate that about 3000 ha (24% of the total geographical area of the watershed) is classified as suitable (S2 and S3), providing moderately favorable conditions for guava growth and productivity, while also providing certain soil-related constraints such as depth, which may restrict yield potential unless appropriate management practices and conservation measures possible.

More than 69% of the watershed area is not suitable (N) for guava cultivation due to severe limitations associated with stony, calcareous and shallow soil. Overall, the evaluation suggests that while nearly one-fourth of the watershed is highly suitable for guava cultivation.

**Table 4.40. Area under suitability sub-classes for Guava cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2264.8	17.6
2	Marginally Suitable (S3)	804.2	6.3
3	Not Suitable (N)	8852.2	68.8
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



**Fig. 4.36. Soil site suitability map for Guava cultivation**

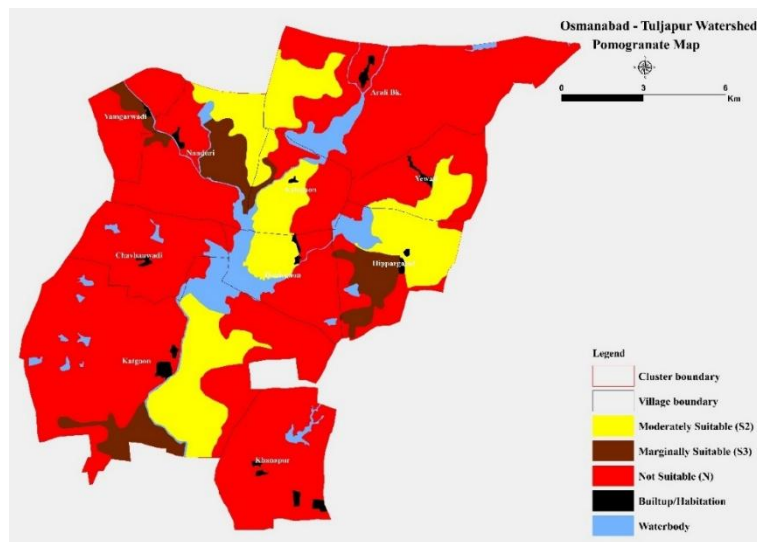
#### 4.8.15 Soil-Site Suitability for Pomegranate Cultivation

The soils of the watershed were evaluated for pomegranate cultivation based on crop-specific requirements. The results indicate that about 3000 ha (24% of the total geographical area of the watershed) is classified as suitable (S2 and S3), providing moderately favorable conditions for pomegranate, while also providing certain soil-related constraints such as depth and calcareousness, which may restrict yield potential unless appropriate management practices and conservation measures possible.

More than 69% of the watershed area is not suitable (N) for guava cultivation due to severe limitations associated with stony, calcareous and shallow soil. Overall, the evaluation suggests that while nearly one-fourth of the watershed is highly suitable for pomegranate cultivation. (Table 4.41 and Fig. 4.37)

**Table 4.41. Area under suitability sub-classes for Pomegranate cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2264.8	17.6
2	Marginally Suitable (S3)	804.2	6.3
3	Not Suitable (N)	8852.2	68.8
4	Built-up/Habitation	131.9	1.0
5	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



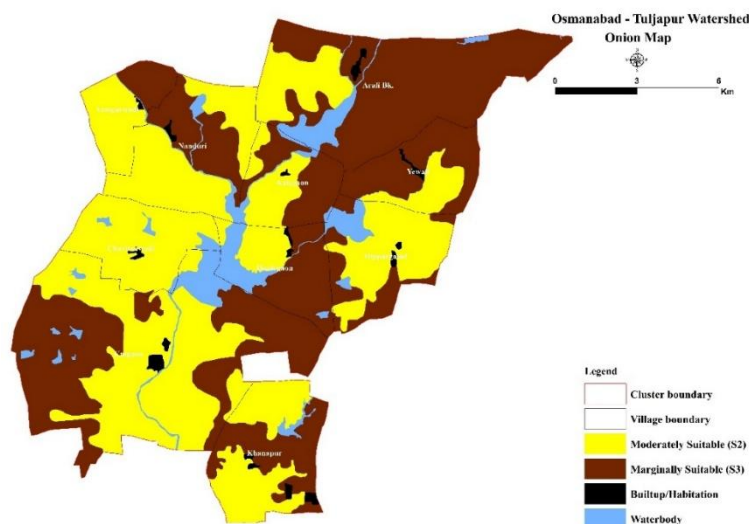
**Fig. 4.37. Soil site suitability map for Pomegranate cultivation**

#### 4.8.16 Soil-Site Suitability for Onion Cultivation

The crop suitability assessment for onion shows that about 12000 ha (~93%) of the watershed area is either moderately or marginally suitable for onion, as presented in Table 4.42 and Fig 4.38. Efficient irrigation practices such as drip irrigation or micro sprinkler irrigation systems can be adopted to support crop growth and yield.

**Table 4.42. Area under suitability sub-classes for Onion cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	5950.9	46.2
2	Marginally Suitable (S3)	5970.3	46.4
3	Built-up/Habitation	131.9	1.0
4	Waterbody	820.8	6.4
	<b>Total</b>	<b>12873.9</b>	<b>100.0</b>



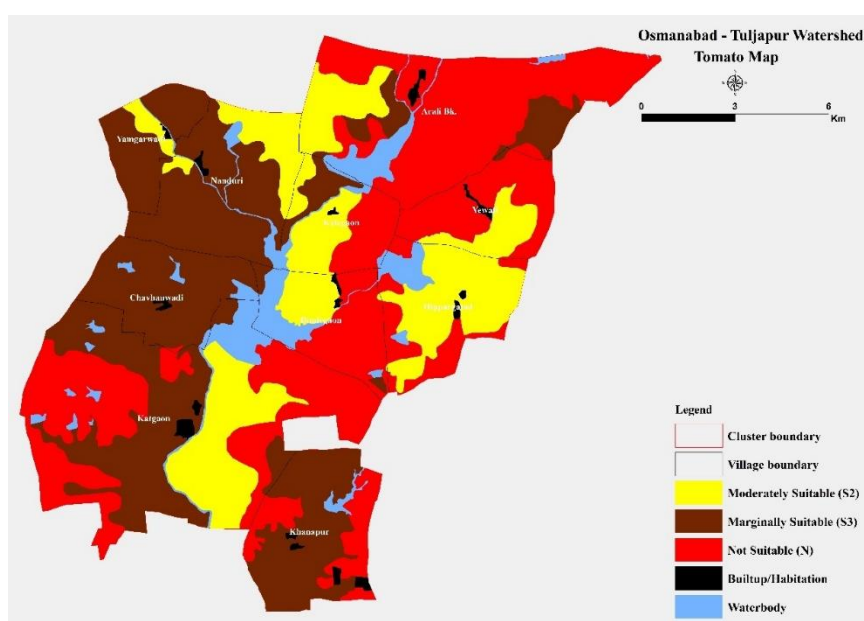
**Fig. 4.38. Soil site suitability map for Onion cultivation**

#### 4.8.17 Soil-Site Suitability for Tomato Cultivation

The crop suitability assessment for tomato shows that more than 54% of the Tuljapur watershed (Table 4.43 and Fig 4.39) is suitable for garlic cultivation, albeit after adopting proper conservation practices such as soil moisture and nutrient management.

**Table 4.43. Area under suitability sub-classes for Tomato cultivation**

Sr. No.	Suitability class	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2591.2	20.13
2	Marginally Suitable (S3)	4461.46	34.66
3	Not Suitable (N)	4868.53	37.82
4	Built-up/Habitation	131.89	1.02
5	Waterbody	820.79	6.38
	<b>Total</b>	<b>12873.9</b>	<b>100</b>



**Fig. 4.39. Soil site suitability map for Tomato cultivation**

#### 4.9 Soil and Water Conservation measures

Soil and Water Conservation planning for the Tuljapur Taluka village cluster watershed has been formulated based on physical information and hydrological observations, aiming to enhance in-situ moisture retention, regulate runoff, reduce soil erosion, and improve groundwater recharge. The plan is grounded on actual watershed characteristics, including landforms, slope gradients, soil textures, and existing water harvesting structures such as the Harni Dam at Katgaon and upstream waterbodies near Arali Bk., ensuring that all interventions are technically appropriate and site-specific.

Agricultural lands occurring on very gentle slopes (0-3%) have been identified for treatment with the Broad Bed and Furrow (BBF) system. This measure is appropriate for

nearly level cultivated fields where controlled surface drainage is required to prevent waterlogging while retaining adequate soil moisture. To improve on-farm water availability, farm ponds and lined farm ponds have been recommended at suitable locations within BBF-treated areas, based on site conditions. These structures enable storage of surplus monsoon runoff generated within the fields and support protective irrigation during dry spells.

Cultivated lands falling under the 3-6% slope range have been assigned field bunding and strengthening of existing bunds with safe disposal of runoff water. These measures are suitable for gently sloping agricultural fields where bunds help in reducing runoff velocity, conserving soil moisture, and minimizing sheet erosion. In selected locations, farm ponds and lined farm ponds have also been recommended in conjunction with bunding to enhance water storage and supplemental irrigation potential.

Agricultural areas characterized by moderate slopes (6-10%) and unbunded conditions have been identified for Conservation Bench Terracing. This treatment is suitable where slope-induced erosion risk is higher and where soil depth permits terracing. Bench terraces reduce effective slope length, control runoff, and allow continued cultivation under improved moisture conditions. In lands having steep slopes exceeding 10%, particularly where soils depth ranges from very shallow to moderately deep, Puretocion terrace and Bench Terraces have been recommended on deep soils. These measures are intended primarily for erosion control rather than intensive cultivation and help stabilize vulnerable slopes.

Areas under natural vegetation, open scrub, and wasteland have been assigned afforestation and in-situ moisture conservation measures to improve vegetative cover, enhance infiltration, and stabilize soils. Stream bank plantation has been recommended along local river. Existing surface water bodies and seasonal storage structures within the watershed have been included for renovation and desilting based on site conditions, in order to restore storage capacity and improve inflow-outflow efficiency. Renovation and desilting of farm ponds have also been proposed, wherever siltation has reduced functional storage.

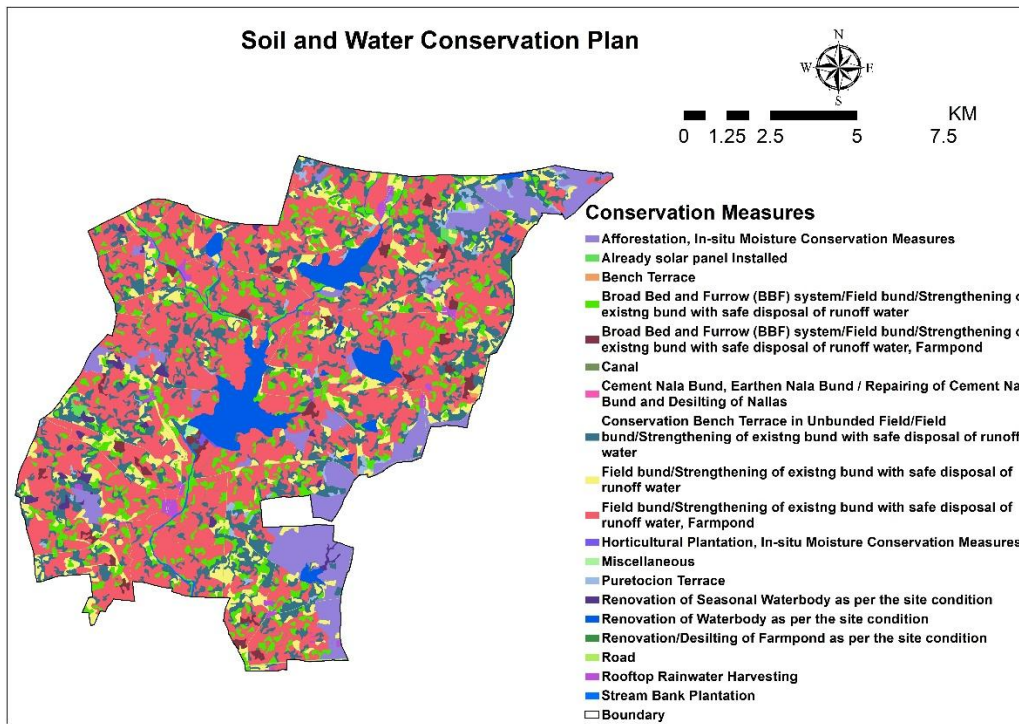
Drainage line treatments in the form of cement nala bunds, earthen nala bunds, repair of existing structures, and desilting of nalas have been proposed at locations identified through field conditions and drainage characteristics. Other land uses such as roads, canals & areas with existing solar panel installations, and miscellaneous uses have been excluded from SWC treatment planning.

Overall, the proposed SWC plan covers a total area, with interventions selected strictly according to slope, soil depth, and land capability. The plan emphasizes strengthening of existing agricultural practices, regulation of surface runoff, and enhancement of local water availability without imposing uniform treatments across the watershed. Through this scientifically grounded and slope-based approach, the SWC plan aims to improve land productivity, reduce erosion risks, and support sustainable agriculture in the Tuljapur Taluka village cluster watershed. 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. The suggested polygon wise soil and water conservation measure is individual or combination of different conservation measures and each polygon is considered as independent unit.

**Table 4.44. Proposed soil and water conservation (SWC) plan for Tuljapur watershed**

Sr. No.	Proposed SWC Plan
1	Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm pond
2	Conservation Bench Terrace in Unbundled Field/Field bund/Strengthening of existing bund with safe disposal of runoff water
3	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water
4	Field bund/Strengthening of existing bund with safe disposal of runoff water
5	Afforestation, In-situ Moisture Conservation Measures
6	Renovation of Waterbody as per the site condition
7	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm pond
8	Puretocion Terrace
9	Rooftop Rainwater Harvesting
10	Renovation of Seasonal Waterbody as per the site condition
11	Road
12	Stream Bank Plantation
13	Already solar panel Installed
14	Bench Terrace
15	Canal
16	Cement Nala Bund, Earthen Nala Bund / Repairing of Cement Nala Bund and Desilting of Nallas
17	Horticultural Plantation, In-situ Moisture Conservation Measures
18	Renovation/Desilting of Farm pond as per the site condition
19	Miscellaneous



**Fig. 4.40. Soil and water conservation measures proposed for Tuljapur watershed**

## CHAPTER 5

### SUMMARY AND CONCLUSION

#### 5.1 SUMMARY

- The Land Resource Inventory (LRI) was conducted for the Dharashiv (WDC-2.0)3/2021-22 watershed located in the Tuljapur Taluka of Dharashiv District, Maharashtra. The area is characterized by a semi-arid, hot and dry climate typical of the Marathwada region, with an average annual rainfall of about 650 mm.
- The region is underlain by Deccan Trap basalt, forming a typical plateau topography. The terrain includes diverse geomorphic units such as escarpment plateau, pediment, pediplain, hills, and valley landforms, with slopes ranging up to 43%.
- The main natural resource constraints are its dependence on irregular monsoon rainfall and associated variability, necessitating efficient water management and soil conservation.
- The assessment, carried out under the PMKSY-WDC 2.0 framework, focused on a systematic characterization of soil and land resources, assessment of land capability and soil-site suitability for various crops, evaluation of groundwater potential zones, and the development of watershed-based alternate land use and soil and water conservation (SWC) plans.
- Soil-site suitability was evaluated for major crops including Wheat, Black gram, Sorghum (Jowar), Pearl millet (bajra), Gram, Pigeon pea, Soybean, Cotton, Sugarcane, and various fruits and vegetables (Mango, Sapota, Chili, Onion, Tomato, etc.).
- Site-specific interventions, including proposals for structural and vegetative measures, were systematically identified based on terrain analysis, land capability, and runoff potential to promote sustainable management of land and water resources.

#### 5.2 CONCLUSION

The effective application of integrated geospatial techniques and field-based observations for comprehensive watershed assessment and planning under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) framework. The systematic analysis of terrain, drainage characteristics, slope, soil resources, and land use in Tuljapur has enabled a detailed understanding of the hydrological and environmental conditions in this semi-arid region.

The assessment confirms that the agricultural system in this area is primarily rainfed and is vulnerable to the variability of the monsoon, making the identification of resource constraints and the prioritization of interventions essential. The evaluation of soil-site suitability for key crops and the mapping of groundwater potential zones form a robust scientific basis for strategic planning. Successful implementation of the proposed soil and water conservation (SWC) measures and alternate land-use options will 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.

## ANNEXURE-1

### **Methodology for 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.

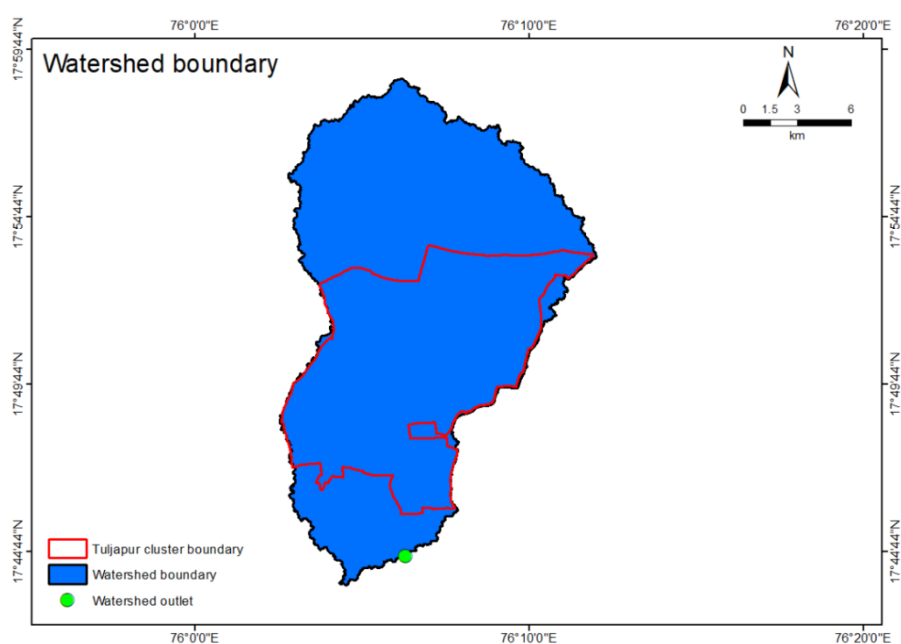
The morphometric analysis was conducted at the watershed and sub-watershed scale, as these parameters depend on natural drainage boundaries rather than administrative limits. The derived indices were subsequently interpreted to understand runoff generation, erosion susceptibility, and groundwater recharge 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 Tuljapur cluster, Dharashiv**

In this study, runoff estimation, groundwater potential zone (GWPZ) mapping, and soil and water conservation (SWC) planning were carried out at the village cluster level to enable site-specific assessment and practical implementation. However, morphometric analysis was conducted at the watershed level because morphometric parameters are controlled by natural drainage boundaries rather than administrative units. Morphometric analysis quantitatively evaluates drainage network characteristics, basin geometry, slope, and relief, which influence runoff generation, erosion, and groundwater recharge. These parameters must be derived from a hydrologically closed unit bounded by natural divides. A watershed represents such a unit, where streams develop hierarchically and drain toward a common

outlet, ensuring reliable computation of indices such as drainage density, bifurcation ratio, stream frequency, form factor, and relief ratio.

Village clusters are administrative entities that do not coincide with complete drainage systems. Since streams often cross village boundaries, morphometric analysis at the cluster level would result in truncated stream networks and distorted basin geometry, leading to inaccurate 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 Tuljapur village cluster, Dharashiv, Maharashtra, comprises ten villages. Together, these villages constitute the study cluster having one watershed (Fig. 1).

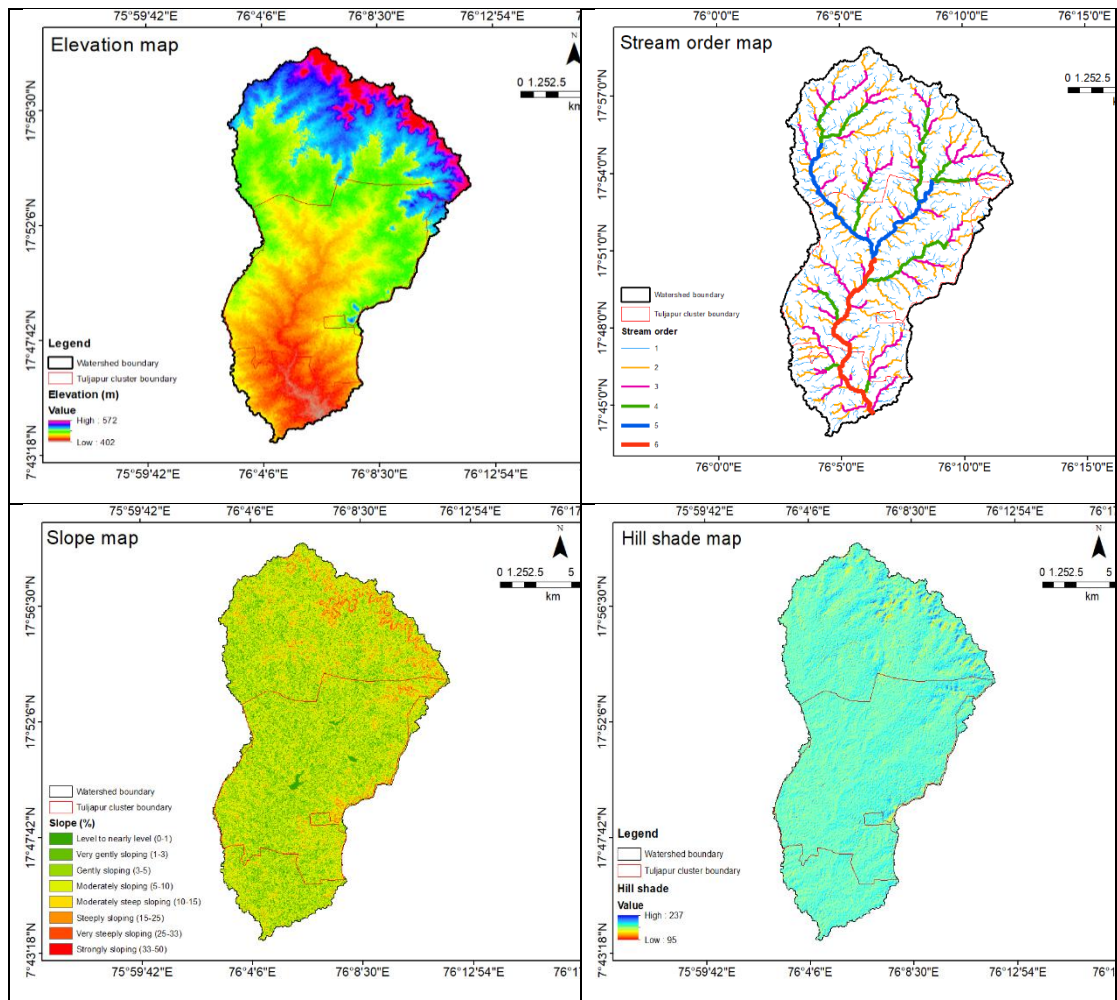


**Fig. 1. Map of Tuljapur cluster, Dharashiv depicted through sub-watershed**

**Table 1. Distribution of area under different sub-watershed, Tuljapur cluster, Dharashiv**

Sl. No.	Sub-watershed name	Sub-watershed order	Elevation (m)	Area (km <sup>2</sup> )	Flow origination
1	W1	6 <sup>th</sup>	402-575	274.21	North to South-east
			<b>Total</b>	<b>274.21</b>	

The sub-watershed wise area, their order, elevation range and drainage network are presented in Table 1 and in Fig. 2. Their morphometric characteristics of these sub-watersheds are analyzed under three aspects: linear, areal, and relief.



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

### Linear aspect

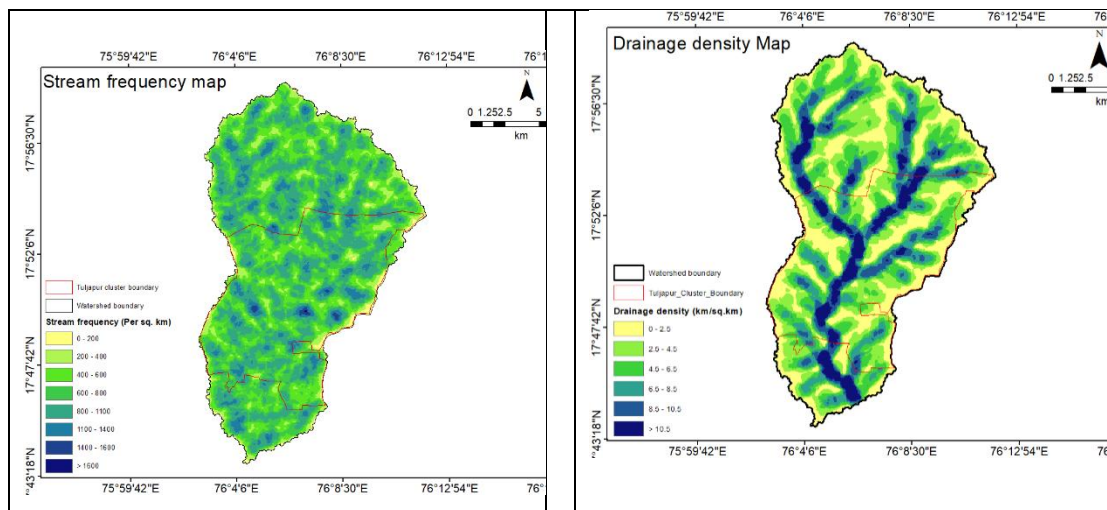
Linear morphometric parameters focus on the stream network characteristics and its influence on runoff and watershed behavior. The morphometric analysis of the sub-watersheds shows clear variation in drainage characteristics. W1 has the number of streams (1366) and total stream length (736.67 km), indicating a well-developed drainage network (Table 2). The bifurcation ratio indicated as 4.26, suggesting relatively greater structural influence watershed. Mean channel length and valley length of watershed, reflecting more mature channel development. Channel index of watershed W1 (1.2), indicating greater sinuosity. Basin perimeter of W1 (116.83 km), confirming it as the most extensive sub-watershed.

**Table 2. Linear morphometric parameters of sub-watersheds, Tuljapur cluster, Dharashiv**

Sr. No.	Morphometric parameter	Symbol	Unit	W1
1	No. of streams	Nu	No	1366
2	Stream length	Lu	km	736.67
3	Bi-furcation ratio	Rb	-	4.26
4	Mean channel length	Cl	km	36.63
5	Valley Length	VI	km	33.45
6	Channel Index	Ci	-	1.2
7	Minimum areal distance	Adm	km	30.46
8	Valley Index	Vi	-	1.10
9	Basin perimeter	P	km	116.83

### 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 (274.21 km<sup>2</sup>) and mean basin width is 7.7 km. Form factor (Ff) and elongation ratio (Re) in W1 (0.22 and 0.52), suggesting a comparatively more circular basin. Circularity ratio (Rc) of W1 is 0.25, while compactness coefficient (Cc) as 2, reflecting greater basin irregularity. Standard sinuosity index (Ssi) as 1.10, indicating relatively higher channel sinuosity in W1. Drainage parameters show that stream frequency (Fs) is 4.98 per km<sup>2</sup> and Drainage density (Dd) as 2.7 km/km<sup>2</sup>. Drainage intensity (Di) follows a similar trend, with the highest value as 1.85. Length of overland flow (Lg) as (0.66 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, Tuljapur cluster, Dharashiv**

Sr. No.	Parameter	Symbol	Method/ Formula	Unit	W1
1.	Mean basin width	Wb	$Wb=A/Lb$	km	7.7
2.	Basin area	A	GIS Analysis	km <sup>2</sup>	274.21
3.	Relative perimeter	Pr	$Pr= A/P$	km	2.35
4.	Length area relation	Lar	$Lar = 1.4*A^{0.6}$	km <sup>2</sup>	40.64
5.	Lemniscate's	k	$K = Lb^2/A$	-	4.6
6.	Form factor	Ff	$Ff = A/Lb^2$	-	0.22
7.	Elongation ratio	Re	$Re = 2/Lb*(A/\pi)^{0.5}$	-	0.52
8.	Circularity ratio	Rc	$Rc = 12.57*(A/P^2)$	-	0.25
9.	Compactness coefficient	Cc	$Cc = 0.2841*P/A^{0.5}$	-	2.00
10.	Standard sinuosity index	Ssi	$Ssi = Ci/Vi$	-	1.10
11.	Stream frequency	Fs	$Fs = Nu/A$	Per km <sup>2</sup>	4.98
12.	Drainage Density	Dd	$Dd = Lu/A$	km/km <sup>2</sup>	2.7
13.	Drainage Intensity	Di	$Di = Fs/Dd$	-	1.85
14.	Length of Overland Flow	Lg	$Lg = A/2*Lu$	km	0.66

### Relief Aspects

The maximum basin height (Z) of W1 (572m) and total basin relief (H) is also maximum as (170 m) (Table 4). Relief ratio (Rhl) as W1 (4.8), indicating steeper terrain conditions, while Relative relief ratio (Rhp) of W1 (145.5) suggesting higher relief intensity in W1. The ruggedness number (Rn) of watershed W1 (0.32), reflecting more dissected and erosion-prone terrain. Similarly, the Melton ruggedness number (MRn) is shown in W1 (10.3), indicating comparatively higher susceptibility to runoff and erosion processes.

**Table 4. Relief morphometric parameters of sub-watersheds, Tuljapur cluster, Dharashiv**

Sr. No	Parameters	Symbol	Methods /Formula	W1
1.	Height of at basin mouth,(m)	z	DEM	402
2.	Maximum height of the basin, (m)	Z	DEM	572
3.	Total basin relief, (m)	H	$H = Z - z$	170
4.	Relief ratio	Rhl	$Rhl = H / Lb$	4.8
5.	Relative relief ratio	Rhp	$Rhp = H * 100 / P$	145.5
6.	Ruggedness number	Rn	$Rn = Dd*(H/1000)$	0.32
7.	Melton Ruggedness number	MRn	$MRn = H / A^{0.5}$	10.3

The slope distribution of watershed W1 shows considerable variation in terrain conditions, influencing runoff generation and soil erosion potential. The majority of the watershed area falls under the moderately sloping category (5–10%), covering 110.26 km<sup>2</sup> (40.21%), which indicates moderately undulating terrain with relatively higher runoff potential. This is followed by gently sloping land (3–5%) occupying 81.59 km<sup>2</sup> (29.7%), suggesting that a large portion of the watershed has moderate gradients suitable for agricultural activities with appropriate conservation measures. Moderately steep slopes (10–15%) account for 29.29 km<sup>2</sup> (10.68%), while very gently sloping areas (1–3%) cover 23.88 km<sup>2</sup> (8.71%). Level to nearly level terrain (0–1%) occupies 15.11 km<sup>2</sup> (5.51%), representing comparatively flat areas where runoff movement is slower and infiltration is relatively higher. Steeply sloping land (15–25%) covers 12.64 km<sup>2</sup> (4.61%), whereas very steep slopes (25–33%) occupy only 1.31 km<sup>2</sup> (0.5%) of the watershed. Strongly sloping terrain (33–50%) is negligible, covering only about 0.14 km<sup>2</sup>

Based on the morphometric analysis and slope distribution, an integrated soil conservation and land use planning strategy is essential for watershed W1. The watershed shows a well-developed drainage network with a high number of streams, long total stream length, and relatively high drainage density, indicating rapid runoff generation and a higher susceptibility to soil erosion. The moderate to high bifurcation ratio (4.26), ruggedness number (0.32), and Melton ruggedness number (10.3) further suggest structurally controlled drainage and dissected terrain prone to erosion. Level to very gently sloping areas (0–3%) can be utilized for intensive agriculture with improved irrigation management, crop rotation, and field bunding to enhance water retention and groundwater recharge. Gently sloping areas (3–5%) should adopt contour farming, graded bunds, and vegetative barriers to reduce runoff velocity and soil loss. Moderately sloping areas (5–10%), which dominate the watershed, are suitable for conservation practices such as field bunding, strip cropping, and farm ponds to store runoff and improve soil moisture. Moderately steep to steep slopes (10–25%) require stronger measures like bench terracing, contour trenches, and agro-forestry systems to stabilize the soil and reduce erosion. Very steep and strongly sloping areas (>25%) should be kept under permanent vegetation cover

such as afforestation, grassland development, or silvi-pasture to protect the fragile terrain. Overall, the morphometric characteristics combined with slope distribution indicate that watershed W1 requires a combination of agronomic, mechanical, and vegetative conservation practices along with appropriate land use planning to minimize soil erosion, regulate runoff, and promote sustainable watershed management.



