

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

**(WDC-2.0)5/2021-22: Malegaon, Dist - Washim**



**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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## 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 subregions 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.



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## **EXECUTIVE SUMMARY**

The Pradhan Mantri Krishi Sinchayee Yojana - Watershed Development Component (PMKSY-WDC 2.0) emphasizes scientific and participatory watershed development through systematic assessment of land and water resources. In this context, Land Resource Inventory (LRI) serves as a critical technical input for informed planning, prioritization of interventions, and sustainable management of natural resources. In line with the programme guidelines, the ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP) has been entrusted with the responsibility of carrying out LRI and providing technical support for watershed development planning.

Accordingly, ICAR-NBSS&LUP conducted Land Resource Inventory and watershed assessment for the Washim (WDC-2.0) Village Cluster-watershed located in Malegaon Taluka of Washim District, Maharashtra. The Village Cluster-watershed forms part of the Mausam River basin and represents the typical basaltic terrain of the Deccan Plateau. Agriculture is the dominant land use in the watershed, largely dependent on monsoon rainfall, with groundwater playing a supplementary role.

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 carried out following standard methodologies and procedures prescribed by ICAR-NBSS&LUP. Pre-field analysis, detailed soil survey, laboratory analysis, and GIS-based interpretation were undertaken to generate spatial and thematic datasets. Base maps were prepared using authenticated sources, and Terrain Mapping Units were delineated through integration of landform, slope, and land use information. Soils were characterized through field observations and laboratory analysis and classified using 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 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 Malegaon sub-watershed constitutes an essential technical framework for watershed development planning and implementation, in accordance with the objectives and guidelines of PMKSY-WDC 2.0.



## CHAPTER 1

### INTRODUCTION

Land Resource Inventory (LRI) of a given area (village, block, district or region) has established its importance as a vital input for planned agricultural development. Encouraged by the success of LRI-based watershed program in Karnataka, many states have started using soil/land data for rural development. Administrators at 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 region and subregions delineated by ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP) therefore forms 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 Maharashtra Government approached the Bureau for assistance in carrying out LRI of 14 watersheds across different agro-ecological regions of the state. This is expected to benefit the farming community through visible improvement and sustainability of agricultural and allied sectors in rainfed areas. The watersheds were selected in proportion to the number of projects in different regions of Maharashtra. As the highest number of projects are being implemented in Vidarbha and Konkan regions, four watersheds each were selected from the region. Two watersheds each from the Western Maharashtra, Marathwada and Northern Maharashtra were selected as there are comparatively lesser number of projects in these regions. The districts in each region were also selected according to the number of projects implemented, and block/watershed selection was randomly done. The details of the randomly selected watersheds are given below:

District	Project name	Block	No. of MWS*	No. of villages	Area (ha)
Akola	Akola (WDC-2.0)1/2021-22	Barshitakli	11	8	4898.00
Buldhana	Buldhana (WDC-2.0)3/2021-22	Lonar	21	4	2498.59
Nandurbar	Nandurbar (WDC-2.0)4/2021-22	Nandurbar	5	14	3533.29
Nashik	Nashik (WDC-2.0)3/2021-22	Malegaon	7	7	2760.49
Osmanabad	Osmanabad (WDC-2.0)3/2021-22	Tuljapur	25	10	3380.00
Palghar	Palghar (WDC-2.0)6/2021-22	Dahanu	7	23	3926.27
Parbhani	Parbhani (WDC-2.0)3/2021-22	Gangakhed	8	9	3791.00

Raigad	Raigad (WDC-2.0)/2/2021-22	Roha	3	11	3825.00
Ratnagiri	Ratnagiri (WDC-2.0)/3/2021-22	Chiplun	13	9	2548.00
Sangli	Sangli (WDC-2.0)3/2021-22	Jath	23	4	3200.00
Sindhudurga	Sindhudurga (WDC-2.0)/3/2021-22	Dodamarga	5	5	3604.40
Solapur	Solapur (WDC-2.0)2/2021-22	Mangalwedha	31	7	4198.17
Wardha	Wardha (WDC-2.0)/3/2021-22	Seloo	12	7	2657.54
Washim	Washim (WDC-2.0)/5/2021-22	Washim-Malegaon	21	8	3806.19
<b>Total</b>			<b>192</b>		<b>48626.94</b>

\*MWS- Micro Watershed

The project, covering an area of **48,626 ha**, was undertaken with the following objectives:

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

This report presents the **Land Resource Inventory (LRI)** of the Washim (WDC-2.0) 2021–22 sub-watershed located in Malegaon taluka of Washim district. The study was conducted under the Pradhan Mantri Krishi Sinchayee Yojana – Watershed Development Component (PMKSY-WDC 2.0).

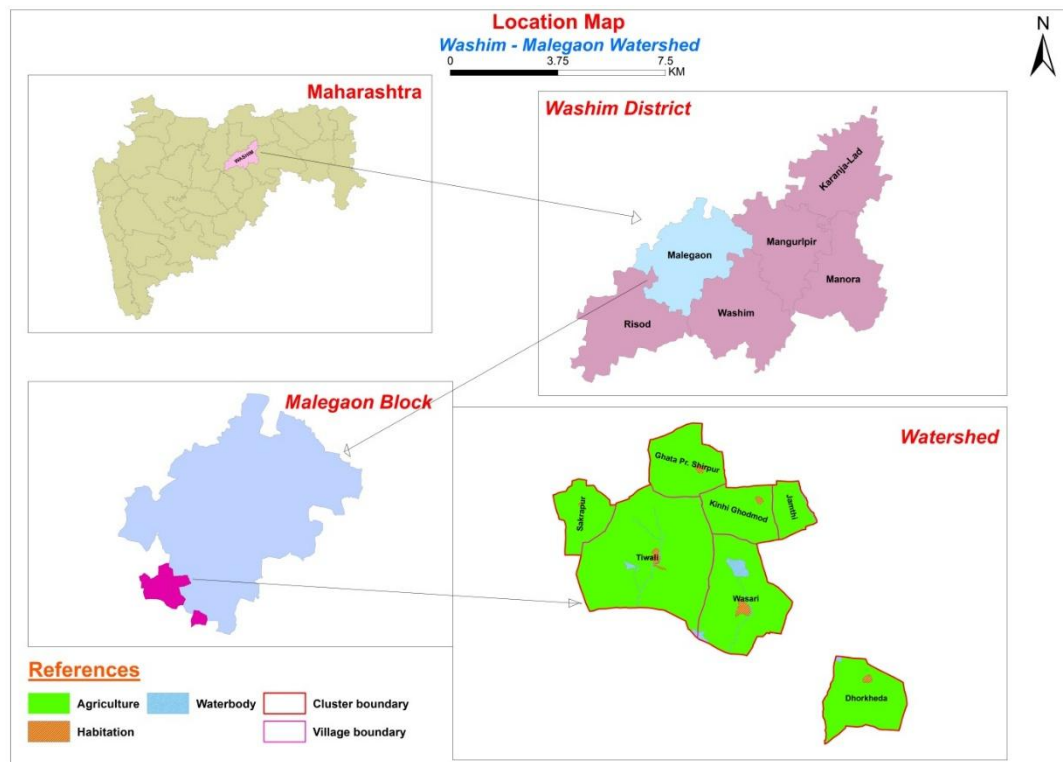
The assessment integrates data generated through systematic field surveys, soil sampling, laboratory analysis, and thematic mapping. In addition, officially available thematic layers, hydrological analysis, and watershed planning principles were utilized to evaluate land and water resources, analyze runoff behavior, and identify technically feasible soil and water conservation measures. The proposed interventions aim to enhance in-situ moisture retention, improve groundwater recharge, and promote sustainable watershed management within the Malegaon watershed area.

## CHAPTER 2

### MALEGAON WATERSHED AT A GLANCE/GEOGRAPHICAL SETTINGS

#### 2.1 Location

The watershed (Fig. 2.1) is located in Malegaon taluka, one of the administrative divisions of Washim District, within the Amravati Revenue Division of Maharashtra. Malegaon Taluka is situated in the southern part of Washim District and experiences a semi-arid tropical climate characterized by hot summers, moderate monsoon rainfall, and mild winters. Geographically, the watershed lies approximately between 76°45' to 77°10' East longitude and 20°25' to 20°45' North latitude. The geology of the taluka is predominantly composed of Deccan Trap basalt, typical of the hard rock terrain of the Vidarbha region. These basaltic formations significantly influence soil characteristics, groundwater occurrence, and drainage patterns. The area forms a hydrologically connected unit within the Godavari River Basin and contributes to the regional drainage network through seasonal streams and minor tributaries



**Fig. 2.1: Location map of the Malegaon watershed**

Malegaon Taluka of Washim District is predominantly rural in character, comprising dispersed villages with an agrarian economy largely dependent on rainfed agriculture. The cropping pattern is mainly governed by monsoon rainfall, with limited irrigation support from dug wells and borewells developed in basaltic formations. The physiography of the watershed is characterized by gently undulating plains across most parts, with moderate relief observed in localized upland, hill, and ridge areas. Slopes generally vary from nearly

level to moderately sloping, influencing runoff generation, soil erosion susceptibility, and in-situ moisture conservation potential.

**Table 2.1: Geographical and Administrative Profile**

Sr. No.	Particulars	Details
1	District	Washim
2	Taluka	Malegaon
3	Revenue Division	Amravati
4	Total sub-watershed Area	4645.16 ha
5	Villages	Seven (Tiwali, Wasari, Kinhi-Ghodmod, Ghata Pr.Shirpur, Jamthi, Dhorkheda, Sakrapur)
6	Major River	Katepurna River
7	Climate	tropical, semi-arid climate
8	Average annual Rainfall	872-966 mm

## 2.2 Geology:

Malegaon Taluka of Washim District forms part of the Deccan Volcanic Province, one of the world's largest continental flood basalt provinces. The area is predominantly underlain by basaltic lava flows of Cretaceous–Eocene age, generally classified as tholeiitic basalts. The basalt flows are typically massive, vesicular, and in places amygdaloidal in nature. Secondary mineralization such as zeolites, calcite, and quartz may occur within vesicles and fractures. Intertrappean beds-comprising thin sedimentary layers of limestone, clay, or shale-are occasionally encountered between successive lava flows, representing quiescent phases during volcanic activity. Structural features such as columnar jointing, horizontal and vertical fractures, and spheroidal weathering are commonly observed. These structural discontinuities play a significant role in groundwater storage and movement within the otherwise hard rock terrain. The basaltic parent material has led to the development of predominantly black cotton soils (Vertisols) ranging from shallow to deep, with medium to high clay content. On elevated uplands and sloping terrains, relatively shallow soils with patches of reddish-brown soils are observed. The lithology and geomorphology together influence drainage characteristics, soil depth variation, runoff behavior, and groundwater recharge potential within the watershed.

## 2.3 Geomorphology:

Geomorphologically, Malegaon Taluka of Washim District forms part of the Deccan Plateau region of central India. The terrain is predominantly undulating to gently rolling, interspersed with low basaltic hillocks and residual uplands formed due to differential erosion of successive lava flows of the Deccan Traps. The elevation in the watershed generally ranges between 350 to 500 meters above mean sea level, with gradual slopes facilitating surface runoff during monsoon months. The landscape is characterized by plateau tops, gently sloping pediplains, and shallow valley fills along seasonal streams. Alluvial patches along stream courses exhibit relatively deeper soils and are comparatively more suitable for agriculture. In contrast, upland and plateau areas often show shallow soil

depth, moderate erosion, and reduced vegetation cover. Soil erosion intensity varies depending on slope gradient, land use practices, and rainfall intensity. The drainage pattern is predominantly dendritic, typical of basaltic terrains, reflecting homogenous lithology and structural control. The watershed comprises distinct geomorphic units such as plateau surfaces, pediments, pediplains, residual hills, ridges, and valley plains. These landforms significantly influence soil depth distribution, groundwater occurrence, runoff generation, and suitability for soil and water conservation interventions.

## **2.4 Physiography and Soil**

The physiographic framework of Malegaon Taluka in Washim District strongly influences surface runoff, soil distribution, and infiltration characteristics across the watershed. The underlying lithology is predominantly Deccan Trap basalt, which weathers to produce soils of varying depth, texture, and fertility depending on slope, elevation, and degree of landscape dissection. Slope values in the watershed range from 0 to over 75 percent. A significant portion of the area comprises gentle slopes below 6 percent, suitable for cultivation, while steeper slopes are restricted to hillocks, ridges, escarpments, and mesa edges. Soils derived from basaltic parent material show marked variability in depth, texture, and physical properties based on their topographic position. Predominantly, the soils belong to loamy classes, with moderate fertility, good moisture retention, and suitability for a variety of crops. However, soils on steeper slopes are vulnerable to surface sealing and runoff generation during short-duration, high-intensity rainfall events, resulting in localized soil erosion. The combination of gently sloping plateau areas, residual hills, and alluvial valleys defines the spatial distribution of soil types, influencing land-use potential, crop suitability, and the design of soil and water conservation measures within the watershed.

## **2.5 Climate**

The watershed in Malegaon Taluka of Washim District experiences a semi-arid to sub-humid climate, typical of the Deccan Plateau region. The climate is primarily influenced by the southwest monsoon, which provides the majority of the annual rainfall between June and September. The average annual rainfall ranges from 600 mm to 800 mm, with considerable spatial and inter-annual variability. About 80–90% of the rainfall occurs during the monsoon, making agriculture and groundwater recharge highly dependent on seasonal precipitation. The rainfall pattern is often erratic, leading to potential droughts and water scarcity in certain years. Temperature variations are moderate to high throughout the year. Summers, from March to May, are hot and dry, with maximum temperatures frequently reaching 38–42 °C. Winters, from November to February, are relatively cooler and dry, with minimum temperatures occasionally falling to 10–12 °C. Relative humidity is generally high during the monsoon (above 70%) and drops significantly in the pre-monsoon summer months. The region experiences high evaporation rates, especially during the summer, contributing to water stress in the absence of sufficient irrigation facilities. The combination of erratic rainfall, high temperatures, and elevated evapotranspiration rates underscores the need for soil and water conservation measures, rainwater harvesting, and efficient groundwater management in the watershed.

## **2.6 Drainage**

The watershed in Malegaon Taluka of Washim District is drained by a network of seasonal streams and tributaries that ultimately contribute to the Penganga River Basin, a major sub-basin of the Godavari River system. The drainage network reflects the undulating basaltic terrain characteristic of the Deccan Plateau. The watershed exhibits a dendritic to sub-dendritic drainage pattern, typical of homogeneous basaltic flows. Moderate to high drainage density is observed in areas with rugged topography, steep slopes, and weathered basaltic outcrops. Most streams are ephemeral, with flow occurring primarily during the monsoon season, while the plateau and upland areas remain dry for the rest of the year. Stream behavior is generally flashy, with rapid rise and fall of water levels during rainfall events, due to high surface runoff and limited infiltration in the shallow, moderately permeable basaltic soils. Smaller tributaries and gullies feed the main drainage channels, enhancing the discharge during the monsoon. The drainage network plays a key role in soil erosion, sediment transport, and groundwater recharge, and provides a basis for designing watershed management and soil and water conservation interventions.

## **2.7 Cropping Pattern, and Demography and Socioeconomic**

### **2.7.1 Cropping Pattern**

The cropping pattern in the cluster is divided into three main seasons: Kharif, Rabi, and Summer. During the Kharif season (June to October), crops mainly depend on monsoon rainfall. The major crops grown in this season include soybean, cotton, turmeric, tur (pigeon pea), moong, urad, and jowar. Among these, soybean and cotton occupy the largest cultivated area because they are well suited to the soil and rainfall conditions of the region. In the Rabi season (October to March), farmers grow crops using residual soil moisture and irrigation from wells, farm ponds, and check dams. The major Rabi crops include wheat, gram (chickpea), rabi jowar, and mustard. Gram and wheat are widely cultivated because they require less water compared to other crops.

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

The population of the cluster consists mainly of small and marginal farmers, agricultural laborers, and rural households. A large portion of the working population is engaged in farming activities such as crop production, livestock rearing, and seasonal agricultural labor. The average family size is moderate, and the literacy level has gradually improved due to better access to schools and educational facilities in nearby villages. Agriculture is the primary source of income for most households in the cluster. Major crops grown include soybean, cotton, Turmeric, tur (pigeon pea), wheat, and gram. However, farm income often depends on rainfall and irrigation availability. Many farmers have small landholdings, which limits their production capacity and income. Some families also depend on secondary occupations such as dairy farming, small businesses, or wage labor to support their livelihoods. In terms of socioeconomic conditions, the cluster includes households from different social groups, including Scheduled Castes (SC), Scheduled Tribes (ST), and Other Backward Classes (OBC). Government programs and watershed development activities encourage community participation, formation of Self-Help Groups (SHGs), and

farmer groups, which help improve income opportunities and financial stability. Access to basic facilities such as drinking water, electricity, roads, schools, and healthcare has improved in recent years, though some rural areas still face limitations. The implementation of irrigation and watershed development projects has helped increase agricultural productivity, employment opportunities, and income levels, which contributes to the overall socioeconomic development of the cluster.

## **2.8 Water Resources**

### **2.8.1 Surface Water**

Surface water in the Malegaon watershed of Washim District is primarily associated with the network of seasonal streams, nalas, and small water bodies within the watershed. These channels exhibit flow predominantly during the monsoon season (June–September), while water availability is extremely limited during the dry, non-monsoon months. The watershed contains minor water-harvesting structures, such as check dams, percolation tanks, and seasonal ponds, which provide localized storage and contribute to groundwater recharge. These small structures are critical for improving water availability for agriculture and livestock during the early post-monsoon period. Over all, the surface water network functions mainly as a runoff conveyance system, with limited capacity to support sustained irrigation or domestic water supply beyond the monsoon season. The ephemeral nature of streams, combined with high seasonal variability, underscores the importance of integrating rainwater harvesting, watershed management, and soil and water conservation measures to enhance surface and subsurface water resources in the watershed.

### **2.8.2 Groundwater**

Groundwater in Malegaon Taluka of Washim District occurs primarily in the weathered and fractured zones of basaltic rock. The depth to groundwater varies depending on local topography, drainage features, and lithological characteristics. Shallow weathered zones in valley areas and alluvial patches generally provide easier access to wells and handpumps, while deeper fracture-controlled zones in uplands and ridges may require borewells for extraction. According to the Dynamic Ground Water Resources of Washim District (CGWB), 2024, the annual extractable groundwater resources indicate that the region falls under the “safe” category, with groundwater extraction levels below 60% of the available resources. This suggests that, at present, the watershed has adequate groundwater potential to meet domestic, irrigation, and livestock needs, provided extraction is managed sustainably. Recharge to the aquifers occurs mainly through monsoon rainfall, seepage from streams, and small water-harvesting structures. Areas with thicker weathered zones, gentle slopes, and permeable soils are more favorable for groundwater recharge, whereas upland ridges and plateau areas with shallow soils and limited fracturing show lower recharge potential. Proper management through in-situ moisture conservation, check dams, percolation tanks, and afforestation can enhance groundwater storage, improve water availability during dry periods, and support sustainable agricultural practices in the watershed.

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

The region receives moderate rainfall of about 750–850 mm annually, but the rainfall is often irregular and unevenly distributed. Because of this, farmers face water shortages during crop growth periods, which affects crop yield. To overcome this problem, the project focuses on efficient irrigation and proper water management practices. Under the - Malegaon cluster, several watershed development activities have been implemented. These include construction of farm ponds, check dams, percolation tanks, and water harvesting structures to store rainwater and recharge groundwater. Soil and water conservation measures such as contour bunding, trenching, and vegetative barriers are also carried out to reduce soil erosion and improve soil moisture retention. The project also promotes micro-irrigation techniques like drip and sprinkler irrigation, which help farmers use water more efficiently. These irrigation methods supply water directly to crops, reducing water loss and improving crop growth. Along with irrigation development, plantation, pasture development, and horticulture activities are encouraged to improve land productivity. Major crops grown in this cluster include cotton, soybean, pigeon pea (tur), and wheat. After implementation of irrigation and watershed activities, farmers have experienced improved soil moisture, better groundwater levels, and increased crop productivity. The project also helps in increasing cropping intensity and providing better livelihood opportunities for farmers.

### **2.9 Constraints**

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

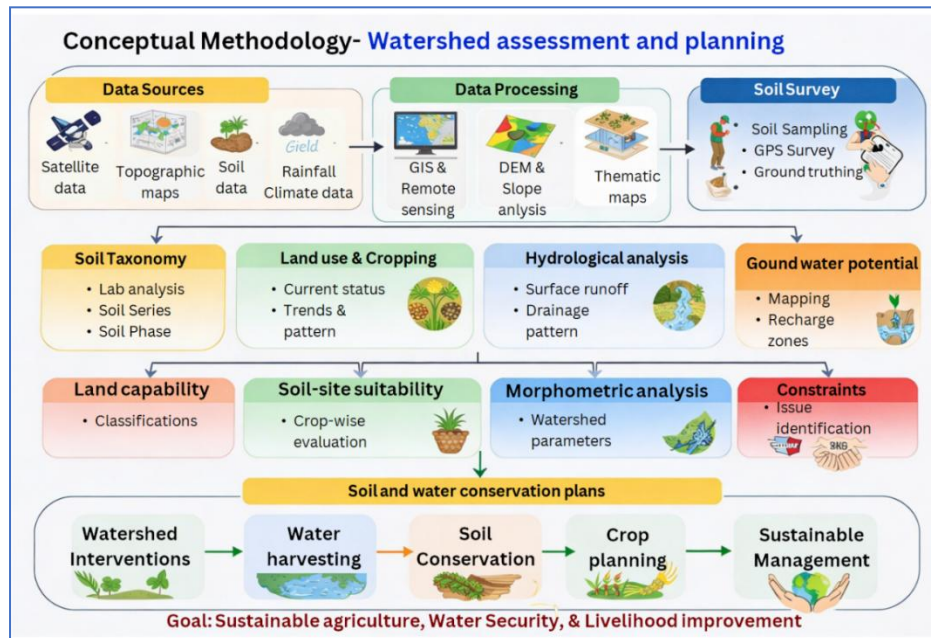
- a. Seasonal water scarcity due to limited and erratic rainfall.
- b. Inadequate structures for soil conservation.
- c. Depleting groundwater Levels.

## CHAPTER 3

### METHODOLOGY

#### 3.1 Overview of activities

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



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

#### A. Pre-field

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

#### B. Soil Survey

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

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

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

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

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

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

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

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

Soil samples from each horizon of all of the representative soil series were collected for laboratory studies. The soil samples collected during the fieldwork were initially air dried in the laboratory at room temperature, ground using a wooden pestle and mortar, screened through a 2 mm sieve, properly labelled, and stored in polythene bags for laboratory analysis. The soil samples were analysed in the laboratory for physical and chemical parameters using standard procedures. The particle size analysis was done by international pipette method. A combined glass-calomel electrode was used to determine the pH measured (1:2.5 soil/solution ratio). Soil organic carbon (SOC) was determined using the wet digestion method of Walkley and Black (1934). Available nitrogen (N) was measured by the alkaline permanganate method as described by Subbiah and Asija (1956). Available

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

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

In the present study, soil series phases were used as the basic mapping units. A soil series refers to a group of soils or polypedons that exhibit similar horizon sequences and share closely related properties within a narrow range of variation (Soil Survey Division Staff, 2000). The phases considered in this study included soil depth, surface texture, slope, erosion status and flooding conditions.

Soil profiles were examined and correlated within each major landform and soil series were identified accordingly. The identified soil series information was then extended to the sub-units of major landforms based on diagnostic soil characteristics observed from soil profile descriptions and auger observations.

A detailed soil map depicting soil series and their respective phases was prepared at a scale of 1:10,000. The soil legend code developed for the map represents the soil series name followed by surface texture, slope class, erosion status and soil depth, as described by Singh et al. (2016).

### **3.6 Surface runoff estimation**

Direct surface runoff occurring in the Malegaon 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 Malegaon 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 Methodology adopted for 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 Malegaon 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, Demography and Socioeconomics

##### 4.1.1 Irrigation and Water Management

The Malegaon cluster in Washim district represents a predominantly semi-arid and rainfed agricultural system characterized by monsoon-dependent farming and moderate groundwater utilization. Agriculture forms the primary livelihood source for the majority of households, with cropping patterns shaped by rainfall variability, soil type (mainly black cotton soil), and market opportunities. The cropping system is largely dominated by soybean and tur during the kharif season, reflecting the cluster's orientation toward oilseed–pulse-based agriculture. In the rabi season, gram and wheat are cultivated on residual soil moisture and limited irrigation. In recent years, farmers with irrigation access have diversified into high-value crops such as turmeric and orange, contributing to income enhancement and risk diversification. Irrigation access remains uneven across the cluster. About 56.91% of farmers depend on open wells as their primary irrigation source, while borewells (4.97%), canal irrigation (1.66%), and lift irrigation (0.55%) contribute minimally. Notably, 35.91% of farmers have no irrigation source and rely entirely on rainfall, making them vulnerable to climatic uncertainties. Water management practices include farm ponds, watershed structures, drip irrigation in horticulture, and in-situ soil moisture conservation measures. However, groundwater dependency, limited surface irrigation infrastructure, and uneven water access create disparities in productivity and income levels. Overall, the Malegaon cluster reflects a transitional agricultural system where farmers are gradually shifting from traditional cereal-based cropping toward diversified and market-oriented crops. While irrigation-supported farmers benefit from higher productivity and income stability, a significant portion of the farming community remains rainfed and climate-sensitive. Strengthening water resource management, expanding micro-irrigation, and promoting sustainable crop diversification are critical for improving long-term agricultural resilience in the cluster.

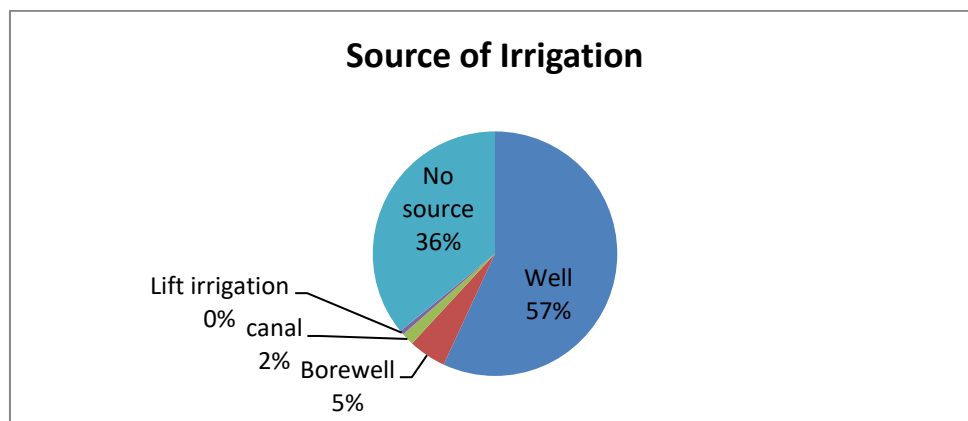


Fig. 4.1: Break-up of irrigation Sources in the watershed

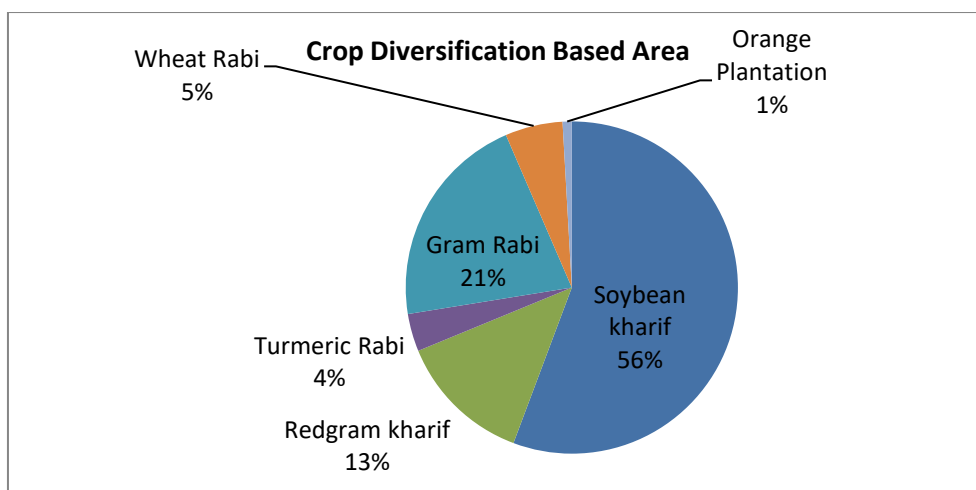
#### 4.1.2 Cropping Pattern

Cropping in the Malegaon cluster is primarily dependent on monsoon rainfall, with the majority of agricultural land under rainfed conditions. During the *kharif* season, farmers predominantly cultivate soybean and tur (pigeon pea), along with pulses. Soybean occupies a major share of the cultivated area due to its suitability to the region's black cotton soils and its strong market demand. Tur serves both as a cash crop and an important source of household protein consumption. In the *rabi* season, gram (chickpea) and wheat are the principal crops grown on conserved soil moisture and limited irrigation. Gram is widely preferred because of its relatively low water requirement and stable market price, while wheat is mainly cultivated for household consumption and local markets. Horticulture has gradually expanded in irrigated pockets, with turmeric and orange emerging as significant high-value crops. Turmeric provides comparatively higher returns per unit area but requires better management and irrigation support. Orange cultivation, though limited to farmers with assured water sources, plays a vital role in long-term income generation and diversification of the farming system.

Data collected from approximately 181 farmers indicate that soybean and tur together account for a substantial proportion of the total sown area, reflecting the cluster's orientation toward oilseed–pulse-based cropping systems. Traditional crops such as wheat and gram continue to contribute to food security and crop rotation practices, improving soil fertility and reducing production risks. Overall, the cropping pattern in the Malegaon cluster demonstrates a shift toward market-oriented crops such as soybean, turmeric, and orange, while maintaining pulses and cereals for livelihood security. This diversification strategy strengthens farmers' economic resilience under semi-arid and rainfall-dependent conditions.

**Table 4.1: Crop Cultivation Pattern Across the Cluster**

Sr. No.	Crop	Season	Area (ha)	Production	Productivity (kg ha <sup>-1</sup> )
1	Soybean	Kharif	226.505	334500	1476.79
2	Tur	Kharif	53.14	80400	1512.98
3	Turmeric	Rabi	14.9	98400	6604.03
4	Gram	Rabi	85.62	95100	1110.72
5	Wheat	Rabi	22.76	72900	3202.99
6	Orange	Plantation	3.63	68300	18815.43



**Fig. 4.2: Crop cultivation pattern across the cluster**

### 4.1.3 Socio-economic status

#### 4.1.3.1 Land holding pattern

The farm size distribution in the cluster shows that agriculture is dominated by small (36.81%) and marginal farmers (42%), indicating highly fragmented landholdings. Villages like Jamthi and Kinhi Ghodmod have a higher concentration of marginal and small farmers, reflecting limited land resources, while Tiwali shows a slightly more balanced distribution with some semi-medium holdings. The very low share of medium farmers (2%) highlights the absence of larger operational units, which restricts opportunities for mechanization, credit access, and diversification.

**Table 4.2 Land holding pattern in Malegaon watershed.**

Categories	Criteria Land (ha)	No. of Farmers Interviewed	Farmers (%)	Average Land holding (ha)
<b>Marginal Farmers</b>	<1	77	42%	0.73
<b>Small Farmers</b>	1-2	67	37.01%	1.5
<b>Semi-Medium Farmers</b>	2-4	25	13.81%	2.78
<b>Medium Farmers</b>	4-10	12	6.6%	5.4
<b>Large Farmers</b>	>10	0	0%	0

#### 4.1.3.2 Income distribution

The income distribution in the Malegaon watershed is presented in Table 4.3 indicate a dominance of cereal and horticultural crops, with significant variation in productivity and economic returns among crops.

**Table 4.3 Average annual income of farmers in Malegaon watershed.**

Name of crops	No. of Farmers interviewed (n)	Crop area (ha)	Average Income (Rs.)
Soybean	181	226.5	102380.9
Tur	124	53.1	24006.5
Turneric	23	14.9	84546.0
Gram	65	85.6	83134.1
Wheat	24	25.7	55801.8
Orange	8	3.6	102380.9

In the watershed area of Malegaon Taluka, located in Washim District, Maharashtra, different crops contribute variably to farmers' livelihoods in terms of cultivated area, farmer participation, and income generation.

Soybean is the dominant crop in the watershed, cultivated by the highest number of farmers (181) and occupying the largest area (226.56 ha). It generates a relatively high average income of Rs1,02,380.95, making it one of the most important crops for farmers in the region. Tur (pigeonpea) is grown by 124 farmers over 53.14 ha, but it provides a comparatively lower average income of Rs24,006.56, indicating lower profitability despite significant farmer participation.

Gram is cultivated by 65 farmers on 85.62 ha, generating a substantial average income of Rs83,134.10, which highlights its importance as a profitable rabi crop. Turmeric, although cultivated by only 23 farmers on a smaller area of 14.9 ha, produces a relatively high average income of Rs84,546.00, indicating the economic potential of spice crops in the watershed.

Wheat is grown by 24 farmers on 25.76 ha, providing a moderate average income of Rs55,801.88. Orange, a horticultural crop, is cultivated by only 8 farmers on 3.63 ha, yet it generates a high average income of Rs1,02,380.95, suggesting that horticulture can significantly enhance farm income despite its limited area.

Overall, the cropping pattern indicates that soybean dominates in terms of area and farmer participation, while high-value crops such as turmeric and orange contribute significantly to higher farm income. Promoting crop diversification with horticultural and high-value crops could improve farmers' profitability and strengthen the economic sustainability of agriculture in the Malegaon watershed.

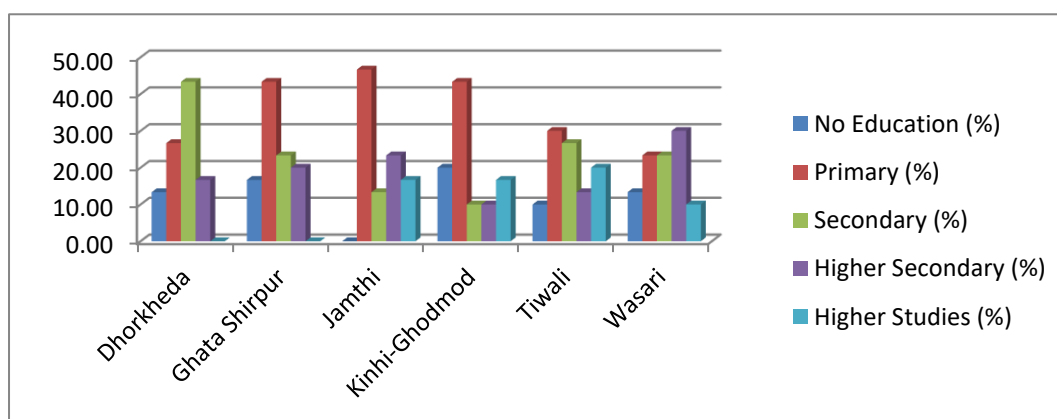
#### **4.1.3.3 Education**

The education profile of farmers in the watershed villages shows a varied distribution across different educational levels. In Dhorkheda, the majority of farmers have attained secondary education (43.33%), followed by primary education (26.67%), while 16.67% have completed higher secondary education and 13.33% have no formal education; none have pursued higher studies. Ghata-Shirpur shows a higher proportion of farmers with primary education (43.33%), while 23.33% have secondary education and 20% have completed higher secondary education; however, 16.67% have no formal education and none have higher studies. In Jamthi, all farmers have some level of education, with 46.67%

having primary education, 23.33% higher secondary education, 13.33% secondary education, and 16.67% pursuing higher studies. Kinhi-Ghodmod records the highest proportion of farmers without formal education (20%), while 43.33% have primary education, 10% secondary, 10% higher secondary, and 16.67% have higher studies. In Tiwali, the distribution is more balanced, with 30% of farmers having primary education, 26.67% secondary education, 13.33% higher secondary education, and a notable 20% pursuing higher studies, while 10% have no formal education. Wasari shows a comparatively higher proportion of farmers with higher secondary education (30%), followed by primary and secondary education (23.33% each), while 13.33% have no formal education and 10% have higher studies. Overall, the data indicate that most farmers possess at least primary or secondary education, while participation in higher education remains limited, though villages like Tiwali and Jamthi show relatively higher representation in higher studies.

**Table 4.4 Education profile of Cluster**

Village	No Education (%)	Primary (%)	Secondary (%)	Higher Secondary (%)	Higher Studies (%)
Dhorkheda	13.33	26.67	43.33	16.67	0.00
Ghata-Shirpur	16.67	43.33	23.33	20.00	0.00
Jamthi	0.00	46.67	13.33	23.33	16.67
Kinhi-Ghodmod	20.00	43.33	10.00	10.00	16.67
Tiwali	10.00	30.00	26.67	13.33	20.00
Wasari	13.33	23.33	23.33	30.00	10.00



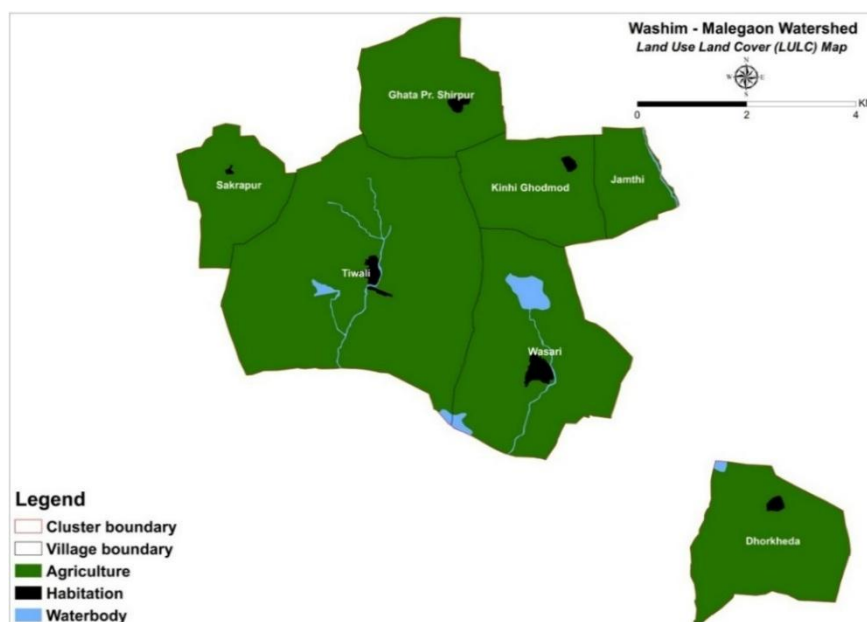
**Fig.4.3 Education profile of Malegaon watershed by population (%)**

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

The Land Use Land Cover (LULC) classification of the area reveals that agriculture is the predominant land use type, occupying 4506.94 hectares, and constitutes approximately 97.02 % of the total area (Table 4.5 and Fig. 4.4). Waterbodies are limited to 81.01 ha, making up 1.74% of the total area, reflecting the presence of limited surface water resources in the region. This LULC distribution highlights the dominance of agricultural activities in the area with secondary coverage by forest and wasteland categories.

**Table 4.5 Land-use/land-cover statistics of Malegaon watershed**

Sr.No.	Land use	Area (ha)	Percent (%)
1	Agriculture	4506.94	97.02
2	Habitation	57.21	1.23
3	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



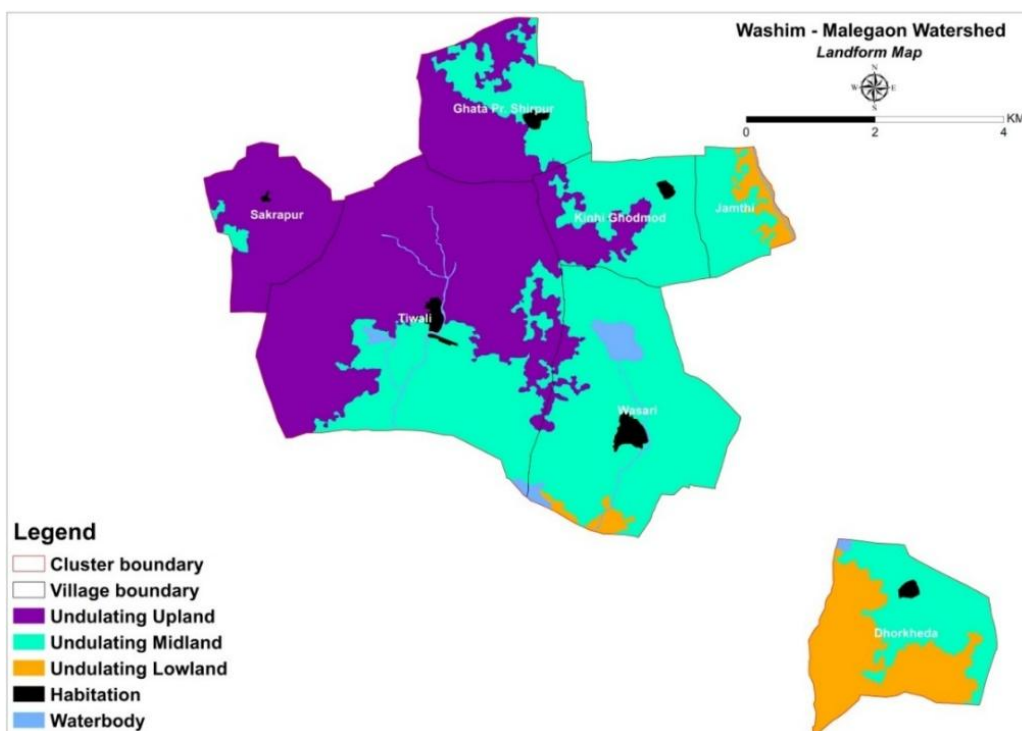
**Fig. 4.4: Land-use/land-cover map.**

### 4.3. Landform Delineation

The landform analysis of the area indicates a diverse geomorphological setting. Undulating upland is the most extensive landform (Table 4.6), covering 1881.37 ha, or 40.57 % of the total area. This is followed by the undulating midland, encompassing 40.11% of the watershed. Undulating lowland occupies 759.31 ha, accounting for 16.35%, reflecting undulating and elevated terrain. Overall, the area is characterized by a predominance of undulating upland, undulating midland and undulating lowland. The landform map of the watershed is presented in Fig. 4.5.

**Table 4.6: Landform features existing in Malegaon watershed.**

Sr.No.	Landform	Area (ha)	Percent (%)
1	Undulating Upland	1884.37	40.57
2	Undulating Midland	1863.26	40.11
3	Undulating Lowland	759.31	16.35
4	Habitation	57.21	1.23
5	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



**Fig. 4.5: Landform map of Malegaon watershed.**

#### 4.4 Soil series and phases

Eight soil series have been identified and mapped with 19 soil mapping units (phases of series Fig 4.7). The taxonomic classification and mapping legend of the soil phase along with its landform was shown in Table 4.8. The detailed descriptions of the of each series are given in (Table 4.7, Fig.4.6).

**Table 4.7. Dominant soil series identified in the watershed.**

Sr.No.	Series	Area (ha)	Percent (%)
1	Dhorkheda-1	637.3	13.7
2	Dhorkheda-2	396.7	8.5
3	Ghata	1026.1	22.0
4	Kinhi	861.8	18.5
5	Sakharpur	555.7	11.9
6	Tiwali	302.4	6.5
7	Wasari-1	621.8	13.3
8	Wasari-2	104.8	2.2
9	Habitation	57.2	1.2
10	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>

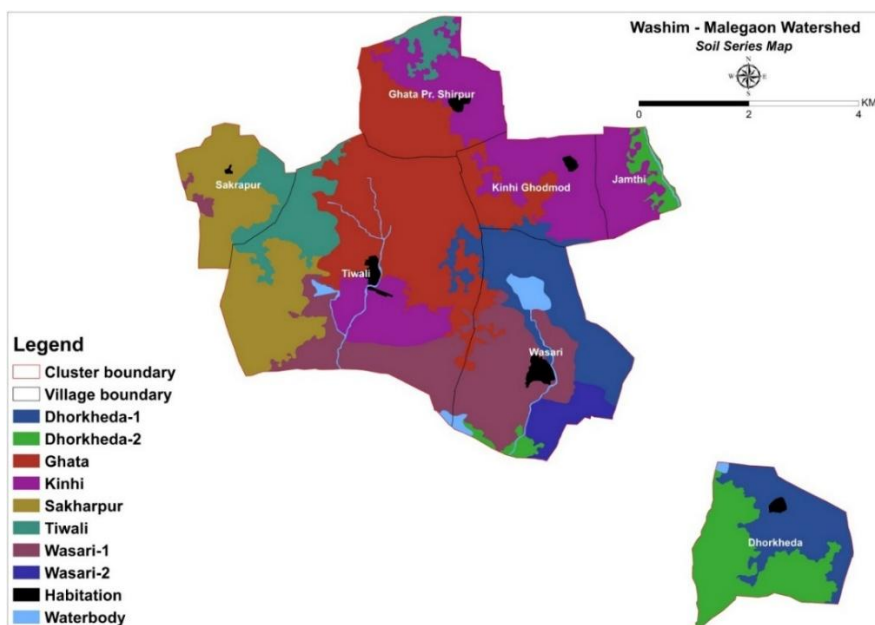
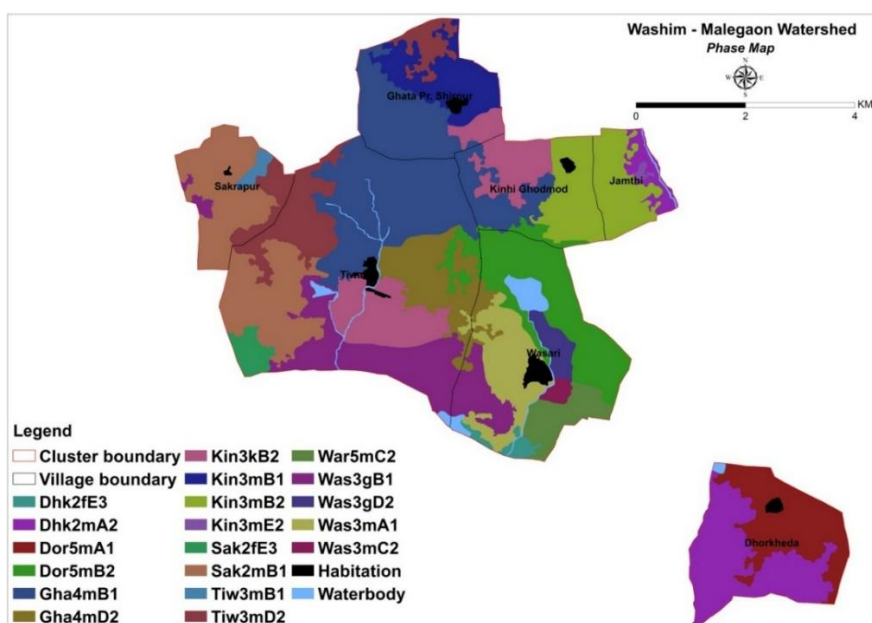


Fig. 4.6: Soil series map of Malegaon watershed.

Table 4.8. Soil phases existing identified in Malegaon watershed.

Sr.No.	Phase Class	Area (ha)	Percent (%)
1	Dhk2fE3	27.47	0.59
2	Dhk2mA2	369.24	7.95
3	Dor5mA1	262.11	5.64
4	Dor5mB2	375.2	8.1
5	Gha4mB1	798.6	17.2
6	Gha4mD2	227.6	4.9
7	Kin3kB2	352.7	7.6
8	Kin3mB1	183.4	4.0
9	Kin3mB2	319.1	6.9
10	Kin3mE2	6.7	0.1
11	Sak2fE3	46.5	1.0
12	Sak2mB1	509.3	11.0
13	Tiw3mB1	20.5	0.4
14	Tiw3mD2	282.0	6.1
15	War5mC2	104.8	2.3
16	Was3gB1	362.6	7.8
17	Was3gD2	50.0	1.1
18	Was3mA1	190.9	4.1
19	Was3mC2	18.4	0.4
20	Habitation	57.2	1.2
21	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



**Fig. 4.7: Soil Phase map of Malegaon watershed**

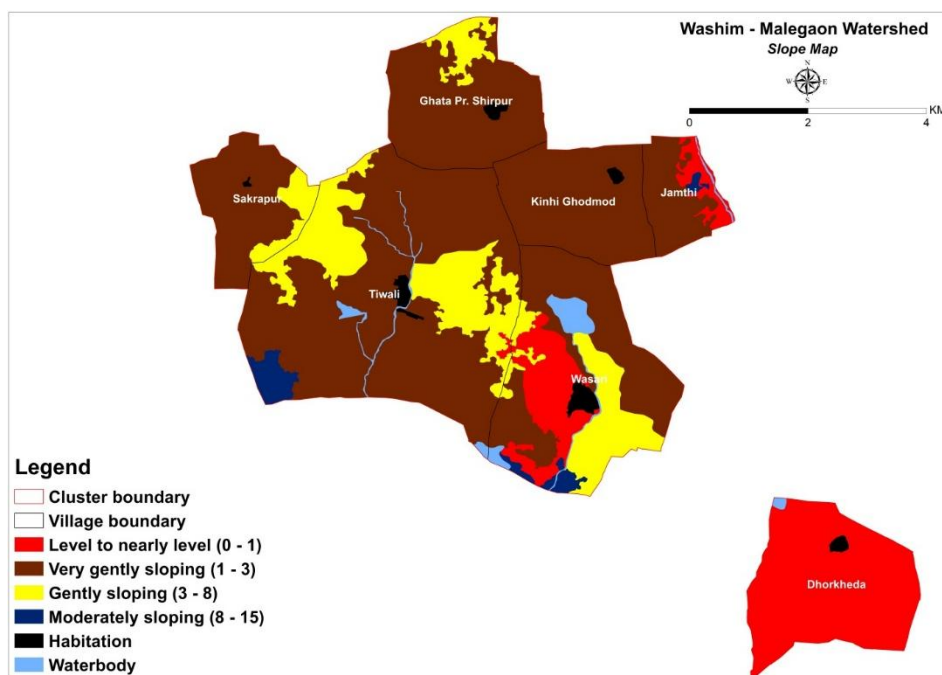
## 4.5 Soil Survey Interpretation

### 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 different slope classes (Table 4.9, Fig. 4.8) the maximum area of watershed is under very gently sloping (1-3%) i.e. 62.89 % followed by level to nearly level (0-1%) i.e. 17.70%, gently sloping (3-8%) i.e. 14.70%, moderately sloping (8-15%) i.e. 1.74%.

**Table: 4.9. Land slope classes in Malegaon watershed.**

Sr.No.	Slope Class	Area (ha)	Percent (%)
1	Level to nearly level (0 - 1)	822.3	17.7
2	Very gently sloping (1 - 3)	2921.3	62.9
3	Gently sloping (3 - 8)	682.7	14.7
4	Moderately sloping (8 - 15)	80.6	1.7
5	Habitation	57.2	1.2
6	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



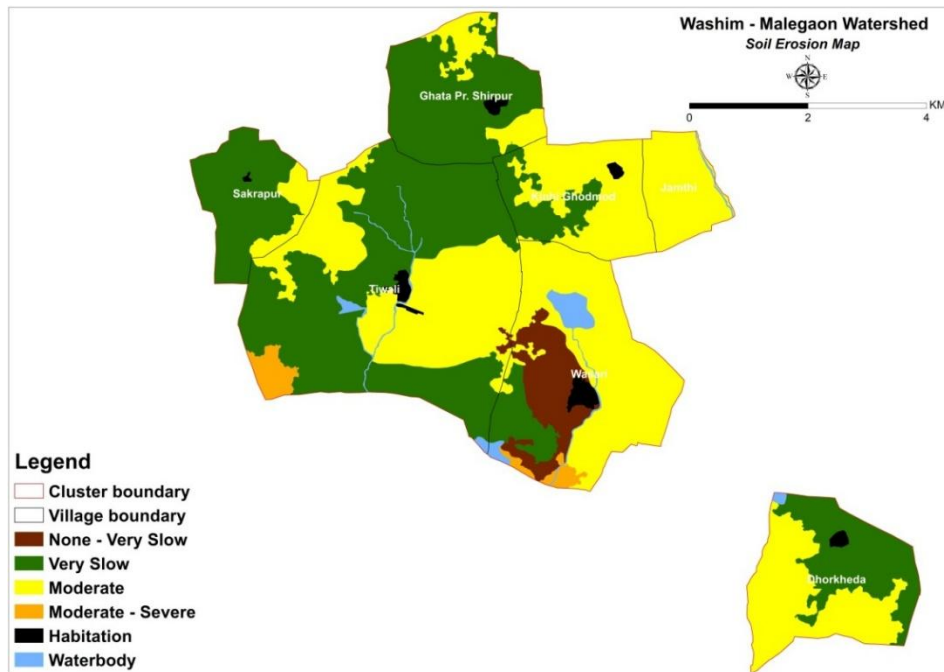
**Fig. 4.8: Slope map of Malegaon watershed**

#### 4.5.2 Soil Erosion

Soil erosion, caused by water, wind, or human activity, strips away the nutrient-rich layers of soil, reducing its ability to retain water and support plant roots. This depletion of soil quality can result in decreased agricultural productivity, making crops more vulnerable to drought, nutrient deficiencies, and pests. Additionally, soil erosion can lead to the sedimentation of nearby water bodies, affecting water quality and ecosystems. Arresting soil erosion through crop cover, mulching and residue management, crop rotation, bunding, terracing, etc. helps to maintain soil structure and prevent further degradation. The majority of the area on Washim-Malegaon watershed falls under very slow (45.99%) to moderate (45.33%) erosion hazards. While 4.11% area falls under none-very slow and 1.59% area under moderate-sever (Table 4.10 Fig. 4.9). particularly parts of the upper half of the watershed, calling for immediate attention.

**Table 4.10: Soil erosion status in the Malegaon watershed.**

Sr.No.	Erosion	Area (ha)	Percent (%)
1	None - Very Slow	190.9	4.1
2	Very Slow	2136.5	46.0
3	Moderate	2105.7	45.3
4	Moderate - Severe	73.9	1.6
5	Habitation	57.2	1.2
6	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



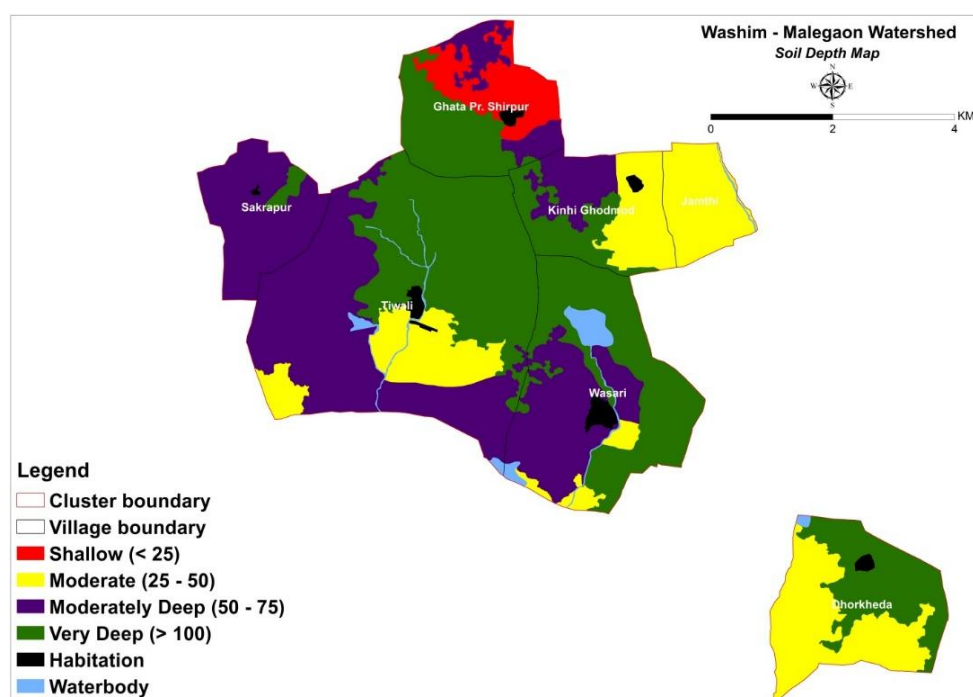
**Fig. 4.9: Erosion map of Washim watershed**

#### 4.5.3 Soil Depth

Soil depth is a critical factor in agriculture as it 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. As a result, 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 plowing, 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. 4.10) varies from shallow (<25 cm) to very deep (>75 cm). Area wise distribution of the data (Table 4.11) showed that maximum area was under very deep (38.51%) followed by moderately deep (33.47%), moderate (21.10%) and shallow (3.95%).

**Table 4.11. Soil depth classes in Malegaon watershed.**

Sr.No.	Soil Depth	Area (ha)	Percent (%)
1	Shallow (< 25) cm	183.4	4.0
2	Moderate (25 - 50) cm	980.1	21.1
3	Moderately Deep (50 - 75) cm	1554.7	33.5
4	Very Deep (> 100) cm	1788.7	38.5
5	Habitation	57.2	1.2
6	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



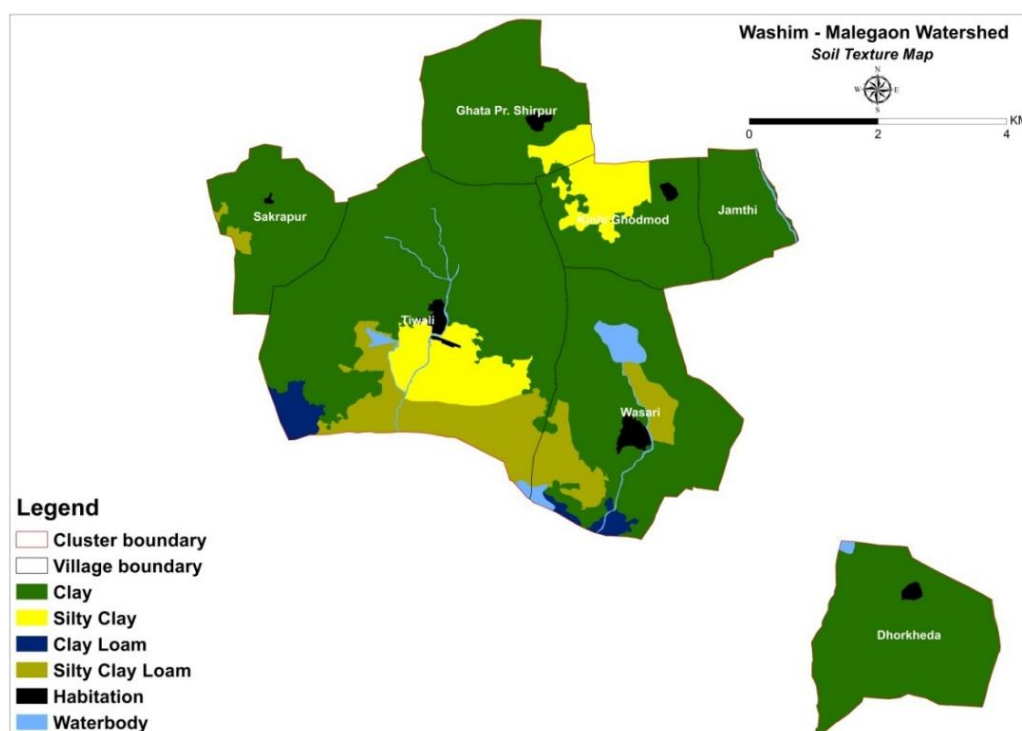
**Fig. 4.10: Depth map of Malegaon watershed**

#### 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 six classes (Table 4.12, Fig. 4.11). Among the different classes clay texture was found in 78.96 % area followed by silty clay loam (8.88%), silty clay (7.59%), clay loam (1.59%). Based on the texture, the soils of the watershed, particularly the moderately deep to very deep soils are expected to be fertile and produce good crops.

**Table 4.12. Soil texture distribution in Malegaon watershed.**

Sr.No.	Texture	Area (ha)	Percent (%)
1	Clay	3667.8	79.0
2	Clay Loam	73.9	1.6
3	Silty Clay	352.7	7.6
4	Silty Clay Loam	412.6	8.9
5	Habitation	57.2	1.2
6	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



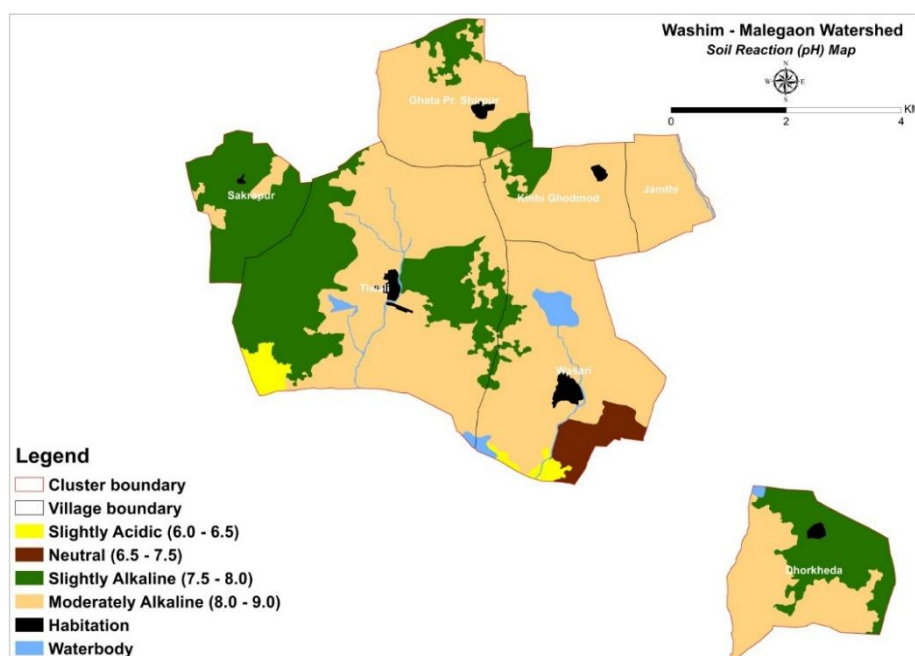
**Fig. 4.11: Soil texture map of Malegaon watershed**

#### 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 4.13, Fig. 4.12). The data revealed that soils in watershed are predominantly moderately alkaline in reaction (pH 7.9-8.4) covering an area of about 63.60% followed by slightly alkaline (pH 6.6-7.3) (29.58%), neutral (2.26%) and slightly acidic (1.59%).

**Table 4.13. Soil pH distribution in Malegaon watershed.**

Sr.No.	pH Class	Area (ha)	Percent (%)
1	Slightly Acidic (6.0 - 6.5)	73.9	1.6
2	Neutral (6.5 - 7.5)	104.8	2.3
3	Slightly Alkaline (7.5 - 8.0)	1374.1	29.6
4	Moderately Alkaline (8.0 - 9.0)	2954.1	63.6
5	Habitation	57.2	1.2
6	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



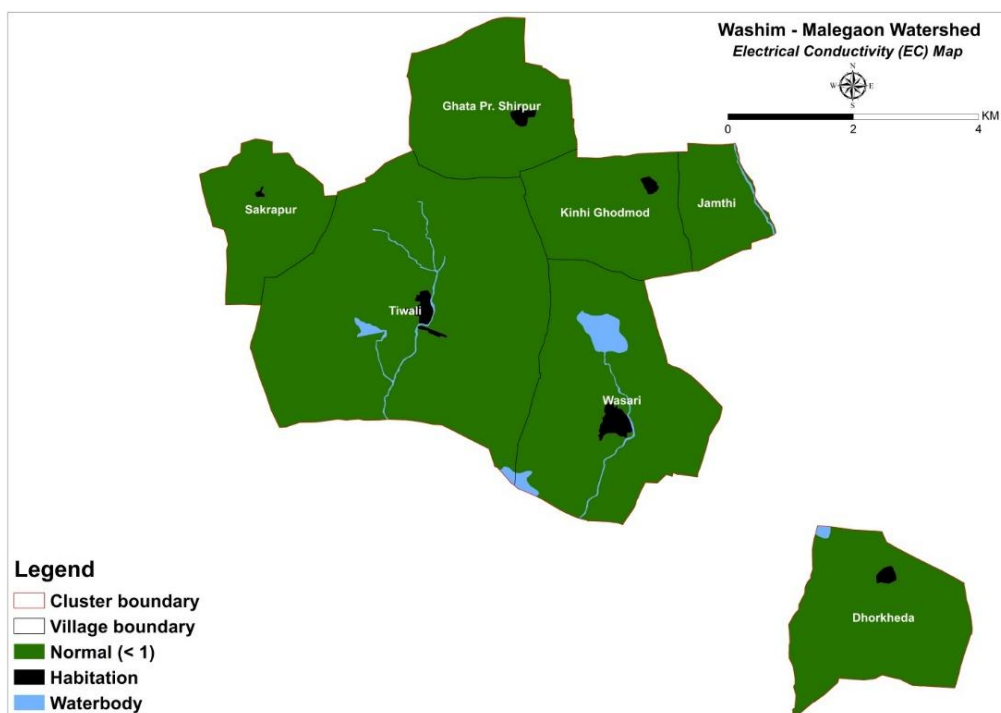
**Fig. 4.12: Soil pH map of Malegaon watershed**

#### 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 4.14) and will not cause any detrimental effect on crop growth. Hence, the map is not shown here.

**Table 4.14 Soil salinity classes in the watershed.**

Sr.No.	Electrical conductivity (dSm <sup>-1</sup> )	Area (ha)	TGA (%)
1	Normal (0 - 1)	4506.9	97.0
2	Habitation	57.2	1.2
3	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



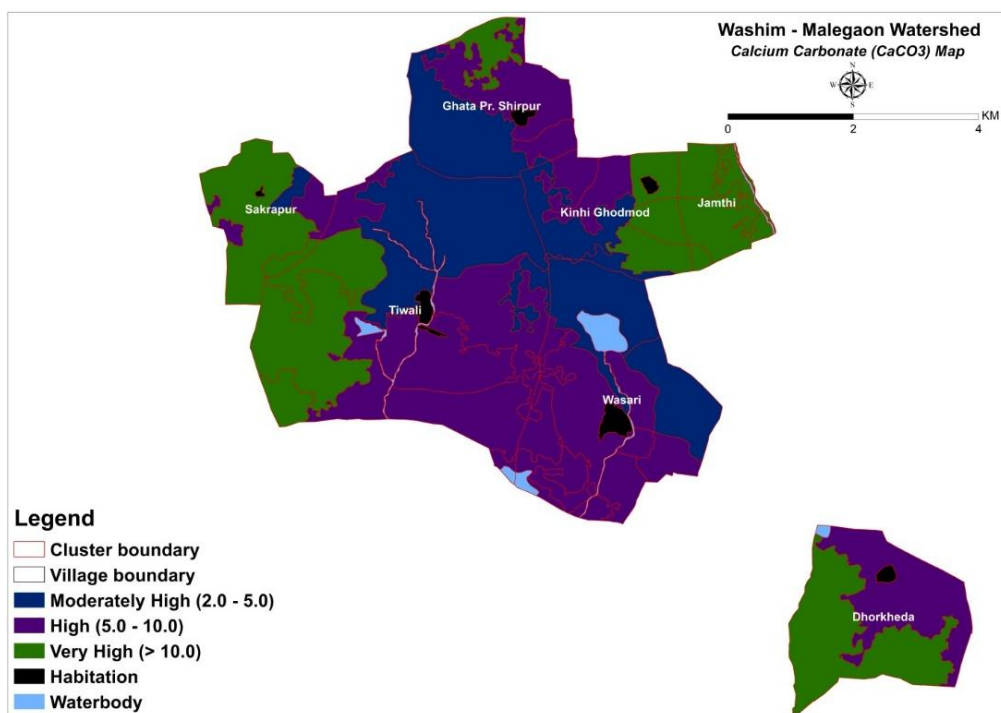
**Fig. 4.13: Soil salinity map of Malegaon watershed**

#### 4.7.7 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 moderately high (2.0 - 5.0%) 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 4.15 and Fig. 4.14, a large part of the watershed area (31.15 %) contains more than 10% CaCO<sub>3</sub> in soil, which could pose problems to normal crop growth.

**Table 4.15. Extent of calcareousness in soils of Malegaon watershed.**

Sr.No.	CaCO <sub>3</sub> Class	Area (ha)	Percent (%)
1	Moderately High (2.0 - 5.0)	1194.3	25.7
2	High (5.0 - 10.0)	1865.9	40.2
3	Very High (> 10.0)	1446.8	31.2
4	Habitation	57.2	1.2
5	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



**Fig. 4.14: Status of soil calcareousness in Malegaon watershed**

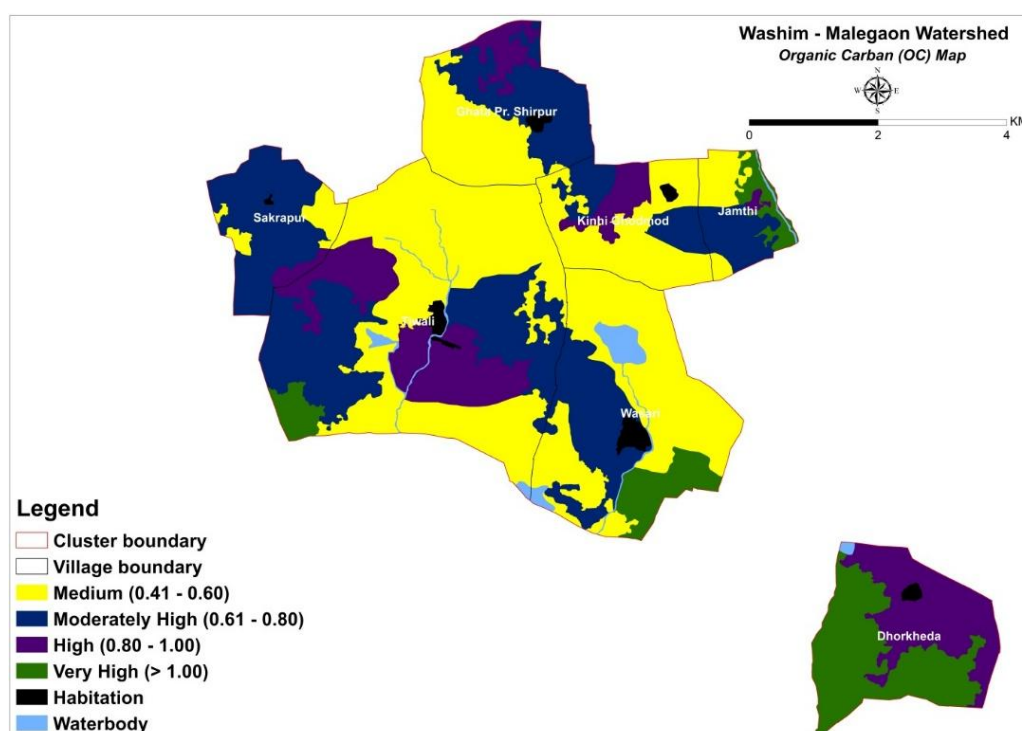
#### 4.5.8 Soil organic carbon

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 Malegaon watershed supported medium to very high SOC content, which can be inferred from Table 4.16 and Fig. 4.15. This is also indicated by the moderate-deep to very deep soils and clay 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 40% of the area exhibiting medium SOC. Very high SOC content was found to occur in approximately 520 ha and high SOC content was found approximately 724 ha of the watershed. Considering the prevailing climatic situation of the watershed the farmers are advised to apply the organic manures on regular basis to sustain the SOC levels and overall soil health.

**Table 4.16. Soil organic carbon status of Malegaon watershed.**

Sr.No.	OC Class	Area (ha)	Percent (%)
1	Medium (0.41 - 0.60)	1901.1	40.9
2	Moderately High (0.61 - 0.80)	1360.9	29.3
3	High (0.80 - 1.00)	724.4	15.6
4	Very High (> 1.00)	520.5	11.2
5	Habitation	57.2	1.2
6	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



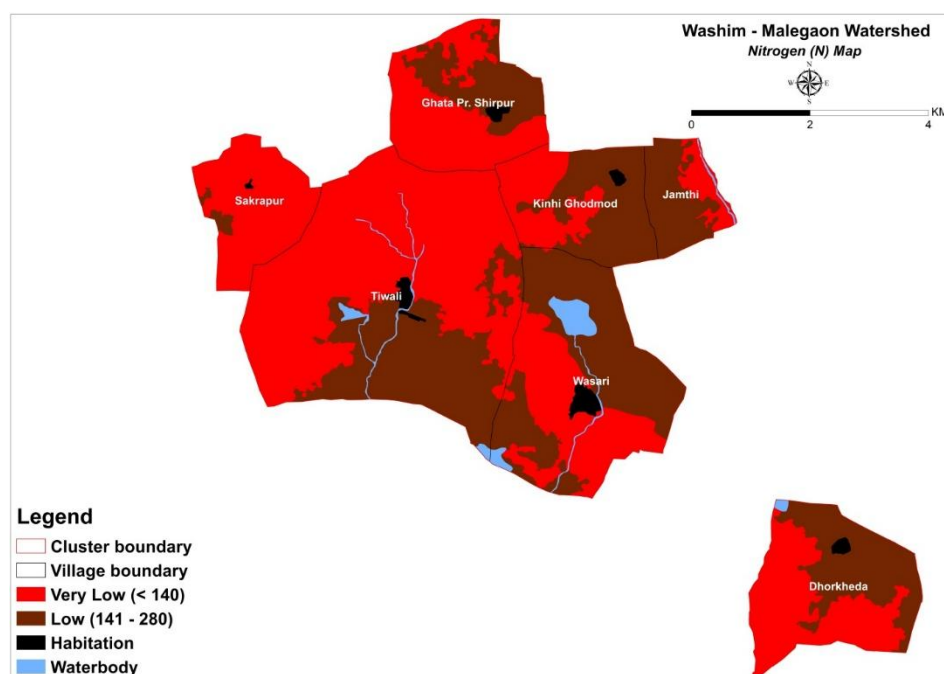
**Fig. 4.15: Soil organic carbon map of Malegaon watershed**

#### 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 4.17 and Fig. 4.16, most of the watershed area registered very low N values ( $<140 \text{ kg ha}^{-1}$ ) (57.43%) whereas in 39.60% area, low N content ( $140 - 280 \text{ kg ha}^{-1}$ ) is a matter of concern. Therefore, it is advocated to apply the nitrogenous fertilizers as per crop needs to maximize crop yields in the watershed area.

**Table 4.17: Available N content in soils of Malegaon watershed.**

Sr.No.	Available N (kg ha <sup>-1</sup> )	Area (ha)	Percent (%)
1	Very Low (< 140)	2667.5	57.4
2	Low (140 - 280)	1839.4	39.6
3	Habitation	57.2	1.2
4	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



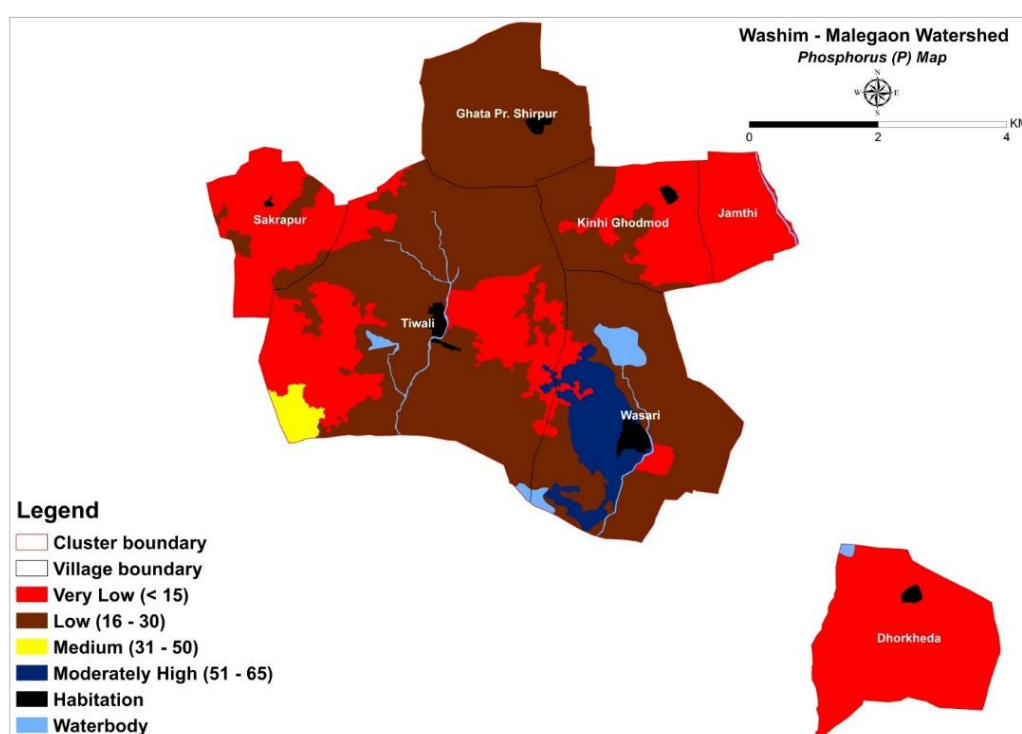
**Fig. 4.16: Available soil nitrogen map of Malegaon-Watershed**

#### 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. The P content of the agricultural soils of the watershed (Table 4.18, Fig. 4.17) ranged from very low (<15 kg ha<sup>-1</sup>) to moderately high (51-65 kg ha<sup>-1</sup>), with the highest area was under very low P status (40.15%) followed by low (51.76%) and moderately high (4.11%). The vast majority (three-fourths) of the area under very low to low status points to the fact that the farmers are not adequately applying phosphatic fertilizers to soils, and/or substantial amounts of applied fertilizer P is fixed in the soils owing to their calcareous nature.

**Table 4.18: Available P content of soils of Malegaon watershed.**

Sr.No.	Available P (kg ha <sup>-1</sup> )	Area (ha)	TGA (%)
1	Very Low (< 15)	1865.2	40.2
2	Low (16 - 30)	2404.4	51.8
3	Medium (31 - 50)	46.5	1.0
4	Moderately High (51 - 65)	190.9	4.1
5	Habitation	57.2	1.2
6	Waterbody	81.0	1.7
	<b>Total</b>	<b>4645.2</b>	<b>100.0</b>



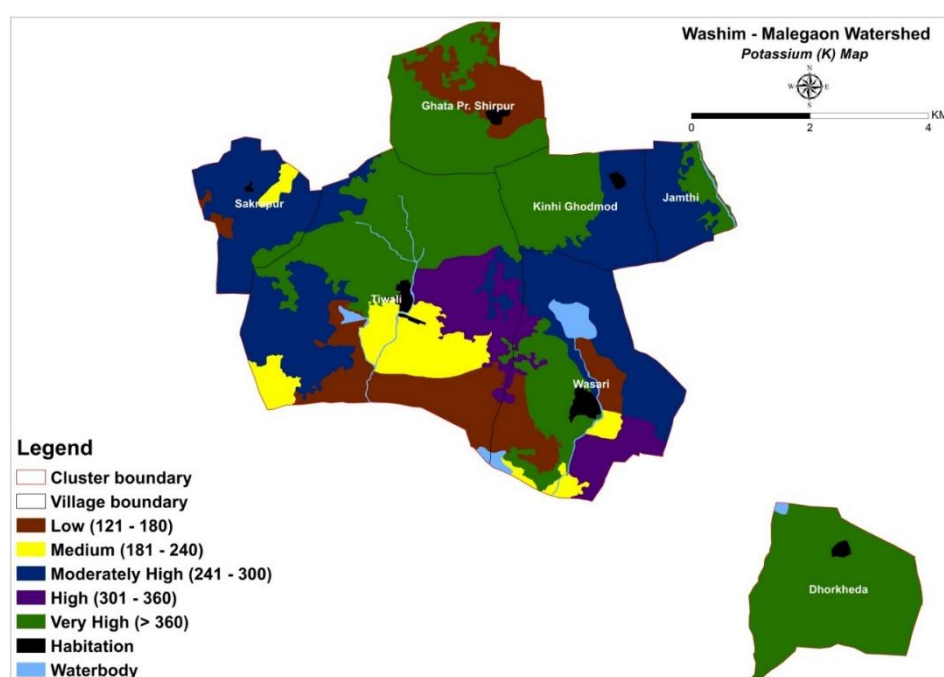
**Fig. 4.17: Available soil phosphorus map of Malegaon watershed**

#### 4.5.11 Available Potassium (K)

The importance of potassium (K) is well recognized in agriculture. Exchangeable K or available K is widely used to evaluate the soil K status and to predict the crop K requirements. Five classes of available K status (Table 4.19, Fig. 4.18) were observed in the watershed soils. Most of the watershed area (42.70%) registered very high (>360 kg ha<sup>-1</sup>) K content followed by moderately high (241-300 kg ha<sup>-1</sup>), low (121 – 180 kg ha<sup>-1</sup>) (12.83%), high (301 -360 kg ha<sup>-1</sup>) (7.16%) and medium (181 – 240 kg ha<sup>-1</sup>) (6.58%). Further, external application of potassic fertilizers is necessary for the combined area of 19.41% exhibiting low (121-180 kg ha<sup>-1</sup>) to medium (181-240 kg ha<sup>-1</sup>) K content.

**Table 4.19: Available K content of soils of Malegaon watershed**

Sr.No.	Available K (kg ha <sup>-1</sup> )	Area (ha)	TGA (%)
1	Low (121 - 180)	595.95	12.83
2	Medium (181 - 240)	305.53	6.58
3	Moderately High (241 - 300)	1289.55	27.76
4	High (301 - 360)	332.38	7.16
5	Very High (> 360)	1983.53	42.70
6	Habitation	57.21	1.23
7	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



**Fig. 4.18: Available soil potassium map of Malegaon watershed**

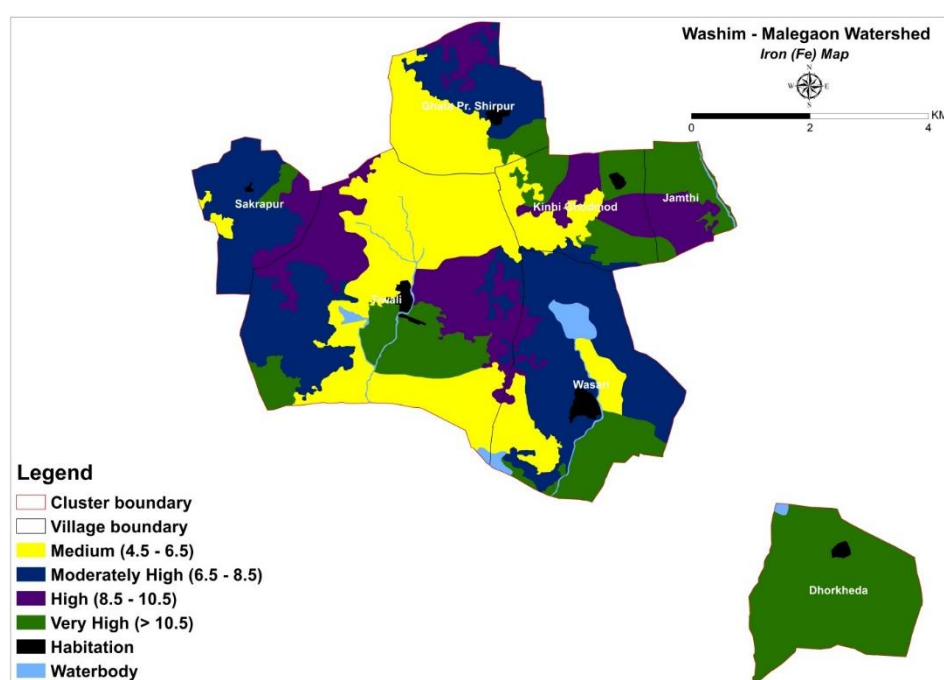
#### 4.5.12 Micronutrient status of soils

Although required in small quantities, soil micronutrients-namely iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn), measured as 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. Proper micronutrient management is particularly important in maintaining soil fertility by optimizing the efficiency of fertilizers. Four classes of available Fe were found in the watershed. Table 4.20 and Fig. 4.19 indicate that about 26.07% of the watershed area is medium in bioavailable Fe, calling for immediate attention in terms of its soil or foliar application through different fertilizer products. On the other hand, about a quarter of the watershed area was categorized as very high (>10.5 mg kg<sup>-1</sup>) in DTPA-extractable Fe. The majority of the area of the watershed is adequately

supplied with Mn (Table 4.21, Fig. 4.20). Soils of the entire watershed are sufficient with respect to DTPA-extractable Cu (Table 4.22, Fig. 4.21), whereas majority of the area exhibit deficiency in bioavailable Zn (Table 4.23, Fig. 4.22), necessitating external Zn fertilization by the farmers.

**Table 4.20: Available Fe content in the soils of Malegaon watershed.**

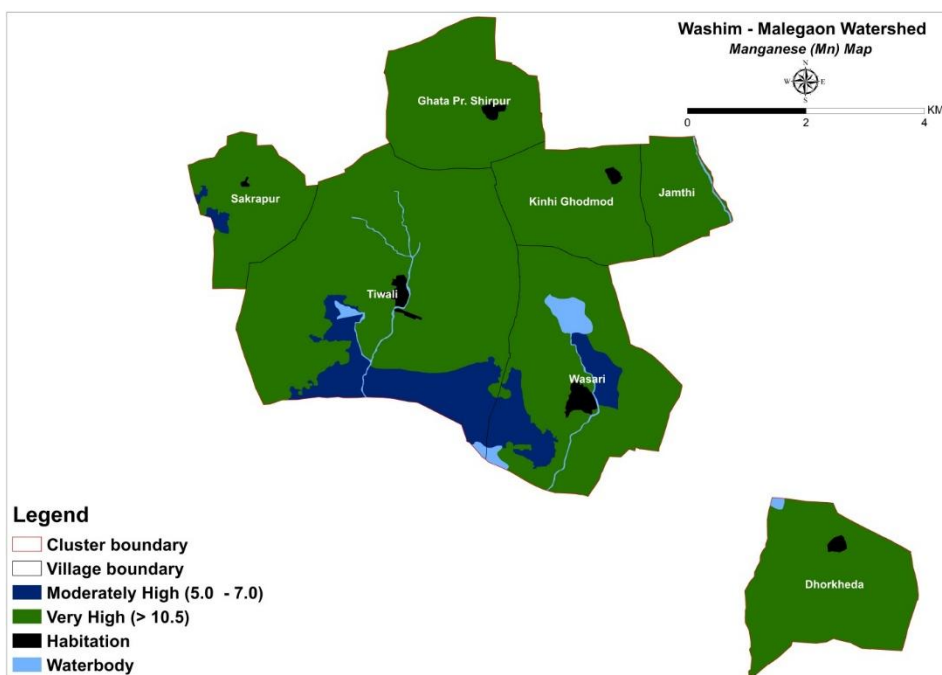
Sr.No.	Available Fe (mg kg <sup>-1</sup> )	Area (ha)	TGA (%)
1	Medium (4.5 - 6.5)	1211.15	26.07
2	Moderately High (6.5 - 8.5)	1258.82	27.10
3	High (8.5 - 10.5)	712.57	15.34
4	Very High (> 10.5)	1324.41	28.51
5	Habitation	57.21	1.23
6	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



**Fig. 4.19: DTPA-extractable soil Fe map of Malegaon watershed**

**Table 4.21: Available Mn content in the soils of Malegaon watershed.**

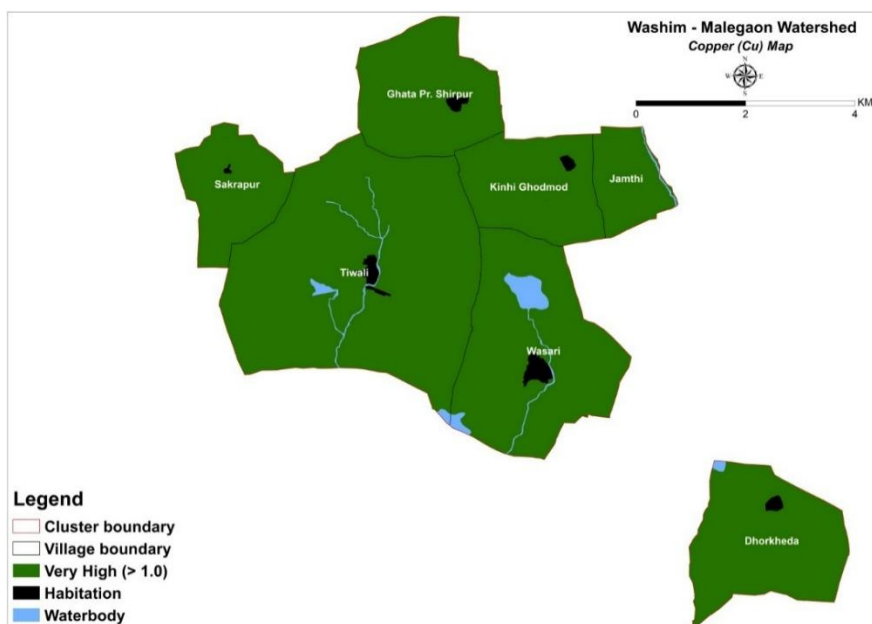
Sr.No.	Available Mn (mg kg <sup>-1</sup> )	Area (ha)	Percent (%)
1	Moderately High (5.0 - 7.0)	412.56	8.88
2	Very High (> 10.5)	4094.38	88.14
3	Habitation	57.21	1.23
4	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



**Fig. 4.20: DTPA-extractable soil Mn map of Malegaon watershed**

**Table 4.22: Available Cu content in the soils of Malegaon watershed.**

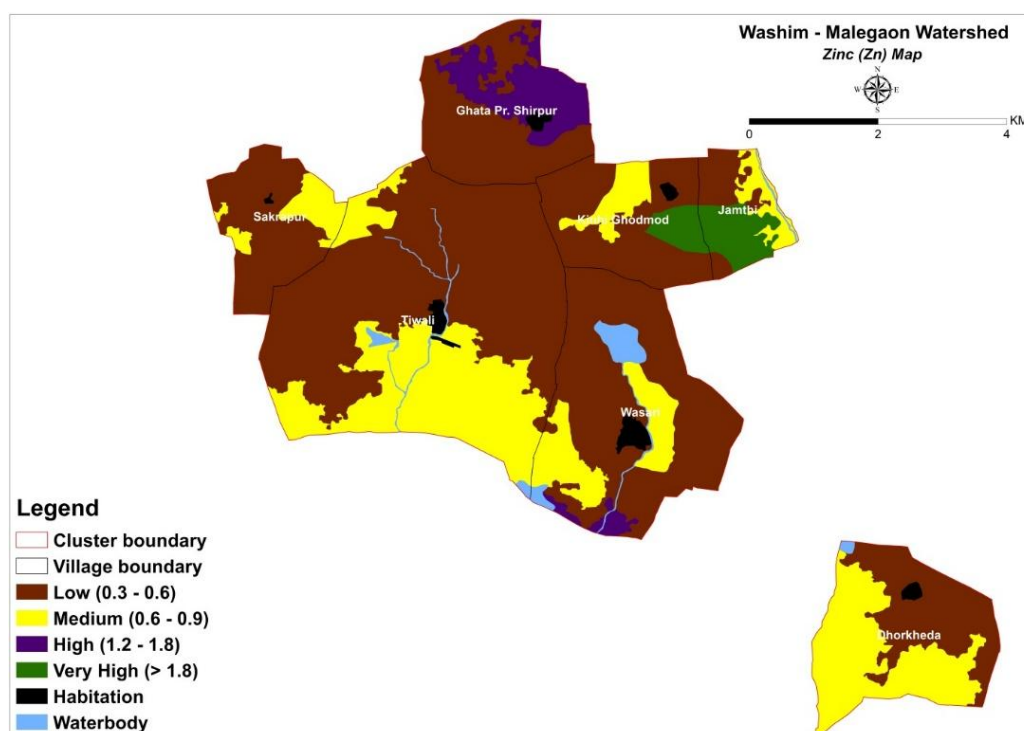
Sr.No.	Available Cu (mg kg <sup>-1</sup> )	Area (Ha)	Percent (%)
1	Very High (> 1.0)	4506.94	97.02
2	Habitation	57.21	1.23
3	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



**Fig. 4.21: DTPA-extractable soil Cu map of Malegaon watershed**

**Table 4.23: Available Zn content in the soils of Malegaon watershed.**

Sr.No.	Available Zn (mg kg <sup>-1</sup> )	Area (ha)	Percent (%)
1	Low (0.3 - 0.6)	2947.27	63.45
2	Medium (0.6 - 0.9)	1212.66	26.11
3	High (1.2 - 1.8)	210.86	4.54
4	Very High (> 1.8)	136.15	2.93
5	Habitation	57.21	1.23
6	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



**Fig. 4.22: DTPA-extractable soil Zn map of Malegaon watershed**

#### 4.6 Surface Runoff

Surface runoff is a critical component in watershed hydrology, particularly in semi-arid regions where rainfall is moderate but unevenly distributed, temporally. In Malegaon Taluka cluster watershed of Washim district, an assessment of surface runoff was carried out for the period 2014 to 2024, with the objective of understanding the rainfall-runoff dynamics and identifying the scope for in-situ water conservation interventions under the PMKSY-WDC 2.0 framework. Based on daily rainfall records for the 11-year period was compiled from IMD and verified land conditions. Land use and soil conditions were mapped through satellite imagery, field surveys, and consultation with local farmers. Based on this, Curve Numbers were assigned and runoff estimated for each monsoon season, adjusted for antecedent moisture based on rainfall distribution patterns. This analysis was based on observed rainfall and derived runoff data across the monsoon season (June to

October) for the cluster villages. The long-term average annual rainfall for the cluster stands at 928.1 mm, with significant inter-annual variability. Runoff response has been calculated for each year, indicating the proportion of rainfall that flows as surface runoff, thereby escaping immediate infiltration or storage.

**Table 4.24 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)
<b>2014</b>	65.1	0.2	182.0	22.5	160.8	17.1	167.8	54.7	50.4	4.6
<b>2015</b>	204.7	42.7	126.1	5.5	231.3	74.6	124.3	33.9	1.2	0.0
<b>2016</b>	158.6	17.4	452.3	205.1	107.0	37.5	226.6	22.4	82.3	3.6
<b>2017</b>	214.3	30.4	161.4	23.4	139.9	6.0	93.5	3.6	100.9	19.0
<b>2018</b>	273.9	54.0	263.3	61.5	192.6	51.9	50.6	0.3	0.0	0.0
<b>2019</b>	99.6	0.3	274.2	74.9	183.3	46.6	228.4	9.7	110.8	14.9
<b>2020</b>	243.1	35.6	264.2	24.5	246.9	28.8	228.2	35.3	81.9	0.4
<b>2021</b>	204.3	45.9	291.9	72.1	130.1	5.2	350.3	119.3	83.2	16.1
<b>2022</b>	66.8	0.0	444.4	179.0	246.1	95.1	154.1	7.1	99.3	6.1
<b>2023</b>	53.4	0.0	294.1	62.0	92.1	0.0	155.0	7.2	2.2	0.0
<b>2024</b>	210.2	2.0	339.3	58.0	180.5	28.8	223.1	41.0	38.2	0.6
<b>Average</b>	<b>163.1</b>	<b>20.8</b>	<b>281.2</b>	<b>71.7</b>	<b>173.7</b>	<b>35.6</b>	<b>182.0</b>	<b>30.4</b>	<b>59.1</b>	<b>5.9</b>

Over the 11-year period, the average annual surface runoff is estimated at 169.1 mm, which corresponds to 17.9% of the total annual rainfall. This suggests that a considerable portion of the rainfall is either infiltrated, used by vegetation, or lost through evapotranspiration with limited runoff available for harvesting unless timely interventions are undertaken. A review of the monthly distribution shows that July consistently produces the highest runoff, averaging 71.7 mm across years. This aligns with the peak monsoon phase when rainfall intensity is highest and soils are already saturated. August follows, with an average runoff of 35.6 mm, while September contributes about 30.4 mm. Runoff in June and October remains low, averaging 20.8 mm and 5.9 mm respectively, due to either initial soil dryness or tapering rainfall activity. Inter-annual analysis highlights years like 2016, 2021, and 2022 as high runoff years recording runoff volumes exceeding 250 mm, indicating rainfall concentration during short periods and reduced infiltration opportunities. In contrast, years such as 2014, 2017, and 2020 exhibited lower runoff generation despite moderate rainfall, which may be attributed to better rainfall distribution and higher absorption.

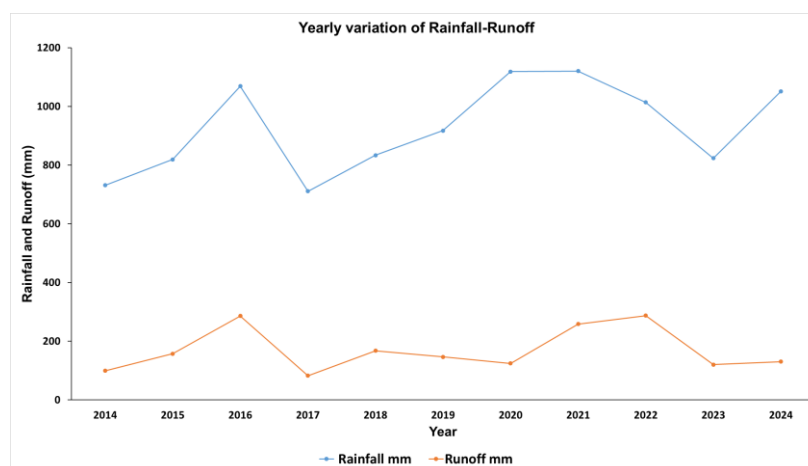
**Table.4.25 Relationship between rainfall and runoff**

Year	Rainfall, mm	Runoff, mm	No. of Runoff Events	Runoff (%)
2014	731.5	99.1	17	13.5
2015	819.4	157.4	13	19.2
2016	1068.7	285.8	29	26.7
2017	710.9	82.5	18	11.6
2018	833.7	167.5	24	20.1
2019	917.2	146.5	20	16.0
2020	1118.3	124.6	34	11.1
2021	1120.5	258.5	35	23.1
2022	1013.7	287.2	26	28.3
2023	823.6	120.4	22	14.6
2024	1051.6	130.4	30	12.4
<b>Average</b>	<b>928.1</b>	<b>169.1</b>	<b>24</b>	<b>17.9</b>

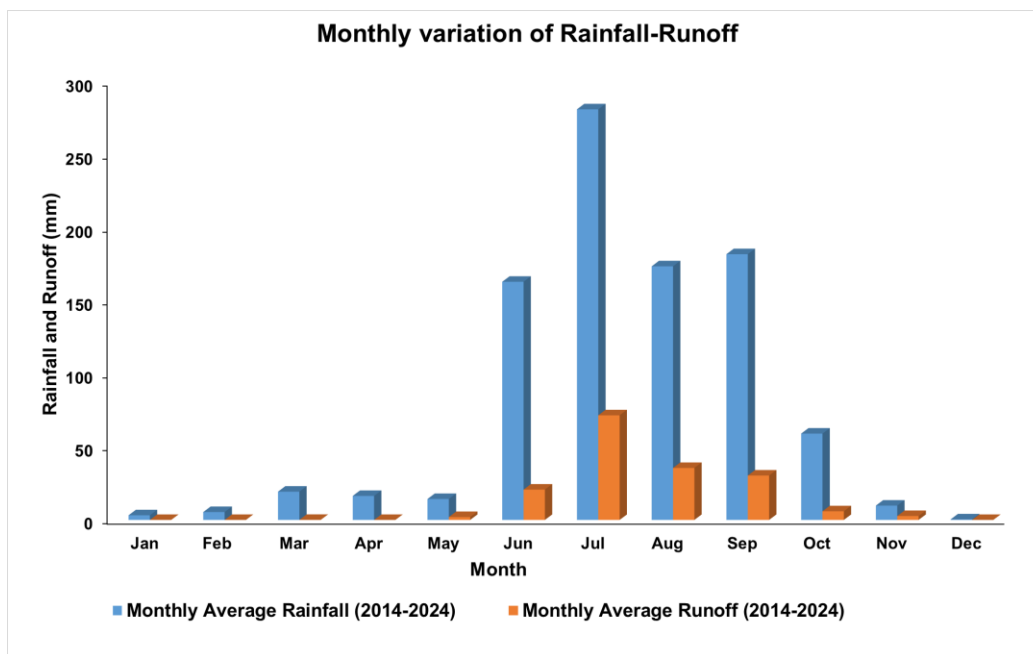
The highest runoff percentage was recorded in 2022 (28.3%) and 2016 (26.8%), suggesting potential years where unchecked runoff may have led to increased erosion or loss of water from the landscape. Conversely, years like 2017 and 2024 showed relatively low runoff percentages (11.6% and 12.4% respectively), indicating better rainfall utilization, albeit with potentially lower availability for storage.

Overall, the cluster watershed shows a runoff behavior typical of semi-arid, gently undulating terrain, where quick runoff occurs during intense spells but overall annual runoff remains modest. This reinforces the importance of timely water harvesting, especially during July and August, through structures such as check dams, farm ponds, compartment bunding, and contour trenches to maximize retention and improve groundwater recharge.

The runoff trends also underline the need for location-specific treatment planning, prioritizing upland and midland areas that contribute significantly to surface flow. Ensuring that this runoff is slowed, spread, and stored within the landscape will be central to achieving the objectives of PMKSY-WDC 2.0 in this watershed cluster.



**Fig.4.23 Yearly variation in rainfall and runoff during 2014-24**



**Fig. 4.24 Monthly variation in average rainfall and runoff during 2014-24**

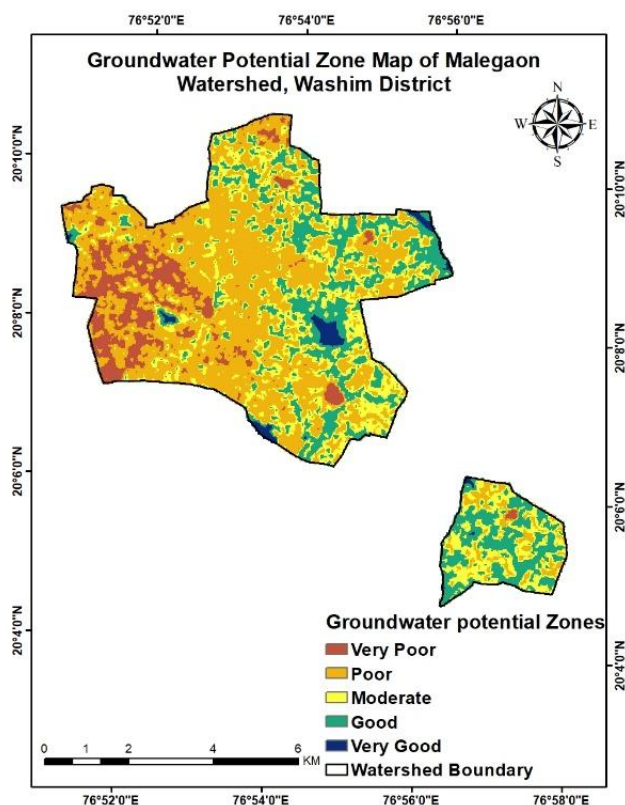
#### 4.7 Mapping of Groundwater Potential Zones

Groundwater resources in Malegaon Taluka play a decisive role in sustaining agriculture, domestic supply, and rural livelihoods. The area is characterized by moderate rainfall 928 mm annually, which is insufficient to guarantee dependable recharge. Surface water availability is seasonal and limited, making groundwater the principal source of supply. The hydrogeological setting, dominated by basalt and laterite formations, combined with variable slopes and soil textures, creates significant spatial differences in recharge and storage potential. These conditions necessitate a scientific assessment of groundwater potential zones to guide watershed development planning.

The study was carried out for a seven-village cluster, covering 4,645 hectares. Elevation ranges between 501 and 571 meters, with slopes varying from flat terrain to gradients of 24 percent. Soils are predominantly clay, silty clay loam, silty clay, and clay loam, arranged in decreasing order of coverage. Landforms include undulating midlands, uplands, and lowlands. Land use is overwhelmingly agricultural, with cultivable land accounting for more than 90 percent of the total area. Other uses such as plantations, built-up land, roads, scrub, and water bodies occupy relatively small proportions. The results reveal that 9.4 percent of the watershed falls in the very poor category and 45.3 percent in poor, together representing more than half of the area with limited recharge potential; 23.4 percent is moderate, while 20.4 percent is good and only 1.6 percent is very good, indicating that overall just 22 percent of the watershed offers favorable recharge conditions whereas nearly 78 percent requires interventions to enhance infiltration and reduce runoff losses.

These findings provide a clear spatial framework for planning under the Pradhan Mantri Krishi Sinchayee Yojana -Watershed Development Component 2.0. The zonation map will assist in identifying priority micro watersheds for treatment, locating recharge structures

and implementing soil and moisture conservation measures. In poor potential zones, emphasis should be placed on artificial recharge and alternative water supply strategies. Moderate zones require balanced management to prevent degradation, while good and very good zones must be safeguarded against over extraction to ensure long term sustainability. The study demonstrates that integrated spatial analysis is an effective tool for groundwater resource planning in semi-arid regions. By combining field data, remote sensing inputs, and expert evaluation, the assessment provides actionable insights for government agencies and local institutions. The outcomes will contribute to improved water security, enhanced agricultural productivity, and strengthened socio economic resilience in Malegaon Taluka.



**Fig. 4.25 Ground water potential zones of Malegaon watershed**

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

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

The suitability of soils for crop cultivation was determined based on the criteria proposed by Naidu et al. (2006). The concept of land utilization types and the classification system

for land evaluation categorizes land into different hierarchical levels, namely orders, classes, sub-classes, and units. Two major orders are recognized: 'S' (Suitable) and 'N' (Not suitable), representing the general suitability status of land. Under the suitable order (S), three classes S1, S2, and S3 indicate high, moderate, and marginal suitability, respectively, while the not suitable order (N) includes two classes N1 and N2 representing current and permanent unsuitability. The assignment of these classes is based on the degree of land limitations affecting crop production.

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

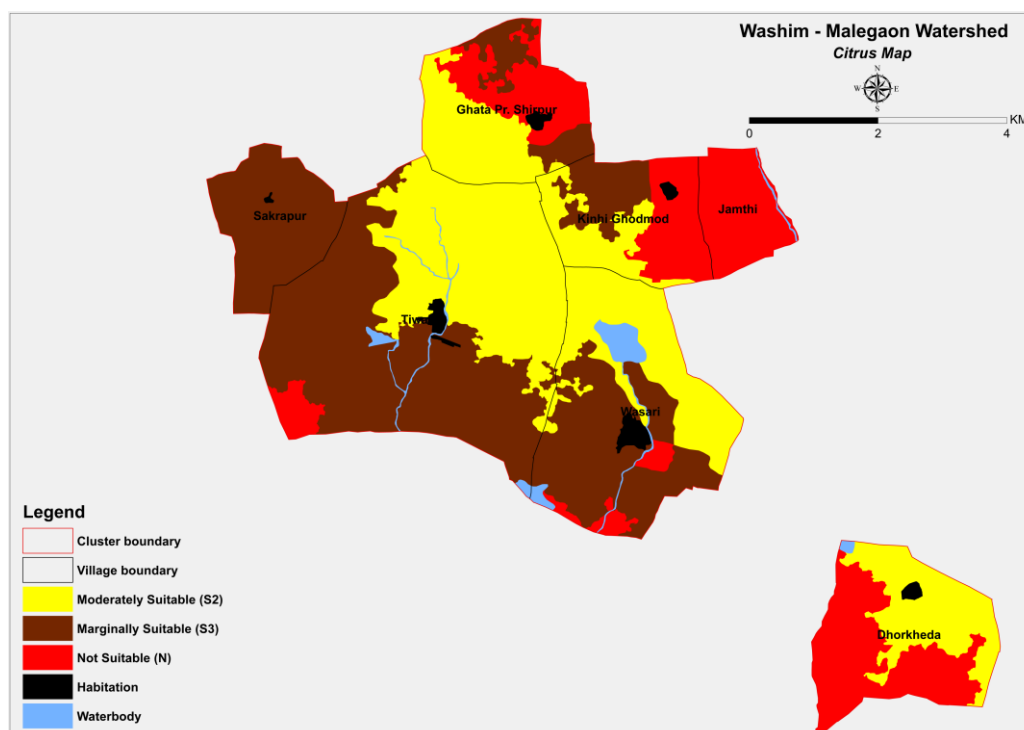
Several soil-site parameters, including climatic variables (rainfall, temperature); topographic features (slope, landscape position, and erosion susceptibility); wetness conditions (drainage, flooding risk and soil aeration); physical soil properties (texture, depth, structure and available soil moisture);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

#### **4.8.1 Soil-Site Suitability for Citrus Cultivation**

The land suitability analysis of the watershed reveals variations in the potential of land for the targeted crop. Out of the total 4645.16 ha area of the watershed, 1663.48 ha (35.81%) was classified as moderately suitable (S2) for citrus. These areas possess relatively favourable soil and terrain characteristics that can support good growth with appropriate management practices. The largest portion of the watershed, 1872.72 ha (40.32%), falls under the marginally suitable (S3) category. This indicates the presence of moderate limitations such as soil fertility constraints, slope, drainage issues, or other environmental factors that may restrict optimal crop productivity. However, these areas can still be cultivated with improved management practices and soil conservation measures. About 970.74 ha (20.90%) of the area was categorized as not suitable (N) for the citrus due to severe limitations that significantly affect crop growth and yield potential. Such areas may require substantial land improvement measures or may be better suited for alternative land uses.

**Table 4.26 Area under suitability sub-classes for Citrus Cultivation**

Sr.No.	Citrus	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1663.48	35.81
2	Marginally Suitable (S3)	1872.72	40.32
3	Not Suitable (N)	970.74	20.90
4	Habitation	57.21	1.23
5	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



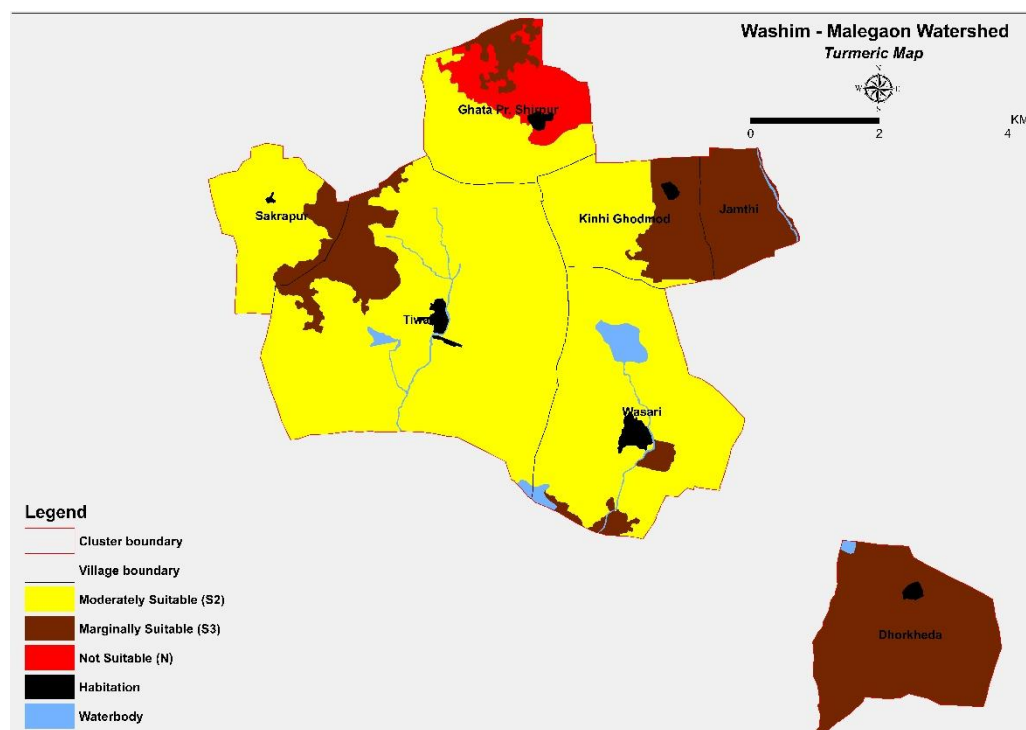
**Fig. 4.26 Soil site suitability map for Citrus Cultivation**

#### 4.8.2 Soil-Site Suitability for Turmeric Cultivation

The land suitability assessment for turmeric cultivation in the watershed indicates that a significant portion of the area is favourable for the crop. Out of the total watershed area 65.41% was classified as moderately suitable (S2) for turmeric cultivation. A considerable portion of the watershed, 27.66%, falls under the marginally suitable (S3) category. This indicates the presence of certain limitations such as moderate soil fertility constraints, drainage issues, or terrain-related factors that may affect optimal turmeric productivity. However, these areas can still be utilized for turmeric cultivation with suitable soil and crop management practices. Only 3.95% of the watershed area was classified as not suitable (N) for turmeric cultivation due to severe limitations that restrict crop growth and productivity. Such areas may require significant land improvement measures or may be more appropriate for alternative land uses. (Table 4.27, Fig. 4.27)

**Table 4.27 Area under suitability sub-classes for Turmeric Cultivation**

Sr.No.	Turmeric	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	3038.57	65.41
2	Marginally Suitable (S3)	1284.98	27.66
3	Not Suitable (N)	183.39	3.95
4	Habitation	57.21	1.23
5	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



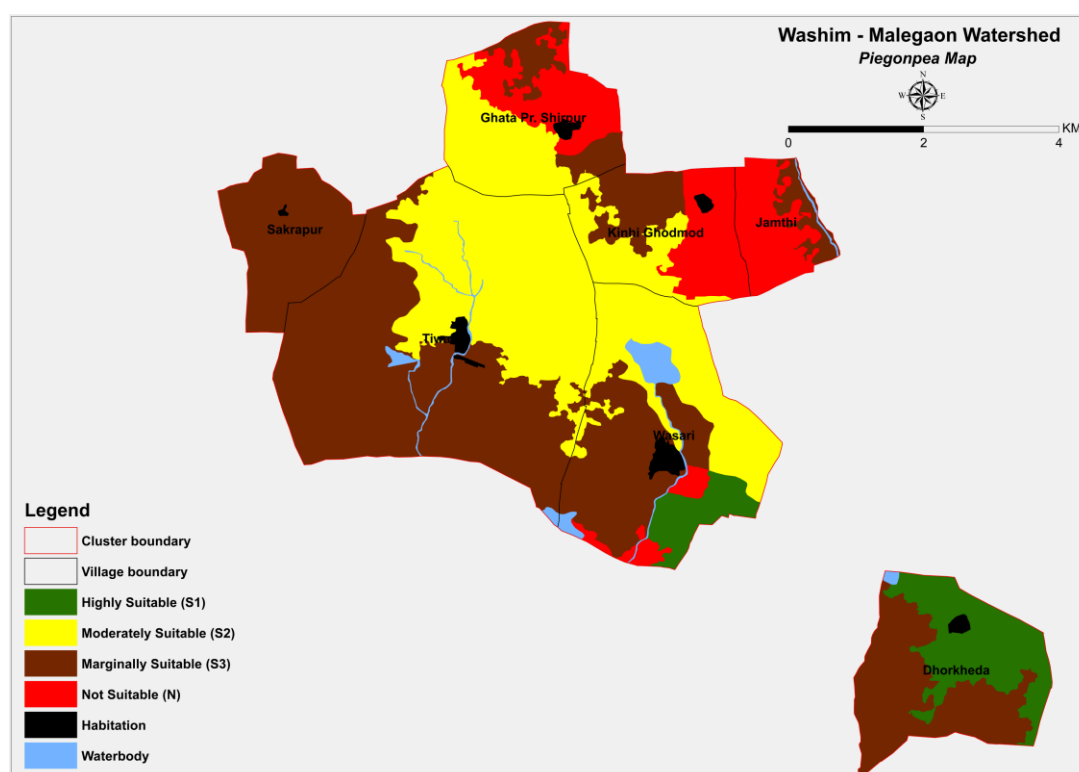
**Fig. 4.27 Soil site suitability map for Turmeric cultivation**

### 4.8.3 Soil-Site Suitability for Pigeonpea Cultivation

Out of the total area of watershed, about 7.90% was classified as highly suitable (S1) for pigeon pea cultivation. A considerable portion of the watershed, 30.17%, falls under the moderately suitable (S2) category. These areas have relatively favorable conditions for pigeon pea cultivation but may experience certain moderate limitations that can be managed through appropriate agronomic practices and soil management measures. The largest share of the watershed, 47.01%, is categorized as marginally suitable (S3). This indicates the presence of several constraints such as moderate soil fertility limitations, slope, or drainage issues that may restrict optimal crop growth and yield. However, these areas can still support pigeon pea cultivation with improved management practices. About 11.95% of the watershed area was found to be not suitable (N) for pigeon pea cultivation due to severe limitations that significantly hinder crop performance. Such areas may require substantial land improvement measures or may be better utilized for alternative land uses. (Table 4.28, Fig. 4.28).

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

Sr.No.	Pigeonpea	Area (ha)	Percent (%)
1	Highly Suitable (S1)	366.92	7.90
2	Moderately Suitable (S2)	1401.37	30.17
3	Marginally Suitable (S3)	2183.61	47.01
4	Not Suitable (N)	555.04	11.95
5	Habitation	57.21	1.23
6	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



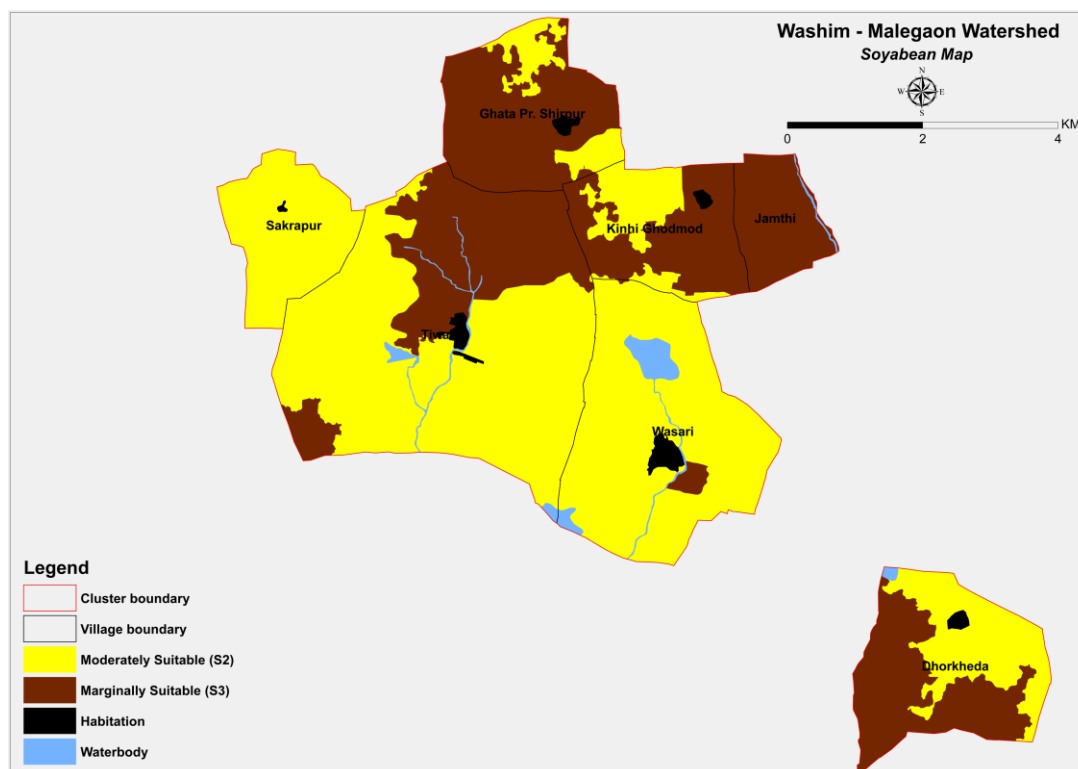
**Fig. 4.28. Soil site suitability map for Pigeonpea (tur) Cultivation**

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

The land suitability assessment for soybean cultivation in the watershed indicates that a substantial portion of the area is favorable for the crop. Out of the total area of watershed, 59.53% was classified as moderately suitable (S2) for soybean cultivation. These areas possess relatively favourable soil and terrain conditions such as adequate soil depth, suitable texture, and moderate slope, which can support satisfactory soybean growth and productivity with proper crop management practices. A significant portion of the watershed, 37.50%, falls under the marginally suitable (S3) category (Table 4.29, Fig. 4.29).

**Table 4.29. Area under suitability sub-classes for Soybean Cultivation**

Sr.No.	Soybean	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	2765.08	59.53
2	Marginally Suitable (S3)	1741.86	37.50
3	Habitation	57.21	1.23
4	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



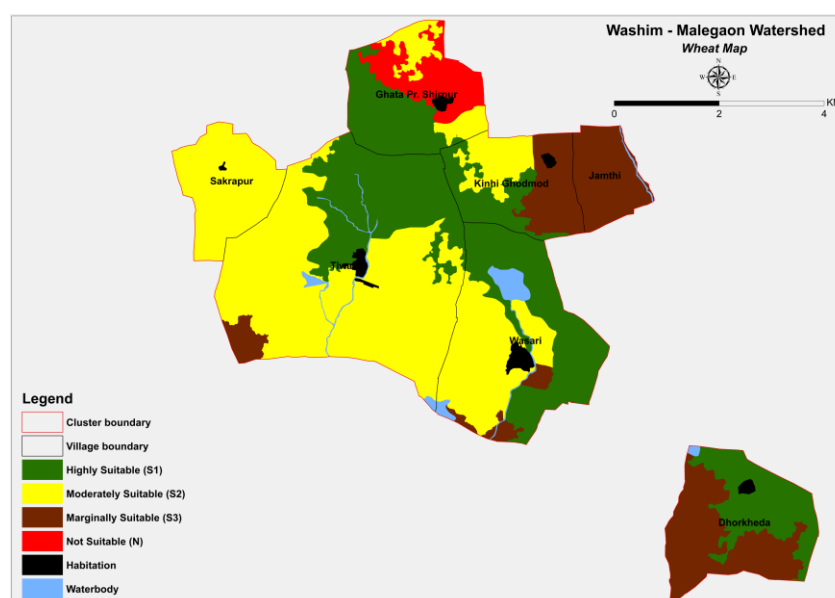
**Fig. 4.29. Soil site suitability map for Soybean Cultivation**

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

The land suitability evaluation for wheat cultivation in the watershed shows that a large portion of the area is favourable for the crop. About 33.17% was classified as highly suitable (S1) for wheat cultivation. A major portion of the watershed, 42.96%, falls under the moderately suitable (S2) category. These areas have generally suitable conditions for wheat cultivation but may experience moderate limitations related to soil fertility, slope, or moisture availability. However, such limitations can be managed effectively through appropriate agronomic and soil management practices. Another 16.95% of the area is categorized as marginally suitable (S3) and 3.95% of the watershed area was classified as not suitable (N) for wheat.

**Table 4.30 Area under suitability sub-classes for Wheat Cultivation**

Sr.No.	Wheat	Area (ha)	Percent (%)
1	Highly Suitable (S1)	1540.71	33.17
2	Moderately Suitable (S2)	1995.48	42.96
3	Marginally Suitable (S3)	787.35	16.95
4	Not Suitable (N)	183.39	3.95
5	Habitation	57.21	1.23
6	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



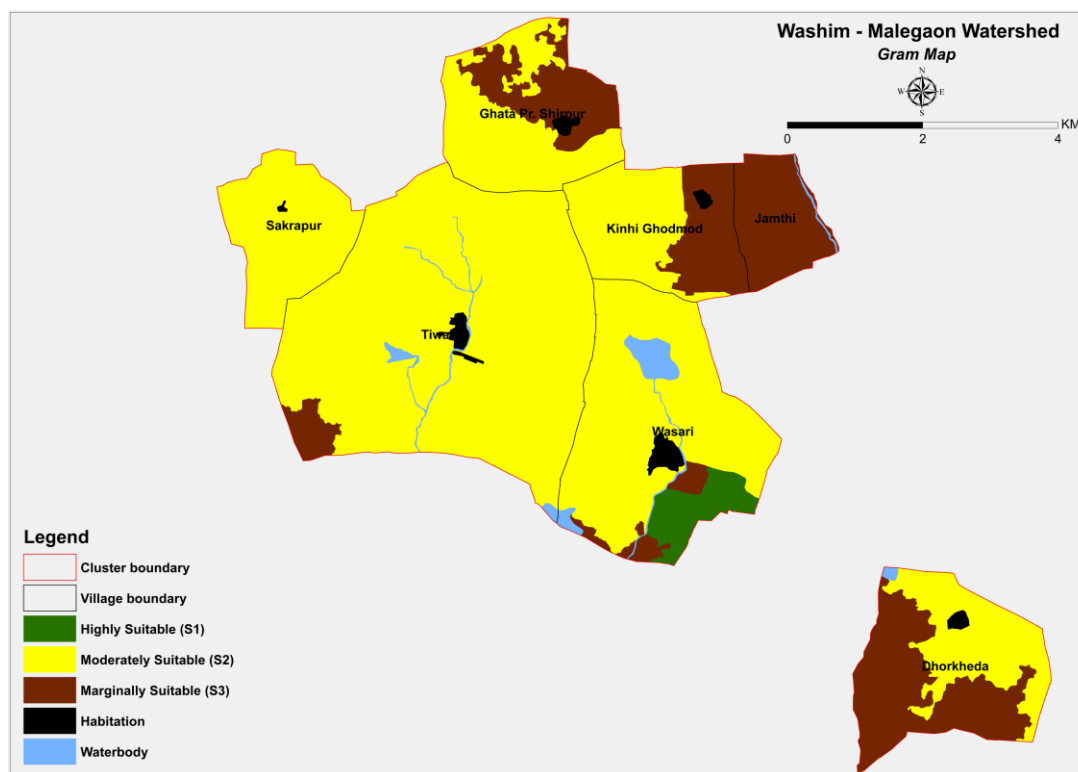
**Fig. 4.30 Soil site suitability map for Wheat Cultivation**

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

The suitability analysis for chickpea indicated that only 2.26% area was classified as highly suitable (S1) for chickpea cultivation. These areas possess optimal soil and terrain characteristics that support excellent crop growth and productivity with minimal limitations. The majority of the watershed area 73.87%, falls under the moderately suitable (S2) category. While, considerable portion of the watershed, 20.90%, is categorized as marginally suitable (S3). (Table 4.31 and Fig. 4.31).

**Table 4.31 Area under suitability sub-classes for Chickpea Cultivation**

Sr.No.	Chickpea	Area (ha)	Percent (%)
1	Highly Suitable (S1)	104.81	2.26
2	Moderately Suitable (S2)	3431.39	73.87
3	Marginally Suitable (S3)	970.74	20.90
4	Habitation	57.21	1.23
5	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



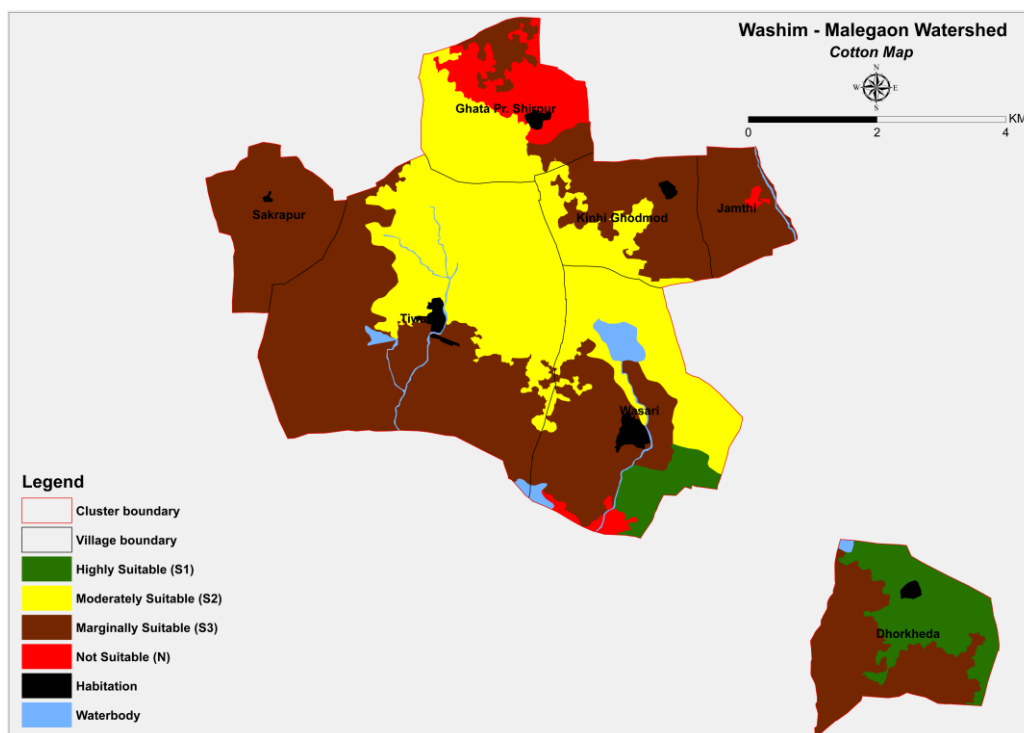
**Fig. 4.31 Soil site suitability map for Chickpea Cultivation**

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

The soil–site evaluation for cotton cultivation shows that 7.90% of the total geographical area is classified as highly suitable (S1) and 30.17% area classified as moderately suitable (S2). These areas provide acceptable conditions for cotton cultivation, though certain soil and site constraints may affect crop performance. A large portion of the watershed, covering 2521.11 ha (54.27.5%), falls under the marginally suitable (S3) category (Table 4.32, Fig. 4.32), indicating the presence of moderate limitations that may restrict yield potential. Furthermore, 217.55 ha (4.68%) of the area is categorized as not suitable (N) for cotton cultivation due to severe soil and site-related constraints.

**Table 4.32 Area under suitability sub-classes for Cotton Cultivation**

Sr.No.	Cotton	Area (ha)	Percent (%)
1	Highly Suitable (S1)	366.92	7.90
2	Moderately Suitable (S2)	1401.37	30.17
3	Marginally Suitable (S3)	2521.11	54.27
4	Not Suitable (N)	217.55	4.68
5	Habitation	57.21	1.23
6	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



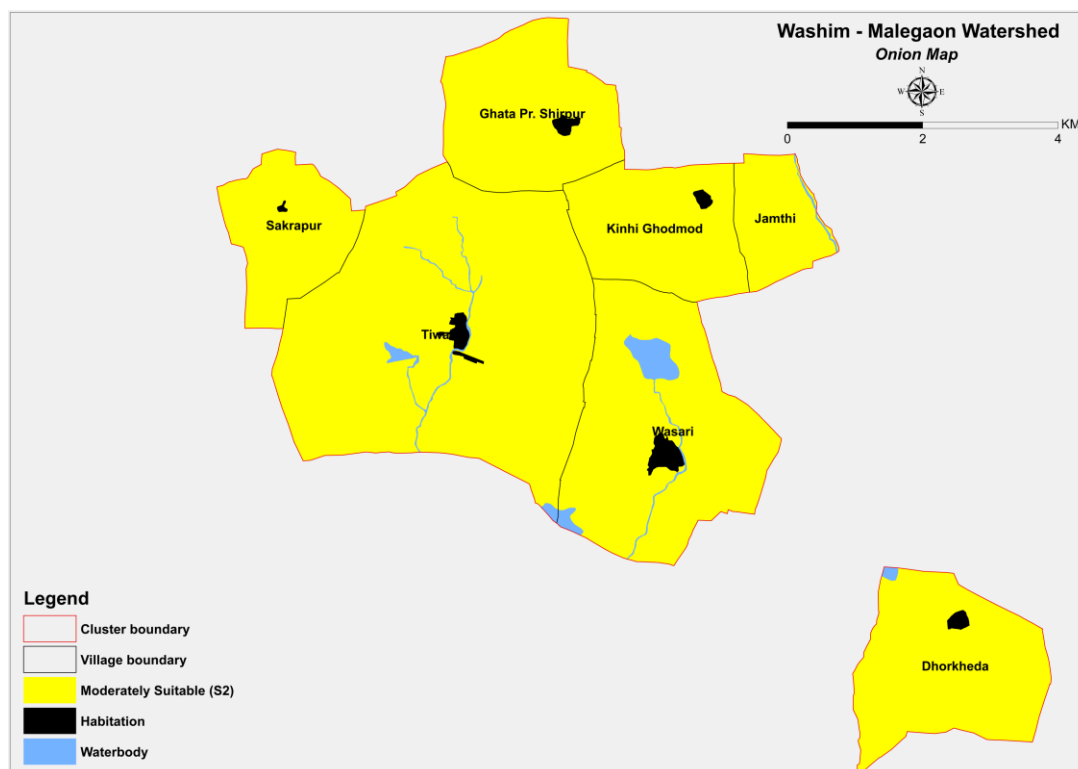
**Fig. 4.32. Soil site suitability map for Cotton Cultivation**

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

The land suitability assessment for onion cultivation in the watershed indicates that the majority of the area is favourable for the crop. Out of the total 4645.16 ha, about 4506.94 ha (97.02%) was classified as moderately suitable (S2) for onion cultivation. This suggests that most parts of the watershed possess generally favourable soil and terrain characteristics such as suitable soil depth, texture, and drainage conditions that can support satisfactory onion growth and yield with proper crop and nutrient management practices (Table 4.33, Fig. 4.33).

**Table 4.33. Area under suitability sub-classes for Onion Cultivation**

Sr.No.	Onion	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	4506.94	97.02
2	Habitation	57.21	1.23
3	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



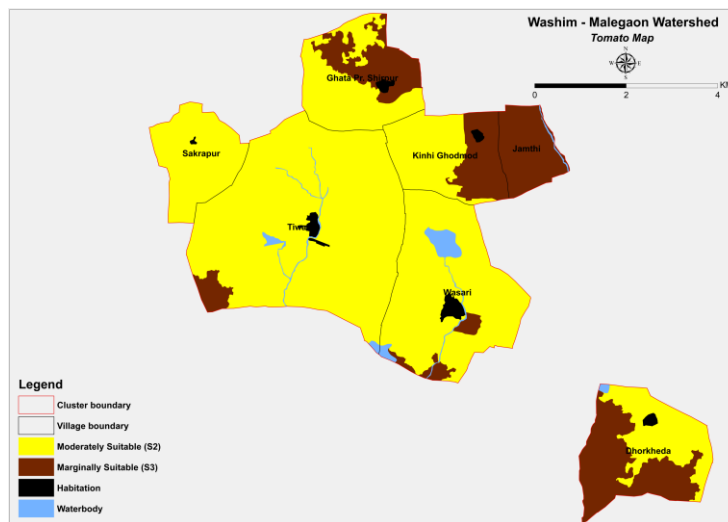
**Fig. 4.33 Soil site suitability map for Onion Cultivation**

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

The land suitability evaluation for tomato cultivation in the watershed indicates that a substantial portion of the area is favorable for the crop. Out of the total 4645.16 ha, about 3536.20 ha (76.13%) was classified as moderately suitable (S2) for tomato cultivation. These areas possess relatively favorable soil and terrain characteristics such as adequate soil depth, suitable texture, and moderate slope, which can support satisfactory tomato growth and productivity with proper crop and nutrient management practices. A significant portion of the watershed, 970.74 ha (20.90%), falls under the marginally suitable (S3) category. This suggests the presence of certain limitations such as moderate soil fertility constraints, drainage issues, or terrain-related factors that may restrict optimal tomato productivity. However, these areas can still be utilized for tomato cultivation with the adoption of improved agronomic practices, soil fertility management, and irrigation management.

**Table 4.34. Area under suitability sub-classes for Tomato Cultivation**

Sr.No.	Tomato	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	3536.20	76.13
2	Marginally Suitable (S3)	970.74	20.90
3	Habitation	57.21	1.23
4	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



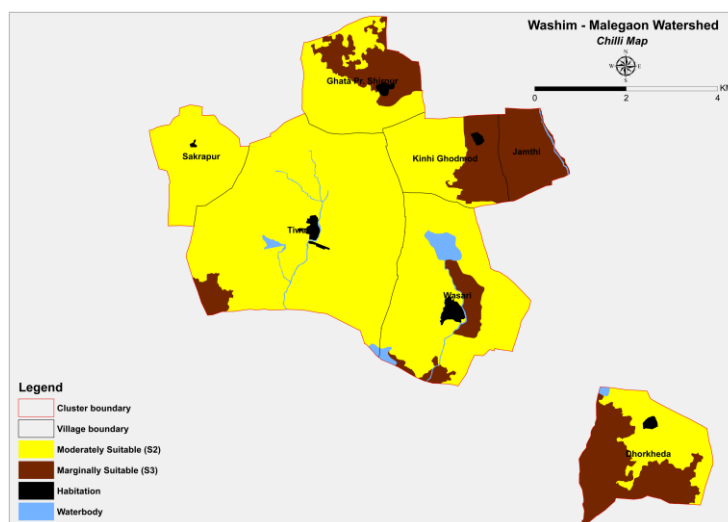
**Fig. 4.34. Soil site suitability map for Tomato Cultivation.**

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

The land suitability assessment for chilli cultivation in the watershed indicates that a major portion of the area is favourable for the crop. Out of the total 4645.16 ha, about 3486.23 ha (75.05%) was classified as moderately suitable (S2) for chilli cultivation. While, a significant portion of the watershed, 1020.71 ha (21.97%), falls under the marginally suitable (S3) category. (Table 4.35, Fig. 4.35).

**Table 4.35 Area under suitability sub-classes for Chilli Cultivation**

Sr.No.	Chilli	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	3486.23	75.05
2	Marginally Suitable (S3)	1020.71	21.97
3	Habitation	57.21	1.23
4	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



**Fig.4.35 Soil site suitability map for Chilli Cultivation**

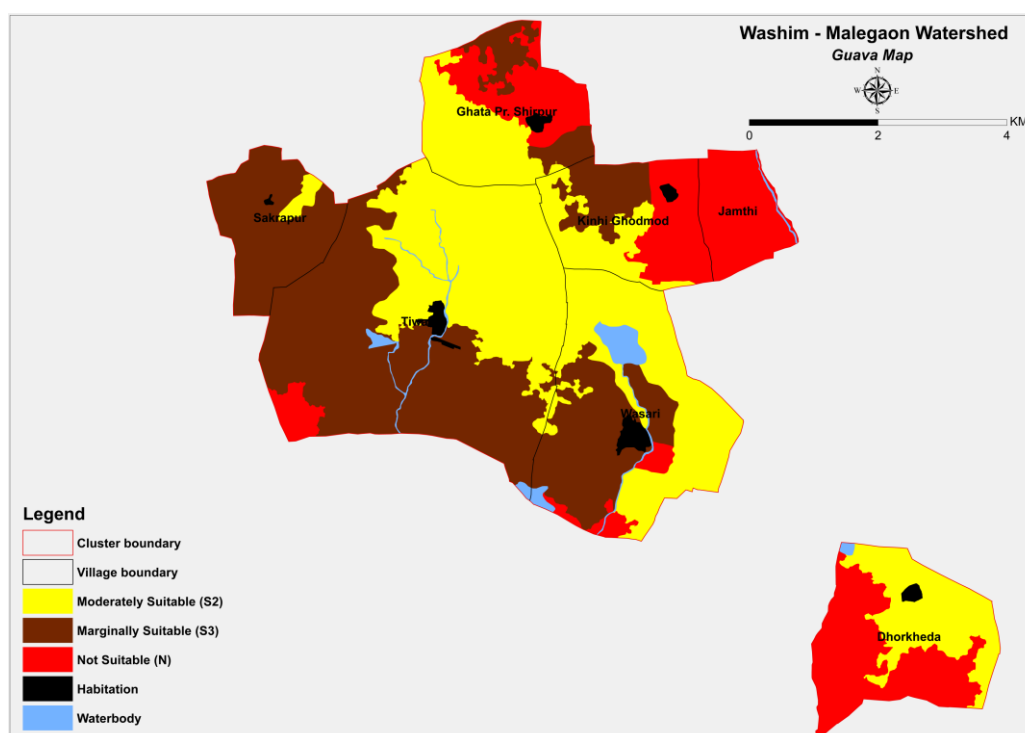
#### 4.8.11 Soil-Site Suitability for Guava Cultivation

The land suitability assessment for guava cultivation in the watershed indicates that the area has moderate potential for the crop, with varying levels of limitations. Out of the total 4645.16 ha, about 1788.74 ha (38.51%) was classified as moderately suitable (S2) for guava. These areas possess generally favorable soil and terrain characteristics that can support good guava growth and productivity with appropriate management practices such as soil fertility improvement, irrigation, and pruning.

About, 1747.46 ha (37.62%), falls under the marginally suitable (S3) category. About 970.74 ha (20.90%) of the watershed was classified as not suitable (N) for guava cultivation due to severe limitations that significantly hinder crop growth, such as shallow soils, steep slopes, or poor drainage. These areas may require substantial land improvements or may be better suited for alternative land uses (Table 4.36, Fig. 4.36).

**Table 4.36 Area under suitability sub-classes for Guava Cultivation**

Sr.No.	Guava	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1788.74	38.51
2	Marginally Suitable (S3)	1747.46	37.62
3	Not Suitable (N)	970.74	20.90
4	Habitation	57.21	1.23
5	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



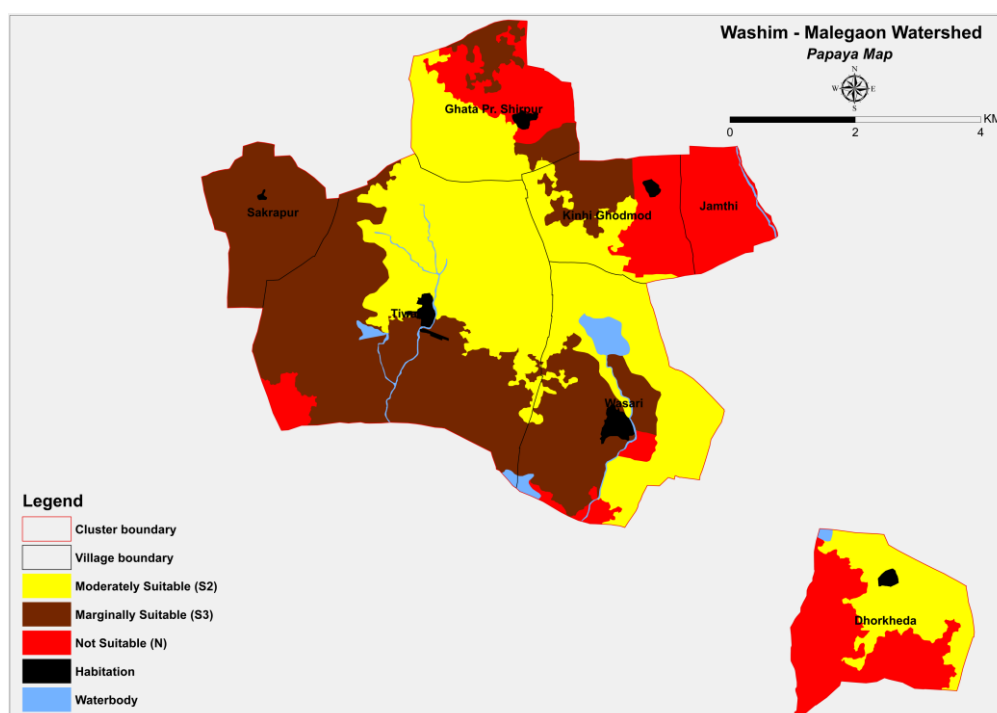
**Fig 4.36 Soil site suitability map for Guava Cultivation**

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

The land suitability assessment for guava cultivation in the watershed indicates that a substantial portion of the area has moderate potential for the crop. Out of the total 4645.16 ha, about 1768.29 ha (38.07%) was classified as moderately suitable (S2). A nearly equal portion, 1767.91 ha (38.06%), falls under the marginally suitable (S3) category. These areas exhibit moderate limitations, such as soil fertility constraints, slope, or drainage issues, which may reduce guava yield unless mitigated through improved agronomic and soil conservation practices. About 970.74 ha (20.90%) of the watershed was classified as not suitable (N) due to severe limitations that significantly restrict guava cultivation. These areas may require substantial land improvements or may be better suited for alternative land uses.

**Table 4.37 Area under suitability sub-classes for Papaya Cultivation**

Sr.No.	Papaya	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1768.29	38.07
2	Marginally Suitable (S3)	1767.91	38.06
3	Not Suitable (N)	970.74	20.90
4	Habitation	57.21	1.23
5	Waterbody	81.01	1.74
	<b>Total</b>	<b>4645.16</b>	<b>100.00</b>



**Fig 4.37 Soil site suitability map for Papaya Cultivation**

#### **4.9 Soil and Water Conservation measures**

Soil and Water Conservation (SWC) refer to scientific measures adopted to control soil erosion, manage runoff, enhance water storage, and sustain long-term agricultural productivity. SWC practices play an essential role in protecting soil structure, improving moisture retention, and reducing land degradation, thereby ensuring stable crop performance and productivity. These measures are crucial in landscapes where variable soil depth, slope gradients, and rainfall intensity influence surface runoff and moisture availability.

The SWC interventions planned for the region are based on actual mapped land conditions including land use, landform, terrain characteristics, and drainage patterns. Across the Washim area, cultivated lands, plantation areas, shallow soils, drainage lines, transportation corridors, and built-up sections have been identified as priority zones for conservation works. The planned measures are designed to control runoff on agricultural fields, enhance soil moisture through in-situ treatments, strengthen existing bunds, increase surface storage through water bodies and farm pond renovation, stabilize stream banks, and improve vegetative cover.

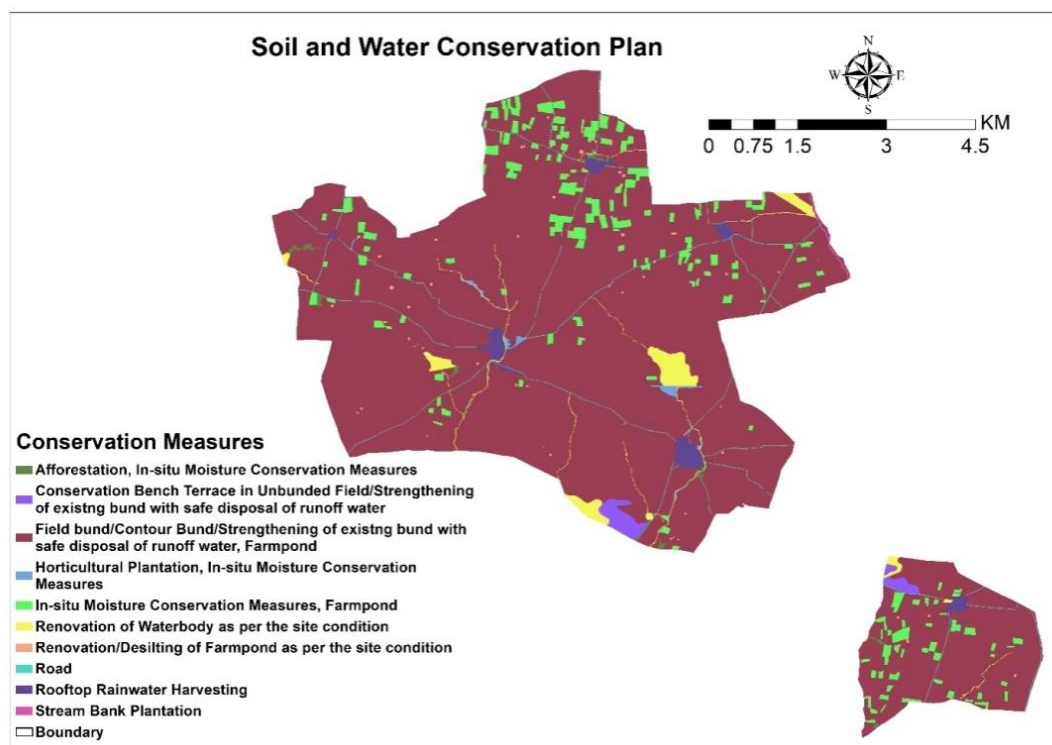
The summary of assigned interventions is presented in the SWC Plan Table. The major portion of the conservation effort is focused on field-level bunding combined with farm pond development, which is critical for retaining monsoon runoff and improving moisture availability in cultivated lands. In-situ moisture conservation treatments have also been included to enhance moisture retention in plantation fields and barren patches. Renovation of existing water bodies, water harvesting, and drainage line stabilization structures are planned to improve storage capacity and water availability during non-monsoon periods.

The plan further incorporates rooftop rainwater harvesting systems in built-up areas to assist domestic water supply and groundwater recharge. Bench terracing, road runoff management, and strengthening of bunds support erosion control in moderately sloping agricultural areas. Repair and desilting of nala bunds, farm pond renovation, and stream bank plantations have been proposed to maintain channel stability and prevent bank erosion. Afforestation and horticultural plantation activities, supported by moisture conservation trenching, are expected to improve vegetative cover, reduce soil loss, and increase ecological stability.

The planned interventions collectively aim to reduce soil erosion, conserve rainwater at its source, support controlled disposal of excess runoff, improve crop productivity, and enhance groundwater recharge across the Washim landscape.

**Table 4.38. Table Proposed soil and water conservation plan for Malegaon watershed, Washim**

S. No.	Proposed SWC Plan
1	Field bund/Contour Bund/Strengthening of existing bund with safe disposal of runoff water, Farm pond
2	In-situ Moisture Conservation Measures
3	Renovation of Waterbody as per the site condition
4	Field bund/Contour Bund/Strengthening of existing bund with safe disposal of runoff water
5	Rooftop Rainwater Harvesting
6	Conservation Bench Terrace in Unbunded Field/Strengthening of existing bund with safe disposal of runoff water
7	Road
8	In-situ Moisture Conservation Measures, Farm pond
9	Cement Nala Bund, Earthen Nala Bund / Repairing of Cement Nala Bund and Desilting of Nallas
10	Afforestation, In-situ Moisture Conservation Measures
11	Renovation/Desilting of Farm pond as per the site condition
12	Horticultural Plantation, In-situ Moisture Conservation Measures
13	Stream Bank Plantation



**Fig. 4.38 Soil and water conservation measures for Malegaon watershed, Washim**

## CHAPTER 5

### SUMMARY AND CONCLUSION

#### 5.1 SUMMARY

- The Malegaon watershed's economy is largely agriculture-based on a soybean/tur and commercial turmeric cropping pattern.
- The water management is hindered by critical issues, seasonal water scarcity, and depleting groundwater levels.
- The watershed is part of the Deccan Volcanic Province, exhibits significant heterogeneity in its landforms (e.g., mesas, pediplains), slope, and land use.
- The soils, which originated from basaltic parent material, show marked variations in their depth, texture, drainage, and overall fertility status.
- An extensive survey was conducted to classify and map the dominant soil series and phases.
- Soil health status was comprehensively mapped, providing critical data on distribution of land slope, different classes of soil erosion, and soil depth. Spatial distribution of soil pH, soil salinity, extent of calcareousness, and the status of soil organic carbon (SOC). Nutrient deficiencies were quantified and mapped for the availability of major nutrients (Nitrogen, Phosphorus and Potassium) and micronutrients (Iron, Manganese, Copper, and Zinc) to identify specific areas requiring soil amendments.
- The hydrological assessment quantified the relationship between rainfall and surface runoff, providing historical data for monthly runoff from 2014 to 2024.
- The groundwater potential zones were successfully mapped using integrated thematic analysis.
- A major outcome of the LRI is the Evaluation of Soil-Site Suitability for Crops. Suitability classes (S1, S2, S3, N) were determined and mapped for major crops, including rainfed agricultural crops and horticultural crops.
- The Malegaon watershed receives an average annual rainfall of 928.1 mm, producing about 169.1 mm of runoff (17.9%), indicating that most rainfall is absorbed through infiltration or evapotranspiration. Runoff is highly seasonal, with July (71.7 mm) contributing the highest runoff followed by August (35.6 mm) and September (30.4 mm) during peak monsoon conditions.
- Inter-annual variability is evident, with 2016, 2021, and 2022 showing high runoff years (>250 mm), while 2017 and 2024 recorded lower runoff due to better rainfall distribution and higher infiltration.
- Groundwater potential mapping showed 9.4% of the area is very poor and 45.3% poor, together covering more than half of the watershed with limited recharge potential. Only 22% of the area shows favourable groundwater recharge conditions, highlighting the need for recharge and conservation interventions.
  - Soil and water conservation measures planned for Washim-Malegaon watershed

include field bunding, farm ponds, water body renovation, drainage line stabilization, afforestation, and in-situ moisture conservation.

## **5.2 CONCLUSION**

The present study demonstrates 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 land cover has enabled a detailed understanding of the hydrological and environmental conditions prevailing within the Malegaon watershed. The generation and interpretation of these thematic layers provide a scientific foundation for identifying priority areas and formulating appropriate soil and water conservation strategies.

The assessment of fertility parameters indicated that the soil of the watershed possesses the multi-nutrient deficiencies like available nitrogen, phosphorus and zinc coupled with majority of the area under medium category of the organic carbon. This needs serious attention to optimized the productivity potential of the watershed soils. The farmers of the Malegaon watershed should make aware about the balance application of the nutrients in order to sustain the soil health in long term. The farmers should also adopt a compulsory approach of utilizing the organic manures in their farm to maintain the soil organic carbon in their soil. The assessment of crop suitability in the watershed area revealed that the soils of watershed can support the crop diversification through agricultural and horticultural crops for enhancing the soil health and socio-economic conditions of the farmers.

The study highlights the importance of integrated watershed management for improving water resources in the Malegaon watershed. Runoff analysis shows that a significant portion of rainfall occurs during short intense monsoon periods, leading to seasonal water losses if not properly conserved. Groundwater potential mapping indicates that only a limited area of the watershed supports favorable recharge conditions, while the majority requires targeted interventions to enhance infiltration. The proposed soil and water conservation measures, including bunding, farm ponds, drainage stabilization, and afforestation, provide a practical framework to capture runoff, reduce soil erosion, and strengthen groundwater recharge. Implementing these measures will improve water availability, enhance agricultural productivity, and support sustainable land and water management in the region.

Overall, the integrated approach adopted in this study enables precise planning, prioritization, and implementation of watershed development activities. The recommended measures are expected to reduce surface runoff and soil erosion, enhance groundwater recharge, and improve crop productivity. Successful execution of these interventions will contribute to long-term water security, environmental sustainability, and socio-economic development of the farming community. The study thus provides a robust scientific framework for sustainable watershed management and supports the broader objectives of the PMKSY programme in achieving efficient and equitable utilization of water resources.

## 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 Malegaon cluster, Washim**

The runoff estimation, groundwater potential zone (GWPZ) delineation, and soil and water conservation (SWC) planning were undertaken at the village-cluster level to support location-specific evaluation and practical execution. In contrast, morphometric analysis was performed at the watershed scale, as morphometric characteristics are determined by natural drainage divides rather than administrative boundaries.

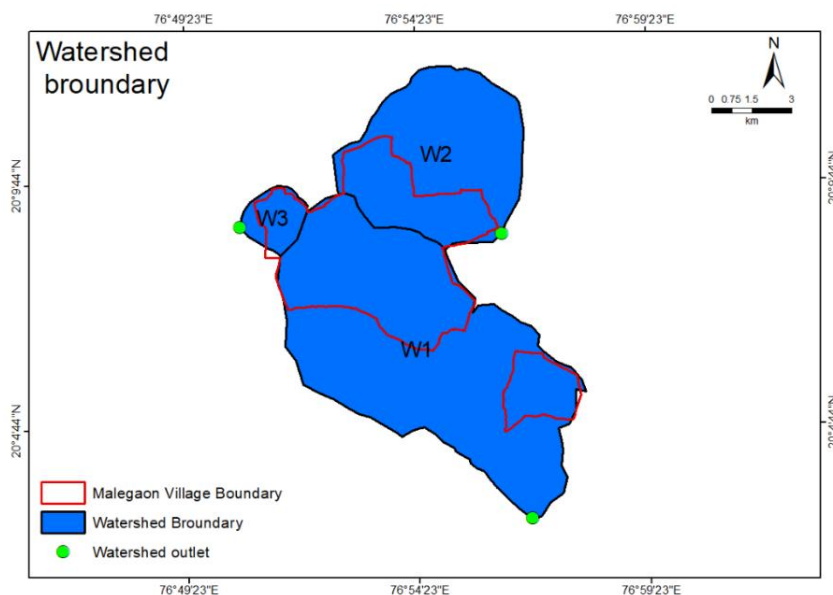
Morphometric analysis involves the quantitative assessment of drainage network properties, basin configuration, slope, and relief, all of which govern runoff generation, soil erosion, and groundwater recharge processes. These parameters need to be derived from a

hydrologically enclosed unit defined by natural divides. A watershed constitutes such a unit, where streams evolve in a hierarchical pattern and converge toward a common outlet, enabling accurate estimation of indices such as drainage density, bifurcation ratio, stream frequency, form factor, and relief ratio.

Village clusters are administrative units that rarely align with entire drainage systems. Because streams frequently extend across village boundaries, conducting morphometric analysis at the cluster scale would lead to incomplete stream networks and altered basin geometry, resulting in misleading hydrological interpretations.

Accordingly, morphometric analysis was deliberately carried out at the watershed level to preserve hydrological integrity, whereas runoff estimation, GWPZ mapping, and SWC planning were implemented at the village-cluster level to ensure effective local-level application. This integrated approach connects natural hydrological dynamics with decentralized planning, promoting sustainable water resource management.

The Malegaon cluster, Washim, Maharashtra, comprises seven villages. Together, these villages constitute the study cluster having 3 sub-watersheds (Fig. 1).

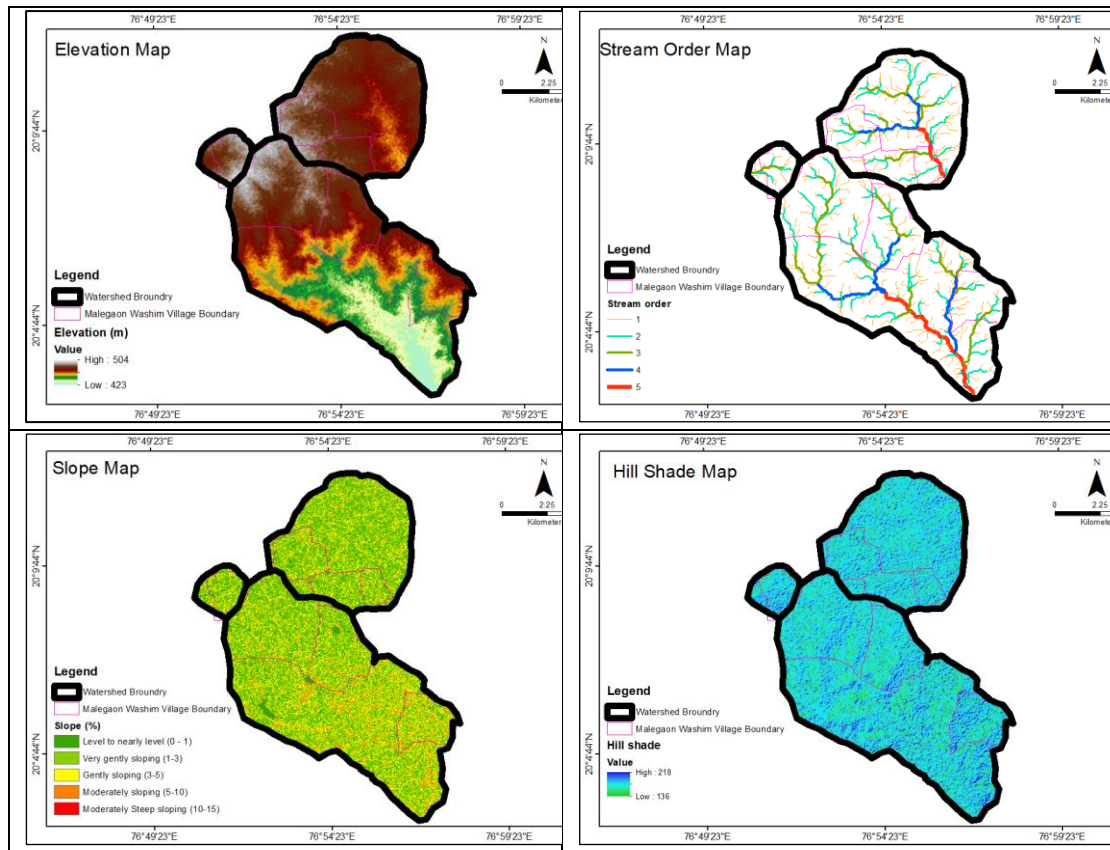


**Fig. 1: Map of Malegaon cluster, Washim depicted through sub-watershed**

**Table 1: Distribution of area under different sub-watershed, Malegaon, Washim**

Sr. No.	Sub-watershed name	Sub-watershed order	Elevation (m)	Area (km <sup>2</sup> )	Flow origination
1	W1	5 <sup>th</sup>	423-504	75.5	South-east
2	W2	5 <sup>th</sup>	474-502	36.7	South-east
3	W3	3 <sup>rd</sup>	457-499	4.5	West
	<b>Total</b>			<b>116.8</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 analysed under three aspects: linear, areal, and relief.



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

### Linear aspect

Linear morphometric parameters focus on the stream network characteristics and its influence on runoff and watershed behaviour. The morphometric analysis of the three sub-watersheds shows clear variation in drainage characteristics. W1 has the highest number of streams (574) and total stream length (199.8 km), indicating a well-developed drainage network, while W3 has the lowest values (**Table 2**). The bifurcation ratio ranges from 1.9 (W1) to 1.71 (W3), suggesting relatively greater structural influence in W1.

Mean channel length and valley length are highest in W1, reflecting more mature channel development, whereas W3 records the lowest values. Channel index is highest in W1 (1.3), indicating greater sinuosity. Basin perimeter is also largest in W1 (39.6 km), confirming it as the most extensive sub-watershed, while W3 is the smallest.

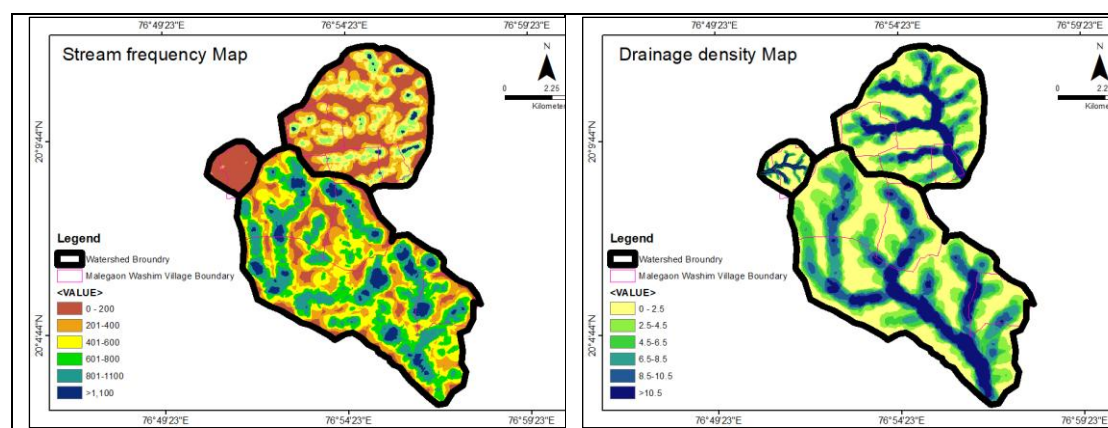
**Table 2: Linear morphometric parameters of sub-watersheds, Malegaon cluster, Washim**

Sr. no.	Morphometric parameter	Symbol	Unit	W1	W2	W3
1	No. of streams	Nu	No	574	272	25
2	Stream length	Lu	km	199.8	100.8	11.47
3	Bi-furcation ratio	Rb	-	1.9	1.8	1.71
4	Mean channel length	Cl	km	18.24	8.15	2.9
5	Valley Length	Vl	km	16.8	7.22	2.6
6	Channel Index	Ci	-	1.3	1.2	1.2
7	Minimum areal distance	Adm	km	14.08	6.55	2.36
8	Valley Index	Vi	-	1.19	1.10	1.10
9	Basin perimeter	P	km	39.6	23.3	7.94

### 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. The analysis reveals variation in basin shape and drainage characteristics among the three sub-watersheds. Basin area is highest in W1 (75.6 km<sup>2</sup>) and lowest in W3 (4.53 km<sup>2</sup>). Mean basin width is also greater in W2 (5.1 km). Form factor (Ff) and elongation ratio (Re) are highest in W3 (0.47 and 0.79), suggesting a comparatively more circular basin. W2 also circular basin and W1 indicating elongated shapes. Circularity ratio (Rc) is maximum in W3 (0.9), while compactness coefficient (Cc) is highest in W1(1.29), reflecting greater basin irregularity. Standard sinuosity index (Ssi) ranges from 1.09 (W1) to 1.13 (W2), indicating relatively higher channel sinuosity in W2.

Drainage parameters show that stream frequency (Fs) is highest in W1 (7.9 per km<sup>2</sup>) and lowest in W3 (6.84 per km<sup>2</sup>). Drainage density (Dd) in W2 (2.7 km/km<sup>2</sup>) but lower in W3(2.5 km/km<sup>2</sup>). Drainage intensity (Di) follows a similar trend, with the highest value in W1 (2.99). Length of overland flow (Lg) is greatest in W3 (0.2 km) and lowest in W2 (0.18 km), indicating shorter runoff travel distance in W2.



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

**Table 3: Areal morphometric parameters of sub-watersheds, Malegaon cluster, Washim**

Sr. No	Parameter	Symbol	Method/ Formula	Unit	W1	W2	W3
1.	Mean basin width	Wb	$Wb=A/Lb$	km	4.6	5.1	1.46
2.	Basin area	A	GIS Analysis	km <sup>2</sup>	75.6	36.73	4.53
3.	Relative perimeter	Pr	$Pr= A/P$	km	1.91	1.58	0.57
4.	Length area relation	Lar	$Lar = 1.4*A^{0.6}$	km <sup>2</sup>	18.7 6	12.17	3.47
5.	Lemniscate's	k	$K = Lb^2/A$	-	3.6	1.3	1
6.	Form factor	Ff	$Ff = A/Lb^2$	-	0.28	0.72	0.47
7.	Elongation ratio	Re	$Re = 2/Lb*(A/\pi)^{0.5}$	-	0.02	0.09	0.79
8.	Circularity ratio	Rc	$Rc = 12.57*(A/P^2)$	-	0.61	0.85	0.9
9.	Compactness coefficient	Cc	$Cc = 0.2841*P/A^{0.5}$	-	1.29	1.09	1.06
10.	Standard sinuosity index	Ssi	$Ssi = Ci/Vi$	-	1.09	1.13	1.12
11.	Stream frequency	Fs	$Fs = Nu/A$	Per km <sup>2</sup>	7.9	7.76	6.84
12.	Drainage Density	Dd	$Dd = Lu/A$	km/km <sup>2</sup>	2.6	2.7	2.5
13.	Drainage Intensity	Di	$Di = Fs/Dd$	-	2.99	2.83	2.7
14.	Length of Overland Flow	Lg	$Lg = A/2*Lu$	km	0.19	0.18	0.2

### Relief Aspects

The maximum basin height (Z) is highest in W1 (504 m) and lowest in W2 (499 m), while total basin relief (H) is also maximum in W1 (81 m) and minimum in W3 (28 m) (Table 4). Relief ratio (Rhl) is highest in W3 (13.3), indicating steeper terrain conditions, whereas W1 shows the lowest value (4.9). Relative relief ratio (Rhp) is greatest in W3 (352.6), followed by W1 and W2, suggesting higher relief intensity in W3. The ruggedness number (Rn) is maximum in W1 (0.24), reflecting more dissected and erosion-prone terrain, while W3 has the lowest value (0.08). Similarly, the Melton ruggedness number (MRn) is highest in W3 (13.2), indicating comparatively higher susceptibility to runoff and erosion processes.

**Table 4.: Relief morphometric parameters of sub-watersheds, Malegaon cluster, Washim**

Sr. No	Parameters	Symbol	Methods /Formula	W1	W2	W3
1.	Height of at basin mouth	z	DEM	423	457	474
2.	Maximum height of the basin	Z	DEM	504	499	502
3.	Total basin relief	H	$H = Z - z$	81	42	28
4.	Relief ratio	Rhl	$Rhl = H / Lb$	4.9	6.2	13.3
5.	Relative relief ratio	Rhp	$Rhp = H * 100 / P$	204.5	180.3	352.6
6.	Ruggedness number	Rn	$Rn = Dd*(H/1000)$	0.24	0.12	0.08
7.	Melton Ruggedness number	MRn	$MRn = H / A^{0.5}$	9.3	6.9	13.2

The slope distribution of the three sub-watersheds indicates noticeable variation in terrain characteristics. W1 is predominantly characterized by very gently sloping land (1-3%), covering 45.7% of the total area, followed by gently sloping land (3-5%) with 25.5%, and level to nearly level areas (0-1%) accounting for 19.1%. Moderately sloping areas (5–10%) occupy 9.6%, while moderately steep slopes (10-15%) are negligible (0.1%). In W2, the terrain is comparatively gentler, with very gently sloping land (1-3%) dominating the watershed (53.2%), followed by level to nearly level areas (0-1%) covering 22.3%, and gently sloping land (3-5%) accounting for 21.8%. Moderately sloping areas (5-10%) occupy only 2.6%, and moderately steep slopes are absent, indicating relatively smoother terrain compared to W1 and W3. In contrast, W3 shows a relatively more undulating terrain, where gently sloping land (3-5%) occupies the largest share (37.3%), followed by level to nearly level areas (0-1%) with 24.8%, and moderately sloping land (5-10%) covering 20.9%. Very gently sloping areas (1-3%) account for 14.8%, while moderately steep slopes are negligible. Overall, W2 is dominated by very gentle slopes, W1 by gentle to very gentle slopes, and W3 shows relatively higher moderately sloping terrain, indicating greater terrain variability in W3 compared to the other sub-watersheds.

Based on the morphometric characteristics, the three sub-watersheds exhibit different hydrological responses and erosion susceptibility, which require varied soil and water conservation strategies. In comparison with W2 and W3, W1 shows the highest number of streams, greater total stream length, highest stream frequency, drainage intensity, and ruggedness number, indicating a more dissected drainage network and greater susceptibility to runoff and soil erosion. Therefore, W1 requires relatively stronger structural interventions such as check dams, gully plugs, gabion structures, and percolation tanks along drainage channels, along with broad bed furrow (BBF) and vegetative barriers to reduce runoff velocity and control soil loss. W2, which has the highest drainage density and shortest length of overland flow, indicates quicker runoff concentration but relatively moderate relief conditions compared to W3. Hence, conservation measures in W2 should focus on runoff harvesting and groundwater recharge through farm ponds, contour trenches,

grassed waterways, and recharge structures. In contrast, W3 shows higher form factor, elongation ratio, circularity ratio, relief ratio, relative relief ratio, and Melton ruggedness number, indicating a more circular basin with steeper terrain and greater relief intensity compared to W1 and W2. These characteristics suggest a faster hydrological response and higher erosion risk in sloping areas; therefore, slope stabilization measures such as staggered contour trenches, afforestation, and terracing are more suitable in W3. Overall, compared to the other sub-watersheds, W1 requires stronger runoff control measures, W2 requires water harvesting and recharge structures, while W3 requires slope stabilization and erosion control practices.



