

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

(WDC-2.0)3/2021-22: Malegaon, Dist - Nashik



**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 sub regions of Maharashtra for formulation of scientific land use plans using geo-spatial techniques. This report presents a comprehensive understanding of soils of the watershed in terms of their physical and chemical characteristics, nutrient status, crop suitability and soil and water conservation requirements. It is expected that this report will serve as a valuable resource for land users, watershed planners, researchers and policy developers in rationalizing land use and for implementing ongoing agricultural development schemes.



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We are grateful to the Deputy Director General (NRM), Indian Council of Agricultural Research for his continuous support and guidance in successful completion of this project. We also sincerely thank the Assistant Director General (S&WM), NRM Division for his timely efforts and encouragement while implementing the project.

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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 Nashik (WDC-2.0) Village Cluster-watershed located in Malegaon Taluka of Nashik 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 programs in Karnataka, many states have started using soil/land data for rural development. Administrators at the national and state level(s) have recognized the significance of LRI and documented in the PMKSY 2.0 document that at least 10% area of the watersheds be covered under LRI in the plateau and upland region of the country. In addition to LRI, the agro-ecological zone approach is deemed to be most effective for regeneration of in-situ resources for sustaining the biological growth, and in turn soil health. Agro-ecological 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.

The project, planned for 48626 ha was implemented with the following objectives: (a) To characterize and map the soil and water resources of the watersheds (b) To assess the soil-site suitability of the crops based on land evaluation at watershed level, (c) To develop watershed-based alternate land use options, and soil and water conservation plans, and (d) To assess and characterize the groundwater potential of the watersheds. This report documents the LRI of the Nashik (WDC-2.0)3/2021-22 sub-watershed located in Malegaon taluka, along with the findings and planning framework of the watershed and groundwater assessment undertaken under the Pradhan Mantri Krishi Sinchayee Yojana - Watershed Development Component (PMKSY-WDC 2.0). Along with the information generated through a systematic survey, analysis and mapping, the watershed assessment is also based on officially available thematic layers, hydrological analysis, and watershed planning principles, for evaluating land and water resources, analyzing runoff behavior,

and proposing technically feasible soil and water conservation measures to improve in-situ moisture retention and groundwater recharge.

List of watersheds earmarked for LRI studies by the ICAR-NBSS&LUP

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

Note-MWS-Micro Watershed

CHAPTER 2

MALEGAON WATERSHED AT A GLANCE/GEOGRAPHICAL SETTINGS

2.1 Location and Extent

The watershed (Fig. 2.1) is located in Malegaon taluka, one of the administrative divisions of Nashik District, within the Nashik Revenue Division of Maharashtra. Malegaon Taluka is situated in the northeastern part of Nashik District and receives comparatively lower rainfall than the western parts of the district. Geographically, the watershed lies between 74.35° to 74.47° longitude and 20.66° to 20.75° latitude. The geology of the taluka is dominated by Deccan Trap basalt, characteristic of the hard rock terrain in much of Nashik District. The area forms a hydrologically connected unit within the Mausam River basin.

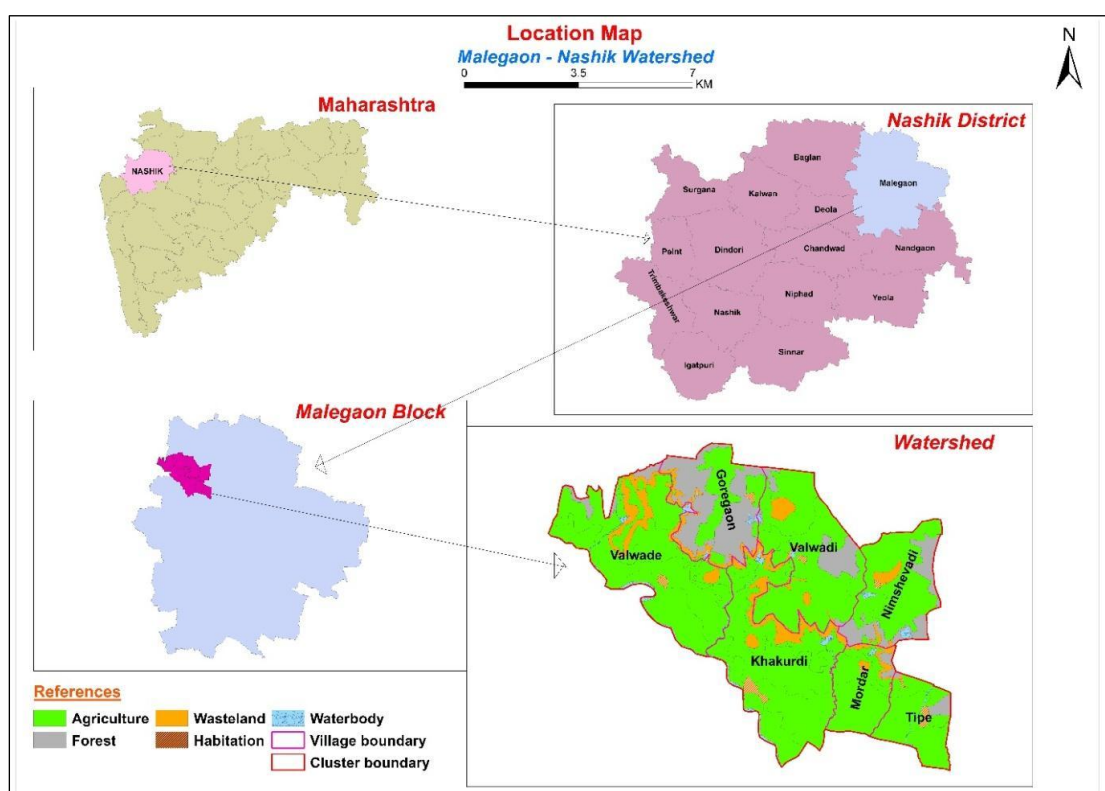


Fig. 2.1: Location map of the Malegaon watershed

Malegaon Taluka is predominantly rural, comprising dispersed villages with an agrarian economy largely dependent on rainfed agriculture. The landscape varies from gentle slopes in most areas to moderate relief in hill and ridge zones. Table 2.1 provides the general profile in respect of the watershed.

Table 2.1: Geographical and Administrative Profile

Sr. No.	Particulars	Details
1	District	Nashik
2	Taluka	Malegaon
3	Revenue division	Nashik
4	Total sub-watershed Area	6672 ha
5	Micro-watershed (cluster/treated) area	2760 ha
6	Villages	07 (Goregaon, Khakurdi, Mordar, Nimshevadi, Tipe, Valwade, Valwadi)
7	Major river	Mausam River
8	Climate	semi-arid to sub humid
9	Average annual Rainfall	627 mm

2.2 Geology

Malegaon, located in the northern part of Nashik district, is geologically part of the Deccan Volcanic Province, one of the world's largest continental flood basalt provinces. The area is predominantly underlain by the Basaltic lava flows of the Cretaceous-Eocene age, typically classified as tholeiitic basalts. These flows are commonly massive or vesicular in nature, with occasional amygdaloidal structures. Intertrappean beds-thin sedimentary layers comprising limestone, clay, or shale may occasionally be observed between lava flows, indicating quiescent periods during volcanic activity. The basaltic layers show columnar jointing and spheroidal weathering in places, and the overall lithology contributes to the formation of well-drained, shallow to moderately deep black soils, with patches of red soils on elevated terrains.

2.3 Geomorphology

Geomorphologically, Malegaon lies in a transitional zone between the Western Deccan Plateau and the valley plains formed by the Mausam River, a major tributary of the Girna River. The terrain is predominantly undulating to gently rolling, punctuated by low-lying basaltic hillocks and mesas, which are remnants of differential erosion of volcanic flows. The elevation ranges from approximately 400 to 600 meters above mean sea level. The alluvial plains along the Mausam River have relatively deeper soils and are more suitable for agriculture, while the plateau and upland areas show moderate to severe soil erosion, sparse vegetation cover, and shallow soil profiles. The region has a dendritic drainage pattern typical of basaltic terrains and comprises distinct geomorphic units including buttes, mesas, escarpments, hills and ridges, plateau tops, pediments, and pediplains.

2.4 Physiography and Soil

The landforms mentioned above govern surface runoff pathways, soil distribution, and infiltration behavior across the watershed. The lithology is predominantly basalt, which weathers into soils of varying depth and texture depending on slope position and degree of dissection. Slope values range from 0 to >75 %; however, a large proportion of the watershed area exhibits gentle slopes below 6%, while steeper slopes are confined to hills, ridges, escarpments, and mesa edges. The soils of the watershed, derived from basaltic parent material exhibit variation in texture, depth, and physical characteristics depending on topographic position. Based on texture, the soils are predominantly categorized into loamy classes, generally possessing moderate fertility and good moisture-holding capacity. However, during short-duration, high-intensity rainfall events, soils occurring on sloping landforms are susceptible to surface sealing and runoff generation, which may lead to localized soil erosion.

2.5 Climate

The watershed experiences a semi-arid to sub-humid climate, characteristic of the Deccan Plateau region. The climate is primarily governed by the southwest monsoon, which contributes the bulk of the annual rainfall, typically from June to September. The average annual rainfall in the watershed ranges from 600 mm to 800 mm, with significant inter-annual and spatial variability. The monsoon season accounts for approximately 80-90% of the total rainfall, making the watershed highly dependent on seasonal precipitation for agricultural and groundwater recharge activities. The rainfall pattern is often erratic, leading to concerns related to droughts and water scarcity. Temperature variations are moderate to high throughout the year. The summer season, extending from March to May, is 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 dropping to 10-12°C. Relative humidity is generally high during the monsoon (above 70%) and decreases significantly during the summer months. The region experiences high evaporation rates, particularly in the pre-monsoon period, contributing to water stress in the absence of adequate irrigation infrastructure.

2.6 Drainage

As mentioned above, the primary drainage channel in the Malegaon watershed is the Mausam River, a major tributary of the Girna River, which in turn drains into the Tapi basin. The Mausam originates in the western highlands near the Satmala ranges and flows in a general east to northeast direction through the watershed. It is joined by several seasonal and ephemeral tributaries, including the Aram and Panjhra streams, which enhance its discharge during the monsoon season. The drainage pattern exhibits moderate to high drainage density, influenced by the rugged topography and weathered basaltic

flows. The streams are generally flashy in behaviour due to the dominance of surface runoff and limited infiltration, reflecting poor to moderate permeability of the

2.7 Cropping Patterns, and Demography and Socioeconomics

2.7.1 Cropping Pattern

The cropping pattern in the Malegaon tehsil of the Nashik district is primarily characterized by a two-crop combination, with Bajra (pearl millet) and Maize being the most prominent crops. Because this eastern part of the district receives relatively lower rainfall, Bajra is a highly favored crop and forms a staple part of the local diet. The agricultural cycle is divided into distinct seasons: the Kharif season predominantly features crops like cotton and bajra, while the Rabi season includes wheat, jowar (sorghum), and gram (chickpea). Beyond traditional cereals, the region has a strong focus on commercial and horticultural agriculture. Villages surrounding Malegaon are major producers of onions, which, along with other vegetables, have been the primary cash crops in the area for decades.

2.7.2 Demographic and Socioeconomic Status

The demographic landscape of the Nashik and Malegaon cluster is a significant indigenous tribal community and a majority Hindu population with a smaller Muslim minority. Education levels are generally strong across the region, though the gender ratio shows fewer females than males overall. Within this broader context, Malegaon emerges as a distinct demographic and economic powerhouse. Fueled by heavy migration into its thriving textile and powerloom industries, Malegaon has transformed into a highly congested urban center. Strikingly different from the surrounding district, Malegaon city features a predominantly Muslim population. Additionally, this bustling textile hub boasts impressive literacy levels and a much more balanced gender ratio, making it a unique cultural and demographic pocket within the region.

2.8 Water Resources

2.8.1 Surface Water

Surface water in the watershed is primarily associated with the Mausam River and its network of seasonal streams, nalas, and small water bodies. Flow in these channels occurs predominantly during the monsoon season, while surface water availability is limited in the non-monsoon period. The watershed contains minor water-harvesting structures and seasonal ponds, which provide localized storage and contribute to groundwater recharge. Overall, surface water functions mainly as a runoff conveyance system, with limited capacity to sustain irrigation or domestic supply beyond the rainy season.

2.8.2 Groundwater

Groundwater occurs mostly in weathered and fractured zones of basalt rock. According to the Dynamic Ground Water Resources of Nashik District (CGWB), 2024, annual

extractable ground water resources place the region under the “safe” category, with the groundwater extraction level under 60%

2.8.3 Irrigation and Water Management

The water management landscape in the Nashik-Malegaon cluster is defined by a strategic shift from traditional, rain-dependent agriculture toward integrated conservation and macro-engineering projects. While the region is primarily drained by the, Mosam, rivers, seasonal conflicts between agricultural needs and urban drinking water mandates. There are 10 waterbodies that are available for irrigation, serving as the backbone for farming initiatives across the parched landscape.

2.9 Constraints

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

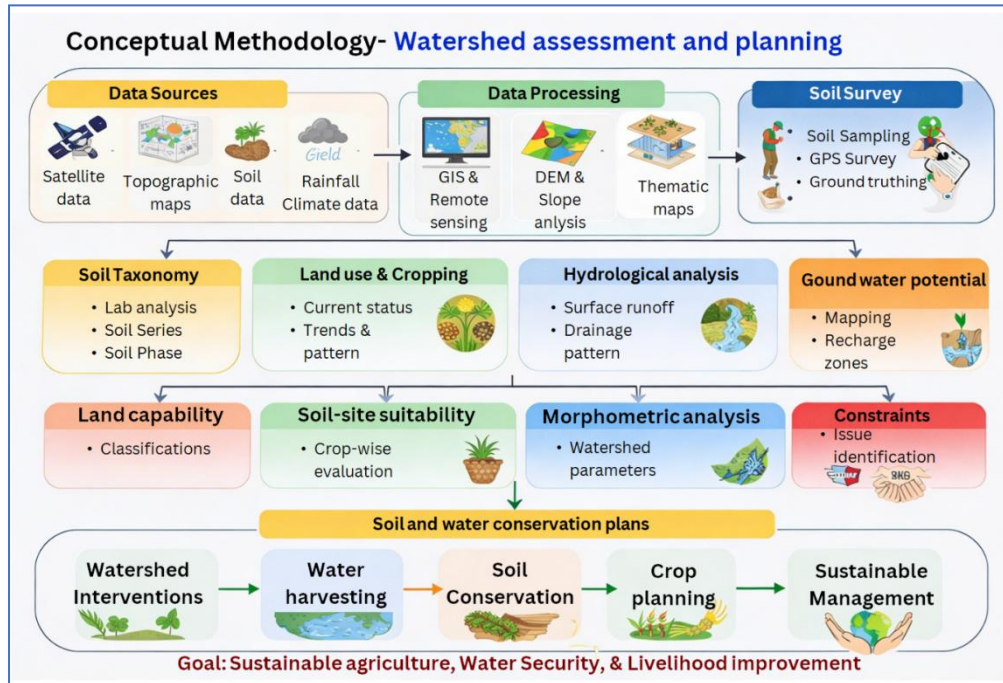
- a) Seasonal water scarcity due to limited and erratic rainfall.
- b) Inadequate structures for soil conservation.
- c) Depleting groundwater Levels.

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 (NH₄Oac) (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, and Demography and Socioeconomics

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

4.1.1 Irrigation and water management

The irrigation pattern (Fig. 4.1) in the Malegaon cluster of District Nashik reveals a strong dependence on wells, which account for 77% of irrigation sources across surveyed villages. Ponds contribute only 7%, while combined irrigation systems such as well + borewell (3%) and well + pond (2%) remain limited. Notably, 12% of households have no irrigation source, indicating high exposure to rainfall variability. Villages such as Khakhadi and Nimsewadi rely almost entirely on wells, whereas Tipe and Mordar show slightly more diversification through ponds and mixed sources. The overall pattern reflects restricted access to assured water infrastructure, which limits the capacity for stable year-round irrigation.

Seasonal water scarcity is a major concern in the Malegaon cluster, particularly during the rabi and summer months when well water levels decline sharply. Farmers without dependable irrigation often rely on rainfall or purchase tanker water, increasing production costs. Although some households have constructed farm ponds for supplemental storage, these interventions currently benefit only a small portion of farmers. To reduce vulnerability and improve irrigation reliability, the cluster requires broader adoption of rainwater harvesting, farm ponds, and micro-irrigation technologies.

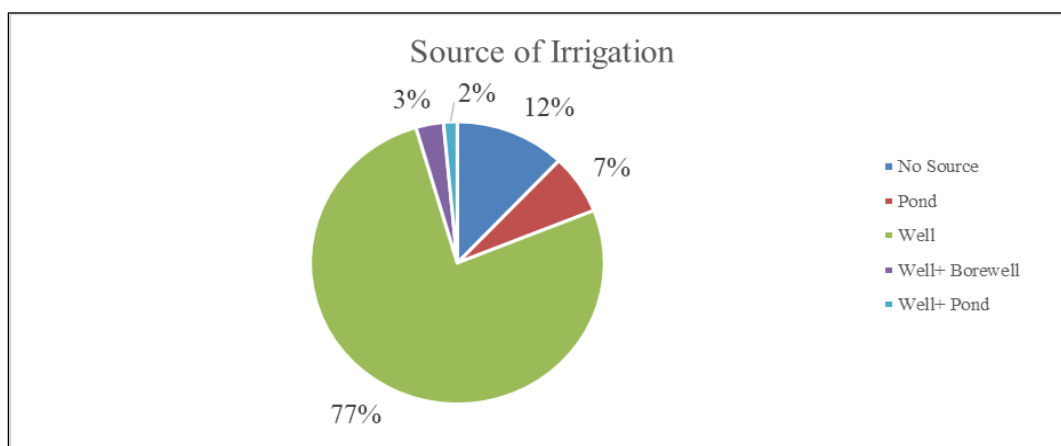


Fig. 4.1: Break-up of irrigation Sources in the watershed

4.1.2 Cropping Pattern

Cropping in the watershed is heavily dependent on monsoon rainfall. During the kharif season, farmers cultivate maize, sorghum, pearl millet, and pulses, while rabi crops include

wheat, chickpea, and onion. The cropping pattern in the cluster reveals a strong dominance of maize and onion cultivation, which together account for more than 82% of the total sown area. Horticulture has expanded in recent years, with pomegranate and onion gaining importance under irrigation schemes. Irrigation coverage is limited to valley pockets, while upland farming continues to be predominantly rainfed.

Based on the data obtained from about 200 farmers in the cluster (Table 4.1) maize contributes significantly to both household consumption and livestock fodder needs. Onion, cultivated mainly during the rabi season, occupies the highest cropped area and demonstrates exceptionally high productivity, making it the most profitable crop in the cluster. This trend is consistent with research showing that onion-based farming systems considerably enhance farmer income in Western Maharashtra. Pomegranate cultivation, though adopted by fewer farmers, plays an important role in income diversification and long-term economic stability. Traditional crops such as bajra, wheat, groundnut, and cotton continue to support food security and crop rotation needs. The observed shift toward high-value crops like maize, onion, and pomegranate reflects market opportunities and farmers' need to strengthen economic resilience in semi-arid agricultural systems

Table 4.1 Crop-wise Distribution in the Malegaon watershed

Sr. No.	Crop	Farmers interviewed (n)	Season	Area (ha)	Productivity (kg ha ⁻¹)
1	Pearl millet	61	Kharif	27.20	1453
2	Cotton	5	Kharif	6.62	10909
3	Maize	115	Kharif	138.24	6670
4	Onion	112	Rabi	139.24	26202
5	Pomegranate	14	Planting	14.24	10031
6	Wheat	20	Rabi	8.51	3290
7	Groundnut	5	Kharif	1.30	1508

4.1.3 Socioeconomic Status

4.1.3.1 Land holding pattern

The distribution of land holdings in the Nashik (Malegaon) watershed reveals a dominance of small and marginal farmers. From Table 4.2 it was observed that the total farmers interviewed, the highest number of farmers were observed in the small farmer category (1–2 ha), having 78 respondents (38.61%) with an average land holding of 1.60 ha which is followed by marginal farmers (<1 ha), having 71 respondents (35.14%) with an average holding of 0.82 ha. Medium farmers (4–10 ha) having 41 respondent (20.30%) with an average land holding of 5.60 ha, while semi-medium farmers (2–4 ha) having 12

respondents (5.95%) with an average land holding of 2.60 ha. No farmers were reported in large category (>10 ha).

Table 4.2 Land holding pattern in Malegaon watershed

Category	Criteria Land (ha)	No. of Farmers Interviewed (n)	Farmers (%)	Average Land Holding (ha)
Marginal Farmers	< 1	71	35.14%	0.82
Small Farmers	1 – 2	78	38.61%	1.6
Semi-Medium Farmers	2 – 4	12	5.95%	2.6
Medium Farmers	4 – 10	41	20.30%	5.6
Large Farmers	> 10	0	0%	0
Average Land Holding	—			2.65

4.1.3.2 Income distribution

The income distribution in the Nashik (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 (%)	Average Income (Rs.)
Bajra	61	8.11%	17488
Cotton	5	1.97%	163200
Maize	115	41.22%	192438
Onion	112	41.52%	325741
Pomegranate	14	4.25%	714200
Wheat	20	2.54%	33600
Groundnut	5	0.39%	25480
Total	132		

In Kharif, maize has the largest cropped area (41.22%) with an average income of 1,92,438 Rs, indicating its importance as a major income contributing crop in the watershed. Bajra covered 8.11% of the area with an average income of 17,488 Rs, indicating lower income. Cotton, cultivation only covers (1.97% area) with an average income of 1,63,200 Rs indicating higher income than the Bajra. Groundnut covers marginal areas (0.39%) an average income of 25,480.

In the Rabi season, onion has the largest cropped area (41.52%) with a an average income of 3,25,741 Rs, indicating its importance as a major income contributing crop in the watershed. Wheat covers the area of (2.54%) with an average income of ₹33,600.

Pomegranate, cultivated in 4.25% area and has the highest average income (₹7,14,200), indicating the potential of horticultural crops in the watershed.

The income pattern indicated that horticultural crops, particularly pomegranate and onion, significantly enhance farmers income compared to traditional cereal crops. The significant area covered by maize and onion reflects their adaptability and economic viability, while high-value perennial crops contribute to overall farm income.

4.1.3.3 Education

At the watershed level, the highest percentage of respondents have no education (30%), followed by primary education (25%), secondary (18%), and higher secondary (16%), while only 11% have completed higher studies.

Village-wise data (Table 4.4) has significant variations among villages. Village Valwadi has the highest illiteracy rate (60%) with no respondents attaining Higher Secondary or Higher Studies, highlighting significant educational deprivation. Khakhadi and Valwade each report 30% illiteracy, but Valwade shows a relatively higher proportion (19%) with Higher Studies. Mordar has the highest population under Primary education (40%) but only 1% with Higher Studies. Nimsewadi and Tipe has better educational attainment, with higher studies (20% and 18%) of respondents, respectively. Goregaon has a moderate education attainment, with primary education (30%) and Higher Studies (13%).

The watershed is characterized by low to moderate educational attainment, which may influence awareness levels, adoption of improved agricultural practices, and responsiveness to extension interventions.

Table 4.4 Education profile of villages in Malegaon watershed by population

Village	No Education (%)	Primary (%)	Secondary (%)	Higher Secondary (%)	Higher Studies (%)
Khakhadi	30	15	18	27	10
Mordar	14	40	18	27	1
Nimsewadi	27	25	14	14	20
Tipe	20	28	23	11	18
Goregaon	22	30	15	20	13
Valwade	30	20	15	16	19
Valwadi	60	15	25	0	0

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 4989.56 hectares, and constitutes approximately 74.8% of the total area (Table 4.5 and Fig. 4.2). Forested land cover accounts for 14% of the landscape, indicating a moderate presence of natural vegetation. Wastelands represent 8.26% of the area, which may indicate land degradation or areas unsuitable for cultivation. Waterbodies are limited to 127 ha, making up 1.91% 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

Land use	Area(ha)	Percent (%)
Agriculture	4989.56	74.81
Forest	936.62	14.04
Waterbody	127.14	1.90
Wasteland	550.91	8.26
Habitation	65.78	0.99
Total	6670.01	100.0

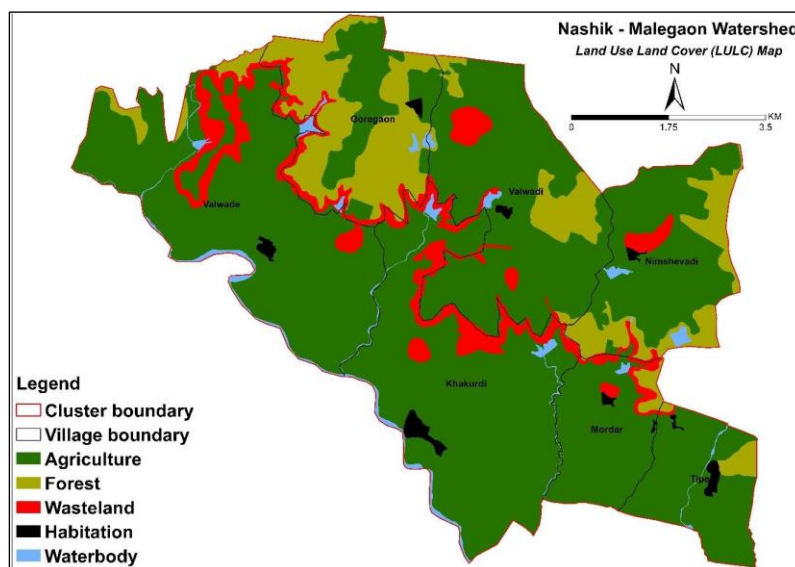


Fig. 4.2: Land-use/land-cover map

4.3 Landform Delineation

The landform analysis of the area indicates a diverse geomorphological setting. Plateau top is the most extensive landform (Table 4.6), covering 1803 ha, or 27 % of the total area. This is followed by the alluvial plain, encompassing 22.1 % of the watershed, indicating significant fluvial activity and fertile land. Hills and ridges occupy 1050 ha, accounting for 15.8 %, reflecting undulating and elevated terrain. The pediplain covers 882 hectares (13.2%), while the pediment, often representing gently sloping rock surfaces, spans 830.68 hectares. Escarpments are relatively less extensive (6.55% of the area), signifying steep slopes or breaks in the landscape. Overall, the area is characterized by a predominance of plateau and alluvial features, with a mixture of erosional and depositional landforms. The landform map of the watershed is presented in Fig. 4.3.

Table 4.6: Landform features existing in Malegaon watershed

Landform	Area(ha)	Percent (%)
Plateau Top	1802.7	27.0
Alluvial Plain	1473.9	22.1
Hills and Ridges	1050.5	15.8
Pediplain	882.3	13.2
Pediment	830.7	12.5
Escarpment	437.1	6.6
Waterbody	127.1	1.9
Habitation	65.8	1.0
	6670	100.0

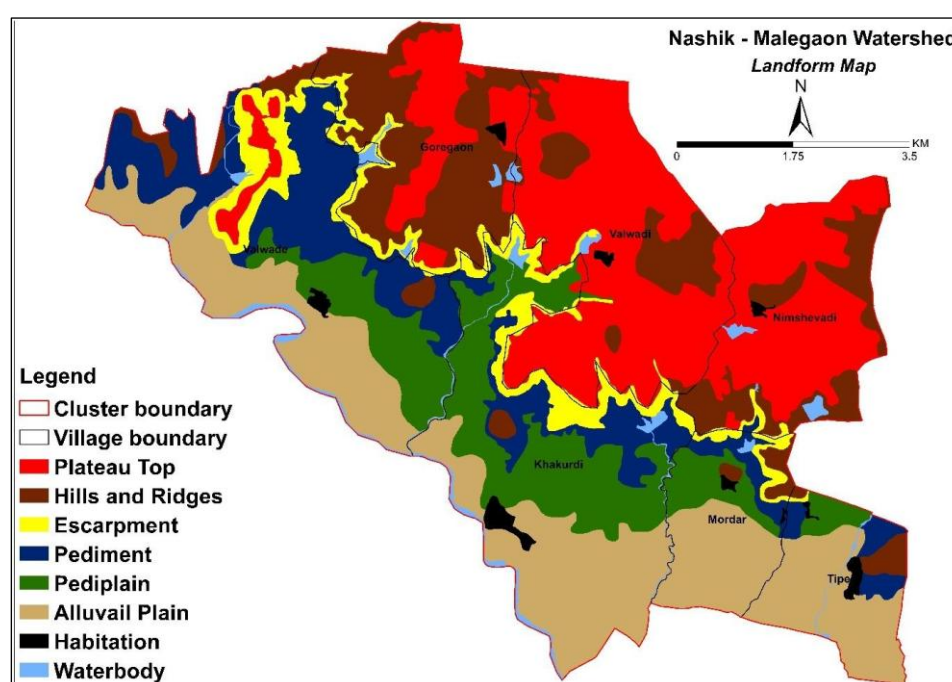


Fig. 4.3: Landform map of Malegaon watershed.

4.4 Soil series and phases

Nine soil series have been identified and mapped with 26 soil mapping units (phases of series) (Fig 4.4). The detailed descriptions of each series are given in Table 4.8.

Table 4.7. Dominant soil series identified in the watershed.

Sr. No.	Series	Area(ha)	Percent (%)
1	Mordad	1412.4	21.2
2	Nimshevadi	1327.5	19.9
3	Garegaon_1	1050.5	15.8
4	Walwadi	893.0	13.4
5	Ambasar	545.6	8.2
6	Garegaon	475.2	7.1

7	Valvada	437.1	6.6
8	Tippe	274.4	4.1
9	Waterbody	127.1	1.9
10	Habitation	65.8	1.0
11	Khakurdi	61.4	0.9
	Total	6670	100.0

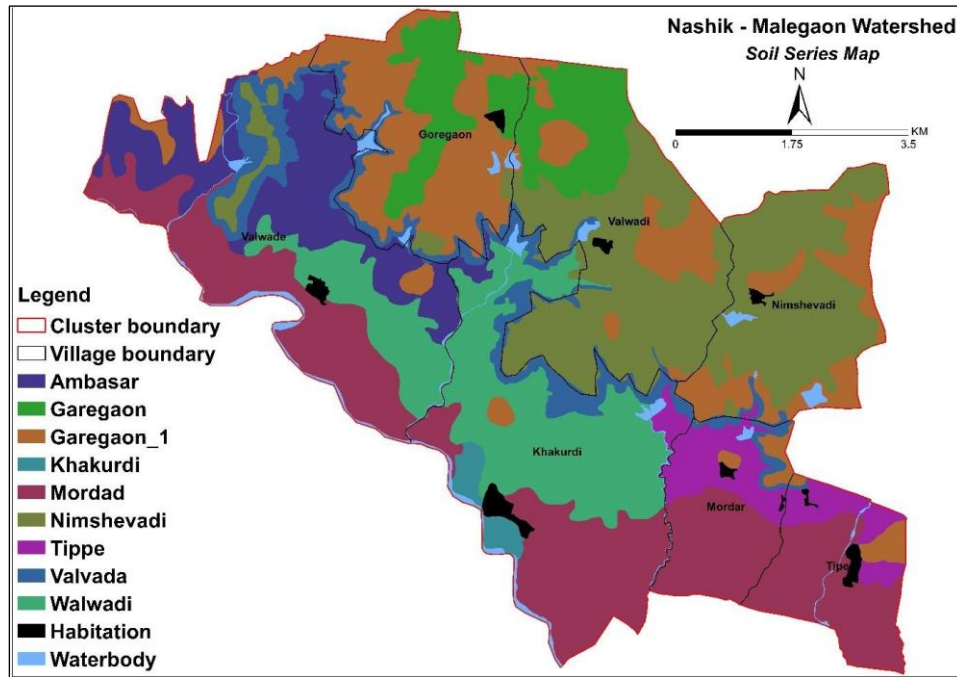


Fig. 4.4: Soil series map of Nashik-Malegaon watershed.

Table 4.8. Soil phases existing in Malegaon watershed.

Sr. No.	Phase	Area(ha)	Percent (%)
1	Gag1eD2g3	773.6	11.6
2	Mor5gB1	597.7	9.0
3	Nim1eB1g3	588.5	8.8
4	Nim1eD2g3	585.2	8.8
5	Wal4fB1g3	563.2	8.4
6	Mor5eD2g3	354.1	5.3
7	Gag1cD2g3	276.9	4.2
8	Mor5eB1g3	269.1	4.0
9	Val1cD3g3	258.4	3.9
10	Wal4fD2g3	245.8	3.7
11	Amb3eC2g3	244.8	3.7
12	Tip1eB1	240.9	3.6
13	Amb3B1	231.7	3.5
14	Gar2kB1g3	218.5	3.3
15	Gar2eD2g3	194.2	2.9

16	Val1eD3g3	178.7	2.7
17	Nim1dB1g3	153.8	2.3
18	Mor5dB1g3	153.2	2.3
19	Waterbody	127.1	1.9
20	Amb3dC2g3	69.2	1.0
21	Habitation	65.8	1.0
22	Gar2dB2g3	62.5	0.9
23	Kha5eB1n0	61.4	0.9
24	Tip1eD2g3	44.2	0.7
25	Wal4dD2g3	41.5	0.6
26	Mor5eD2	38.3	0.6
27	Wal4eD2g3	31.9	0.5
	Total	773.6	100.0

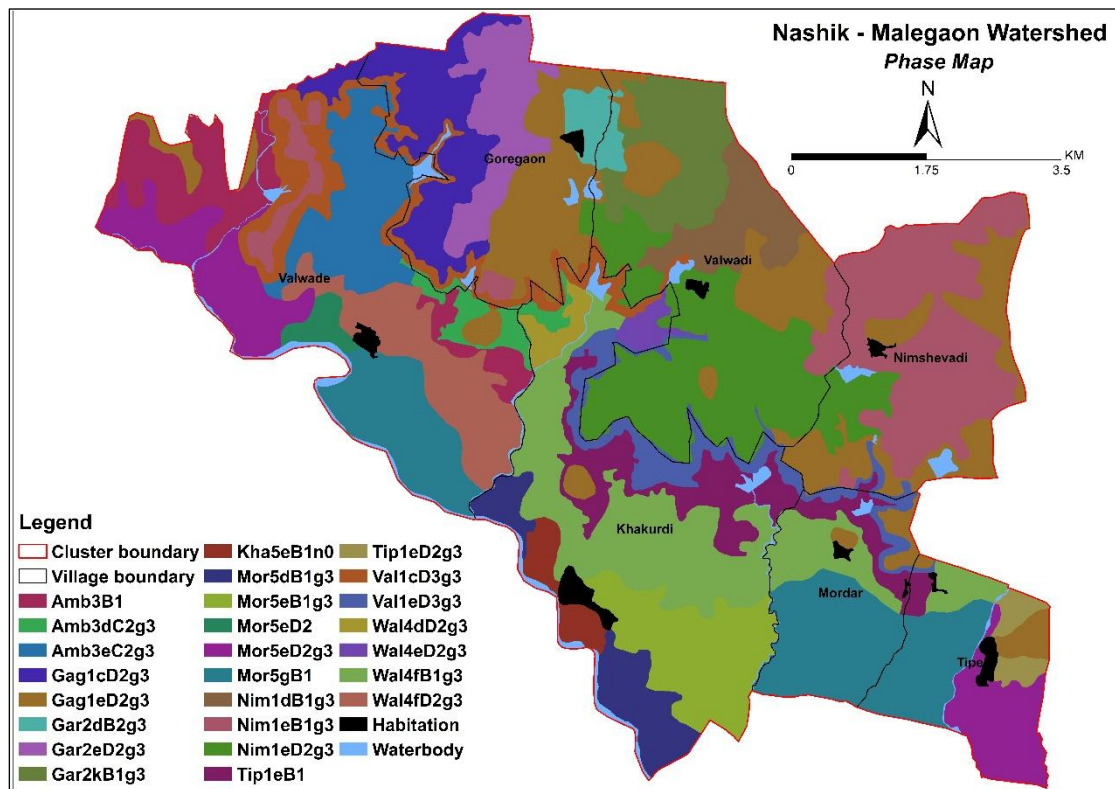


Fig. 4.5: Soil Phase map of Nashik-Malegaon watershed.

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. 4.6) the maximum area of watershed is under gently sloping (3-5%) i.e. 28.24% followed by very gently sloping (1-3%) i.e. 26.38%, moderately sloping (5-10%) i.e. 14.36%, level to nearly level (0-1%) i.e. 13.55%, moderately steeply sloping (10 - 15%) i.e. 10.70% and steeply sloping (15-25%) i.e. 0.99%.

Table: 4.9. Land slope classes in Malegaon watershed.

Sr. No.	Slope Class	Area (ha)	TGA (%)
1	Level to nearly level (0 - 1%)	903.7	13.6
2	Very gently sloping (1 - 3%)	1759.7	26.4
3	Gently sloping (3 - 5%)	1883.8	28.2
4	Moderately sloping (5 - 10%)	958.1	14.4
5	Moderately steeply sloping (10 - 15%)	713.5	10.7
6	Steeply sloping (15 - 25%)	258.4	3.9
7	Habitation	65.8	1.0
8	Waterbody	127.1	1.9
	Total	6670.0	100.0

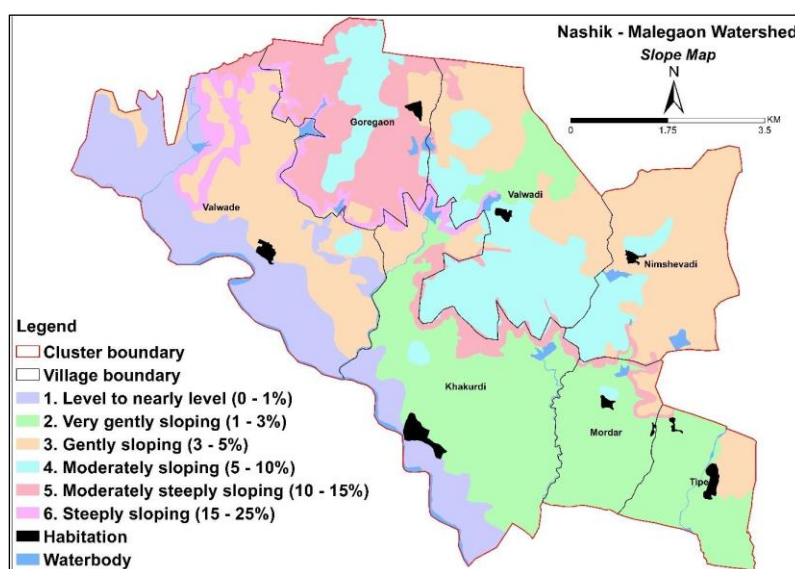


Fig. 4.6: Slope map of Nashik-Malegaon watershed

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 maintain soil structure and prevent further degradation. As 40% of the watershed area exhibits slope below 3%, erosion levels predominantly varied from very low to low (Table 4.10), followed by moderate (36.09%), indicating low erosion hazard in Malegaon watershed. While, 7.03% of the area, suffers from severe erosion (Fig. 4.7), particularly parts of the upper half of the watershed, calling for immediate attention.

Table 4.10: Soil erosion status in Malegaon watershed.

Sr. No.	Erosion class	Area (ha)	Percent (%)
1	None	276.9	4.2
2	Very Slight	3323.7	49.8
3	Moderate	2407.5	36.1
4	Severe	468.9	7.0
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
	Total	6670.0	100.0

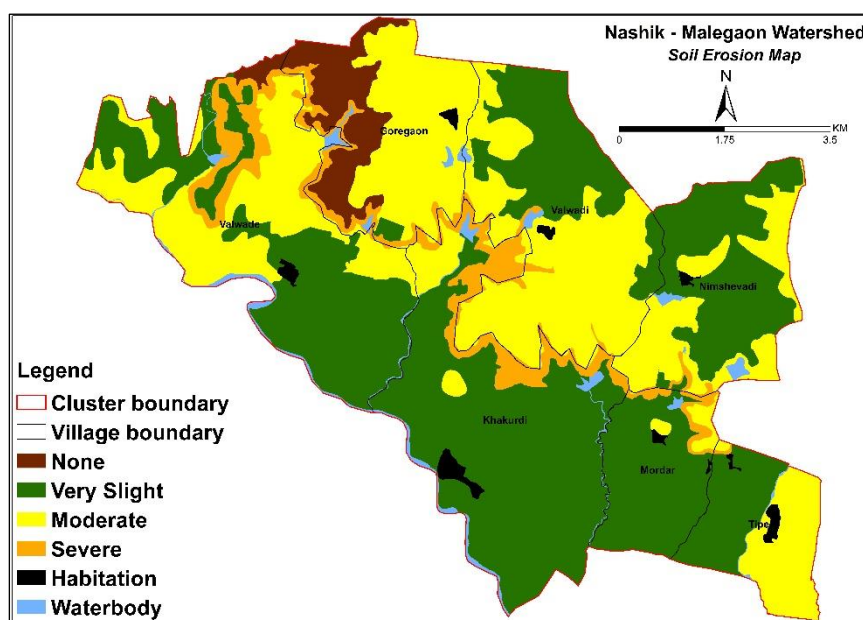


Fig. 4.7: Erosion map of Nashik-Malegaon watershed

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 ploughing, irrigation, or the addition of organic matter to improve soil depth and enhance crop performance. Understanding soil depth helps farmers make better decisions on crop selection, irrigation, and soil management, promoting more efficient and sustainable agricultural practices. The soil depth in the watershed (Fig. 4.8) varies from shallow (<25 cm) to deep (>75 cm). Area wise distribution of the data (Table 4.11) showed that maximum area was under moderately deep (38.07%) followed by shallow (34.88%), very deep (18.58%) and deep soils (5.58%).

Table 4.11. Soil depth classes in Malegaon watershed.

Sr. No.	Depth Class	Area (ha)	TGA (%)
1	Shallow (< 25) cm	2326.5	34.9
2	Moderate (25 - 50) cm	2539.0	38.1
3	Moderately Deep (50 - 75) cm	372.1	5.6
4	Deep (75 - 100) cm	1239.5	18.6
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
	Total	6670.0	100.0

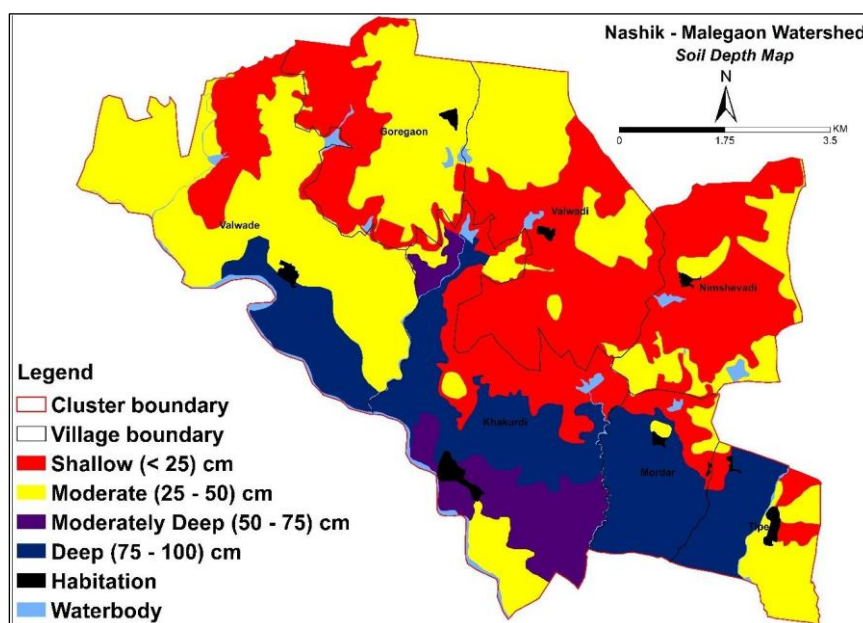


Fig. 4.8: Depth map of Nashik-Malegaon watershed

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. 4.9). Among the different classes silt loam texture was found in 54 % area followed by silty clay loam (12.43%), clay loam (12.13%), sandy loam (8.03%), loam (7.20%) and silty clay (3.28%). Based on the texture, the soils of the watershed, particularly the moderately deep to deep soils are expected to be fertile and produce good crops.

Table 4.12. Soil texture distribution in Malegaon watershed.

Sr. No.	Texture	Area (ha)	TGA (%)
1	Silt Loam	3604.8	54.1
2	Silty Clay Loam	829.4	12.4
3	Clay Loam	809	12.1
4	Sandy Loam	535.3	8.0
5	Loam	480.1	7.2
6	Silty Clay	218.5	3.3
7	Waterbody	127.1	1.9
8	Habitation	65.8	1.0

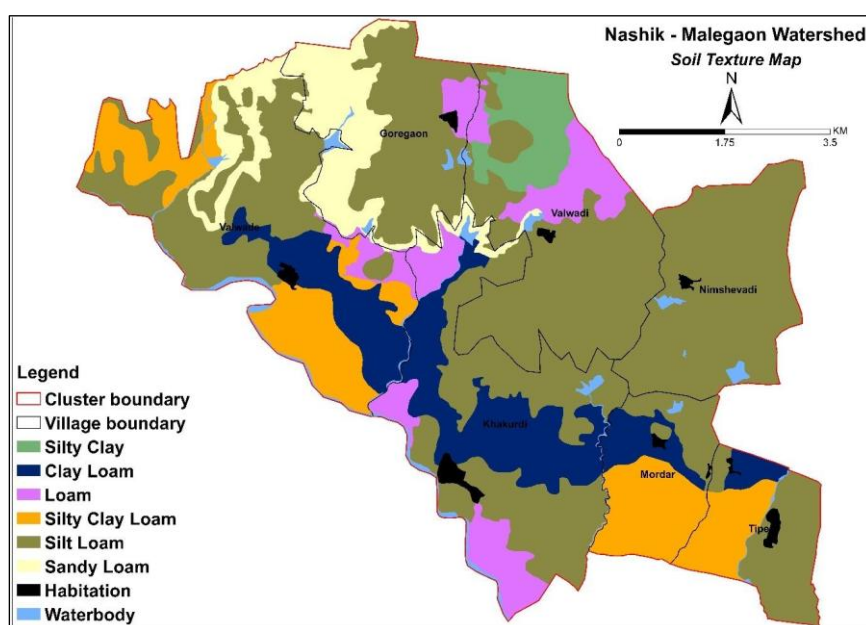


Fig. 4.9: Soil texture map of Nashik-Malegaon watershed

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. 4.10). The data revealed that soils in watershed are predominantly moderately alkaline in reaction

(pH 7.9-8.4) covering an area of about 55 % followed by slightly alkaline (pH 6.6-7.3) and strongly alkaline (pH 8.5-9.0).

Table 4.13. Soil pH distribution in Malegaon watershed.

Sr. No.	Soil pH	Area (ha)	TGA (%)
1	Neutral (6.6 - 7.3)	515.31	7.73
2	Slightly Alkaline (7.4 - 7.8)	1434.23	21.50
3	Moderately Alkaline (7.9 - 8.4)	3643.83	54.63
4	Strongly Alkaline (8.5 - 9.0)	883.71	13.25
5	Waterbody	127.14	1.90
6	Habitation	65.78	0.99
	Total	6670.01	100.0

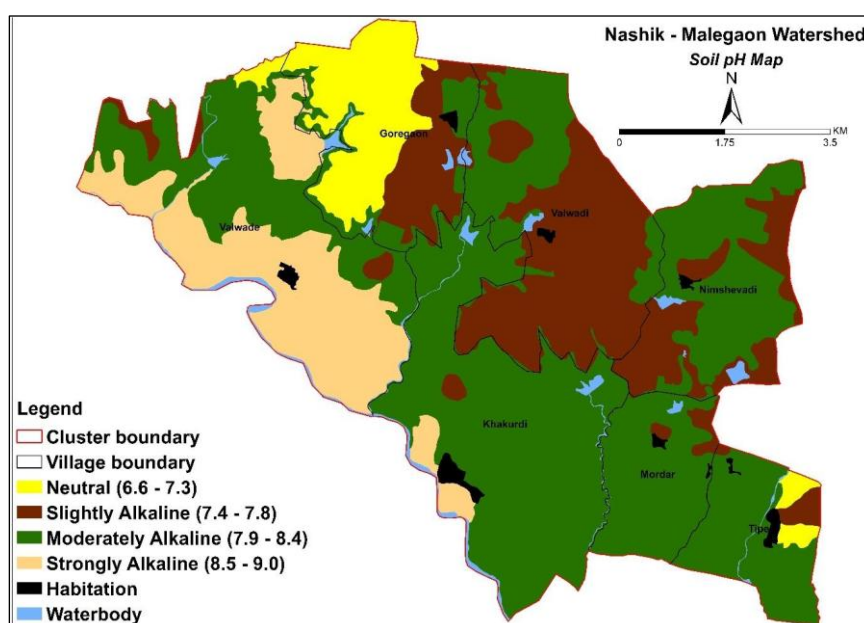


Fig. 4.10: Soil pH map of Nashik-Malegaon watershed

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 Malegaon watershed.

Sr. No.	Electrical conductivity (dSm ⁻¹)	Area (ha)	TGA (%)
1	Normal (0 - 1)	6477.09	97.11
2	Habitation	65.78	0.99
3	Waterbody	127.14	1.90
	Total	6670.01	100

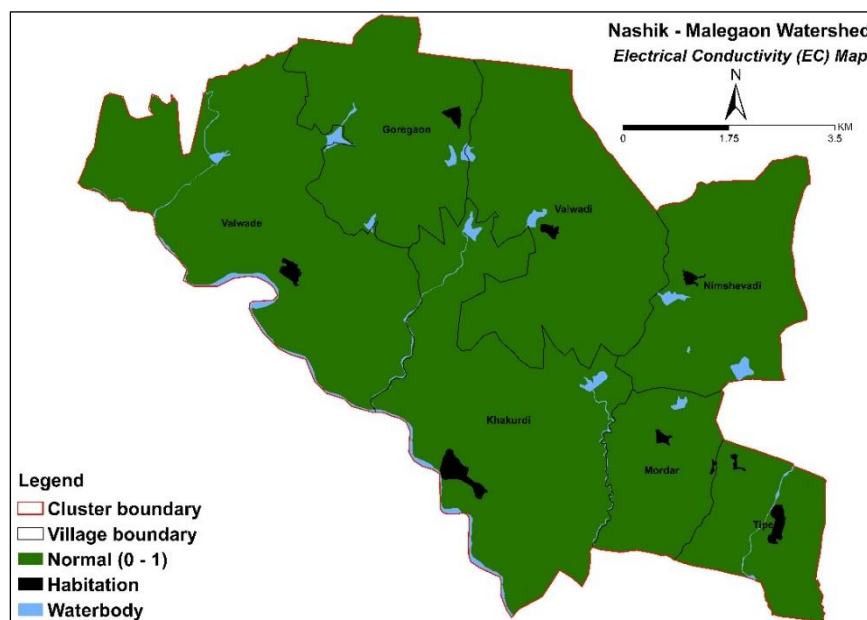


Fig. 4.11: Soil EC map of Nashik-Malegaon watershed

4.5.7 Calcium carbonate (CaCO₃) content

The soils of the watershed are generally calcareous in nature with the CaCO₃ content ranging from moderate to very high (>10%). Semi-arid climatic features with low rainfall and high PET favour release of substantial amount of alkali bicarbonates and carbonates into the soil solution, thereby rendering the soils calcareous. As can be inferred from Table 4.15 and Fig. 4.12, a large part of the watershed area (37 %) contains more than 10% CaCO₃ in soil, which could pose problems to normal crop growth.

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

Sr. No.	CaCO ₃ content (%)	Area (ha)	TGA (%)
1	Moderately High (2.0 - 5.0)	2268.73	34.01
2	High (5.0 - 10.0)	1720.41	25.80
3	Very High (> 10.0)	2487.95	37.30
4	Waterbody	127.14	1.90
5	Habitation	65.78	0.99
	Total	6670.01	100

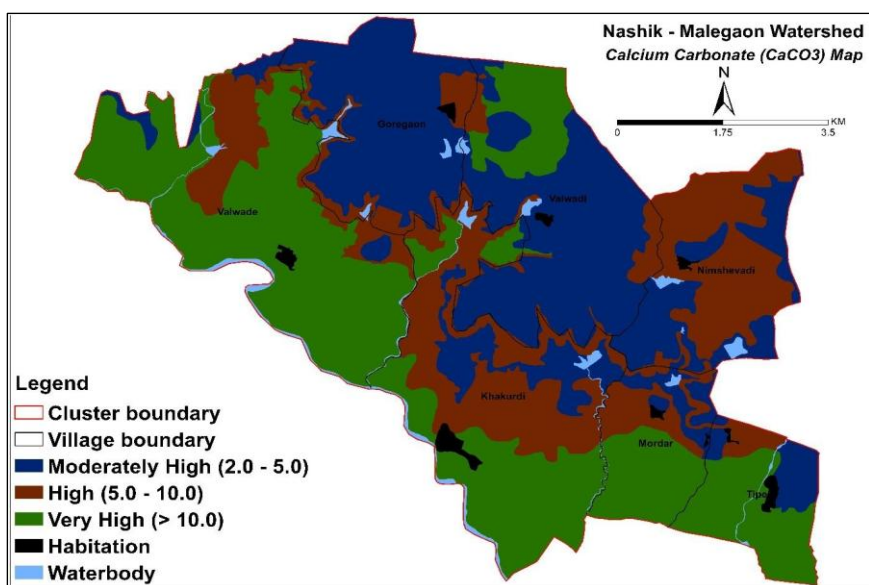


Fig. 4.12: Status of soil calcareousness in Nashik-Malegaon watershed

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 moderately high SOC content, which can be inferred from Table 4.16 and Fig. 4.13. This is also indicated by the moderate-deep soils and loamy texture prevalent in the watershed. However, there is an immense need for application of organic manures by the farmers in the watershed area in general, and in about 10% of the area exhibiting low SOC. High SOC content was found to occur in approximately 700 ha of the watershed.

Table 4.16. Soil organic carbon status of Malegaon watershed.

Sr. No.	Organic carbon (%)	Area (ha)	TGA (%)
1	Low (0.21 - 0.40)	617.50	9.26
2	Medium (0.41 - 0.60)	2627.04	39.39
3	Moderately High (0.61 - 0.80)	2551.82	38.26
4	High (0.81 - 1.00)	567.84	8.51
5	Very High (> 1.00)	112.90	1.69
6	Waterbody	127.14	1.90
7	Habitation	65.78	0.99
	Total	6670.01	100

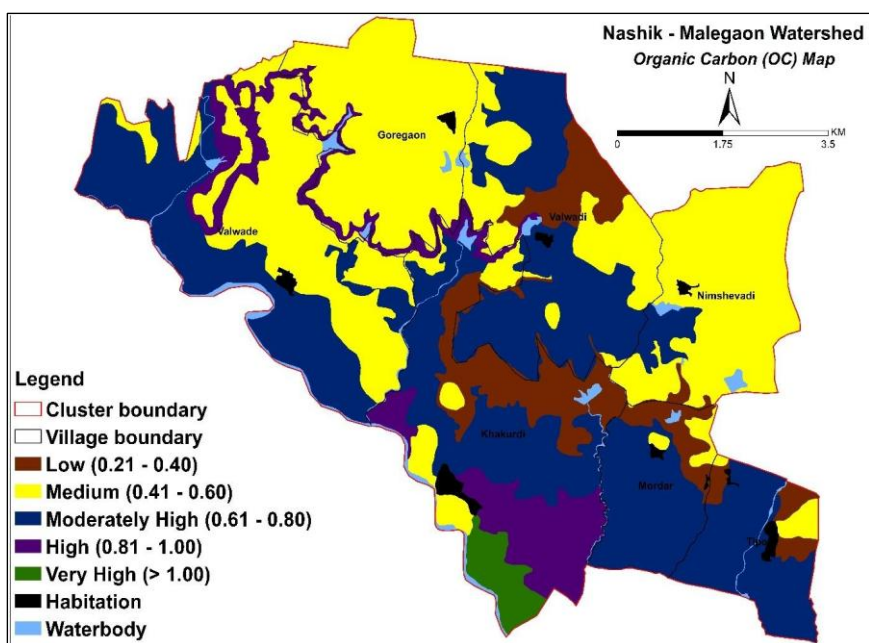


Fig. 4.13: Soil organic carbon map of Nashik-Malegaon watershed

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. 4.14, more than three-fourths of the watershed area registered low N values (140-280 kg ha⁻¹) whereas in 20% area, very low N content (<140 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 ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 140)	1340.58	20.10
2	Low (140 - 280)	5136.50	77.01
3	Waterbody	127.14	1.90
4	Habitation	65.78	0.99
	Total	6670.01	100

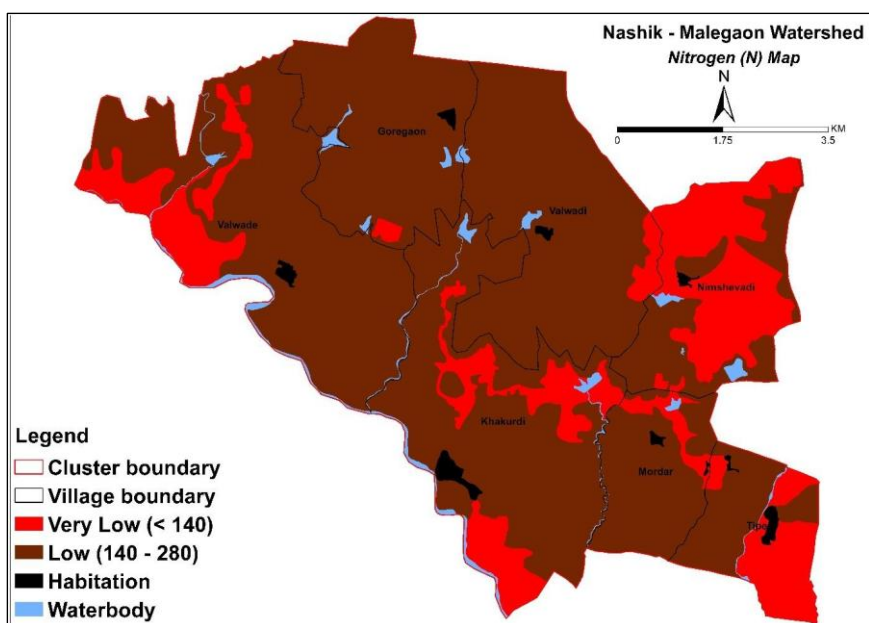


Fig. 4.14: Available soil nitrogen map of Nashik-Malegaon watershed

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. 4.15) ranged from very low (<15 kg ha⁻¹) to moderately high (51-65 kg ha⁻¹), with the highest area was under very low P status (64.55%) followed by moderately high (20.33%) and low (11.64%). 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 in soils of Malegaon watershed.

Sr. No.	Available P (kg ha ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 15)	4305.81	64.55
2	Low (16 - 30)	776.67	11.64
3	Medium (31 - 50)	38.27	0.59
4	Moderately High (51 - 65)	1356.34	20.33
5	Waterbody	127.14	1.90
6	Habitation	65.78	0.99
	Total	6670.01	100

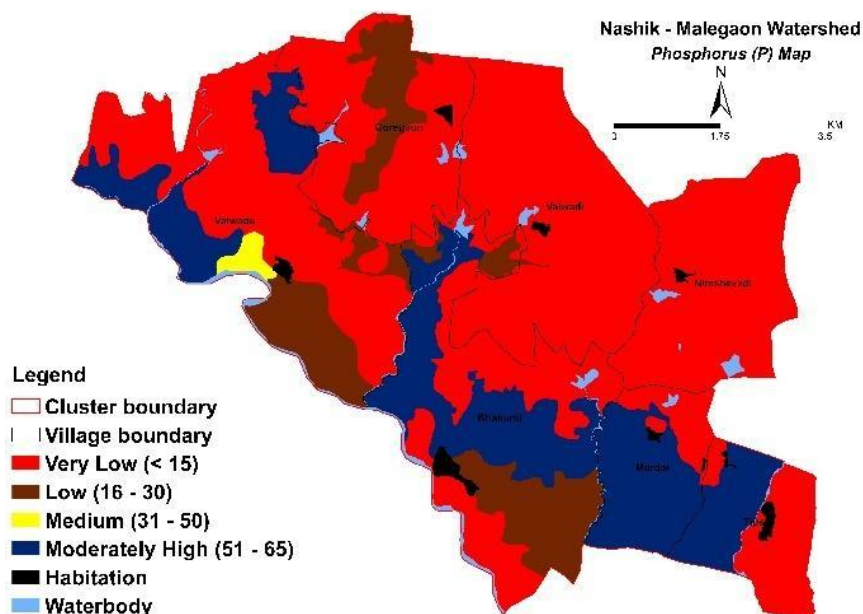


Fig.4.15: Available soil Phosphorus map of Nashik-Malegaon watershed*

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. 4.16) were observed in the watershed soils. Surprisingly, more than a quarter area of watershed was found to be under low category. Further, external application of potassic fertilizers is necessary for the combined area of 45% exhibiting low (121-180 kg ha⁻¹) to medium (181-240 kg ha⁻¹) K content.

Table 4.19: Available K content of soils of Malegaon watershed

Sr. No.	Available K (kg ha ⁻¹)	Area (ha)	TGA (%)
1	Low (121 - 180)	1903.77	28.54
2	Medium (181 - 240)	1101.73	16.52
3	Moderately High (241 - 300)	1800.70	27.00
4	High (301 - 360)	277.66	4.16
5	Very High (> 360)	1393.23	20.89
6	Waterbody	127.14	1.90
7	Habitation	65.78	0.99
	Total	6670.01	100

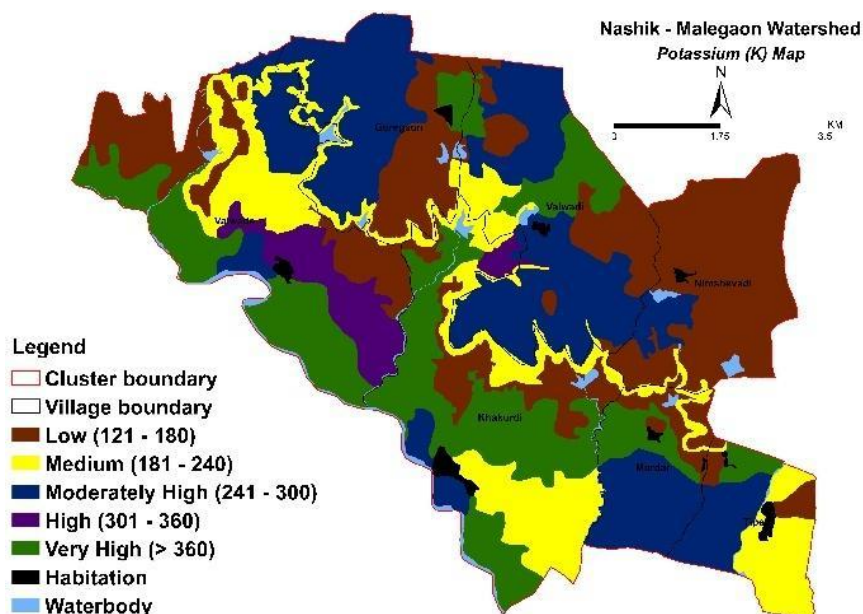


Fig. 4.16: Available soil Potassium map of Nashik-Malegaon watershed*

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. Five classes of available Fe were found in the watershed. Table 4.20 and Fig. 4.17 indicate that about 40% of the watershed area is deficient 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⁻¹) in DTPA-extractable Fe. Approximately 10% of the watershed was found to be deficient in plant-available Mn content, while majority of the area is adequately supplied with Mn (Table 4.21, Fig. 4.18). Soils of the entire watershed are sufficient with respect to DTPA-extractable Cu (Table 4.22, Fig. 4.19), whereas more than 65% of the soils exhibit deficiency in bioavailable Zn (Table 4.23, Fig. 4.20), 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 ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 2.5)	1078.59	16.17
2	Low (2.5 - 4.5)	1505.90	22.58
3	Medium (4.5 - 6.5)	1148.22	17.21
4	Moderately High (6.5 - 8.5)	1114.25	16.71
5	Very High (> 10.5)	1630.12	24.44
6	Waterbody	127.14	1.90
7	Habitation	65.78	0.99
	Total	6670.01	100

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

Sr. No.	Available Mn (mg kg ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 1.0)	662.34	9.93
2	Medium (1.3 - 5.0)	5307.87	79.58
3	Moderately High (5.0 - 7.0)	506.88	7.60
4	Waterbody	127.14	1.90
5	Habitation	65.78	0.99
	Total	6670.01	100

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

Sr. No.	Available Cu (mg kg ⁻¹)	Area (ha)	TGA (%)
1	Very High (> 1.0)	6477.09	97.11
2	Waterbody	127.14	1.90
3	Habitation	65.78	0.99
	Total	6670.01	100

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

Sr. No.	Available Zn (mg kg ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 0.3)	1306.47	19.59
2	Low (0.3 - 0.6)	3096.78	46.43
3	Medium (0.6 - 0.9)	1025.71	15.38
4	Moderately High (0.9 - 1.2)	832.31	12.48
5	High (1.2 - 1.8)	61.43	0.92
6	Very High (> 1.8)	154.40	2.31
7	Waterbody	127.14	1.90
	Total	14237.9	100.0

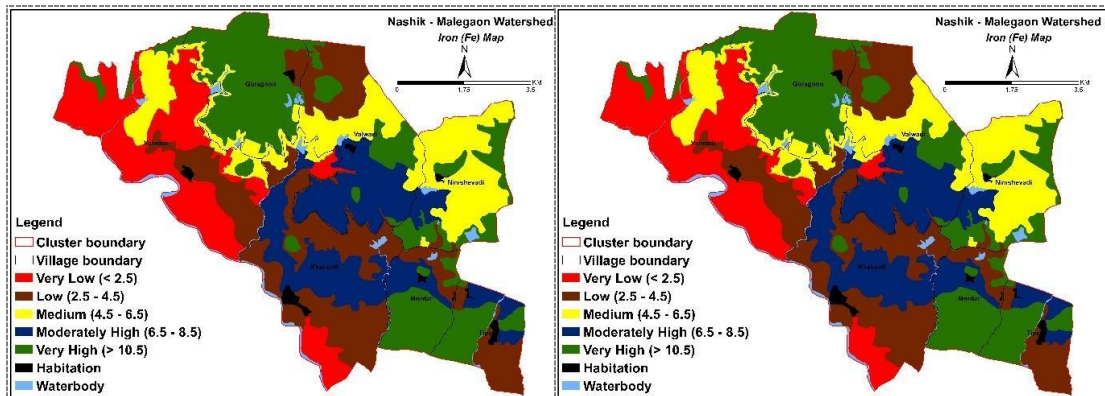


Fig. 4.17: DTPA-extractable soil Fe map of Nashik-Malegaon watershed

Fig. 4.18: DTPA-extractable soil Mn map of Nashik-Malegaon watershed

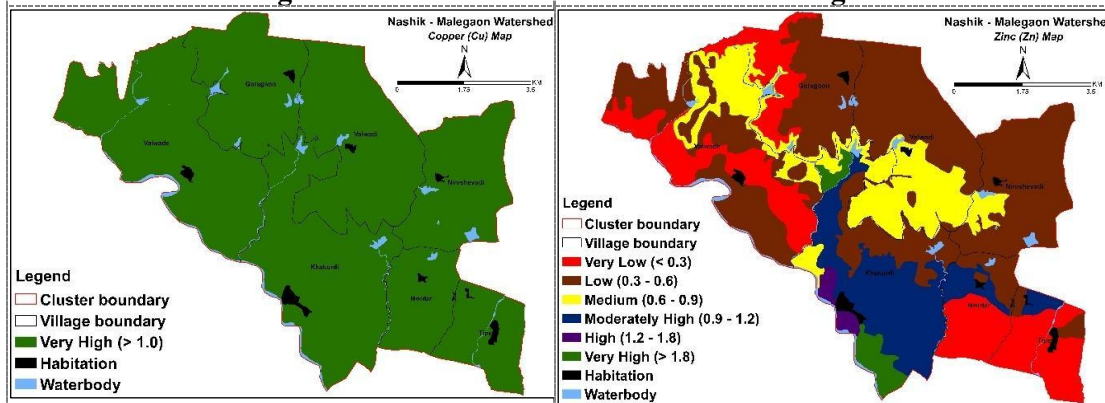


Fig. 4.19: DTPA-extractable soil Cu map of Nashik-Malegaon watershed

Fig. 4.20: DTPA-extractable soil Zn map of Nashik-Malegaon watershed

4.6 Surface Runoff

Surface runoff, a critical component in the hydrological cycle, plays a significant role in water resource management and environmental sustainability. Understanding and accurately estimating runoff is crucial for the development and management of water resources in any region. Runoff in a watershed is influenced by several factors, including rainfall characteristics, terrain features, soil properties, and land use/land cover. Table 4.24 shows a considerable variation in monthly runoff across the 10 years considered for the computation. The highest monthly average runoff occurred in September, with 112.2 mm of runoff, corresponding to the peak of the monsoon season when rainfall intensity is typically highest. Conversely, the lowest monthly average runoff was observed in June and October, reflecting the dry conditions that precede and follow the monsoon period. This highlights the seasonal variability in runoff, driven primarily by rainfall distribution during the year.

In terms of yearly runoff, significant variability was observed, with the maximum yearly runoff recorded in 2021, when the total runoff was 158.8 mm, representing 17.1 % of the total rainfall (Table 4.25). The year 2014, however, experienced the lowest runoff, with only 3.9 mm of runoff, which accounted for just 0.8 % of the rainfall. Over the entire study period from 2014 to 2024, the average runoff was calculated to be 8.4 % of the total rainfall.

This variability in runoff highlights the sensitivity of the watershed to changes in rainfall patterns and emphasizes the importance of considering both the amount and intensity of rainfall when estimating runoff. The yearly and monthly variation in rainfall and runoff are depicted in Fig. 4.21 and 4.22.

The study also analyzed the frequency of runoff events, which varied considerably from year to year. The number of runoff events ranged from 1 to 21, with the year 2020 experiencing the highest number of events. On the other hand, 2023 had the lowest number of runoff events. No clear trend was observed in the number of runoff events across the study period, suggesting that factors such as the intensity and distribution of rainfall, rather than just the total amount of rainfall, play a significant role in determining the frequency of runoff events.

A key takeaway from the exercise is that the region experiences highly erratic rainfall patterns, both in terms of intensity and distribution. The monsoon season exhibits significant variability, with some years experiencing heavy rainfall and high runoff, while others witness much drier conditions. This unpredictability makes it challenging to forecast runoff and plan for water resource management in the watershed. As a result, this study underscores the importance of adaptive management strategies that can accommodate such variability in runoff patterns.

The runoff estimation method provides valuable insights into the hydrological dynamics of the watershed and highlights the need for more detailed analysis of local hydrological conditions, as runoff is influenced by a complex interplay of factors that can vary greatly across different parts of a watershed.

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

Year/Month	June		July		Aug		Sept		Oct	
	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)
2014	23.7	0.0	137.9	3.3	76.7	0.0	101.0	0.6	4.3	0.0
2015	122.5	0.1	59.4	0.0	68.4	0.0	169.7	29.5	24.9	0.0
2016	69.0	0.0	140.0	5.5	49.1	0.0	166.9	42.5	64.7	0.0
2017	135.2	1.9	117.8	0.0	87.0	0.9	88.8	0.9	83.8	5.0
2018	137.4	2.0	83.9	0.0	116.1	25.1	14.3	0.0	0.0	0.0
2019	55.3	0.0	185.7	7.2	167.5	2.0	212.6	22.1	142.1	2.8
2020	298.5	42.1	226.5	34.9	136.8	3.9	259.6	36.4	13.8	0.0
2021	148.6	0.0	106.4	5.4	187.3	35.2	334.1	112.2	22.3	0.8
2022	180.7	17.0	235.0	37.5	160.0	20.1	228.1	37.6	74.2	0.0
2023	63.4	0.0	133.0	0.0	37.9	0.0	191.3	9.9	3.8	0.0
2024	147.1	0.2	176.0	0.1	248.3	55.3	120.6	1.5	135.1	6.9
Average	125.6	5.8	145.6	8.5	121.4	13.0	171.5	26.7	51.7	1.4

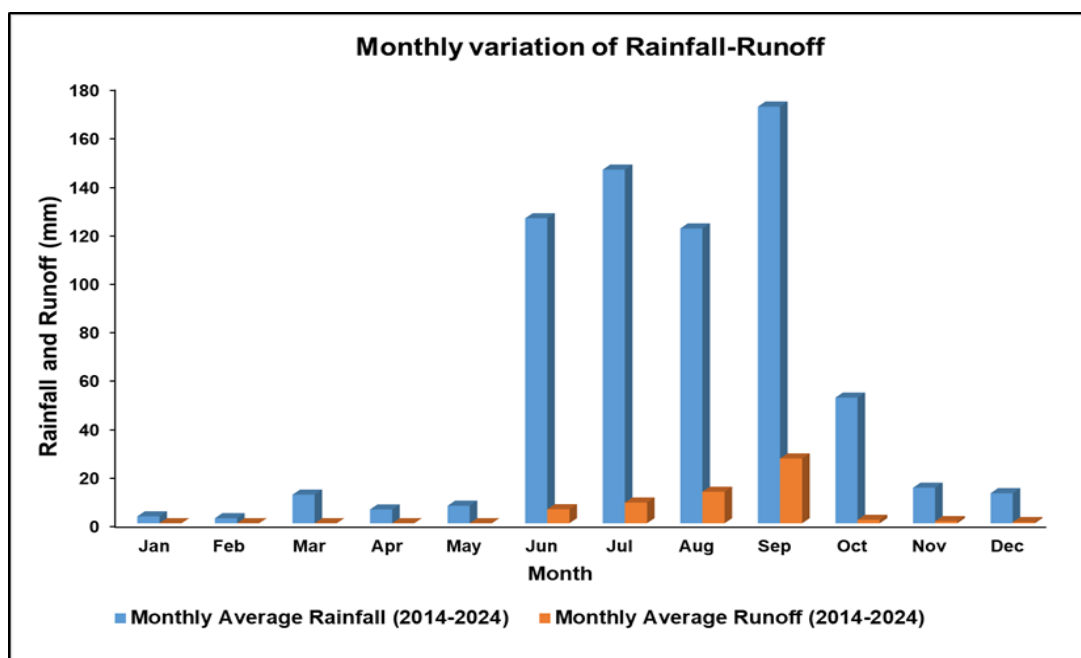


Fig 4.21: Monthly variation of rainfall-runoff in Malegaon watershed

Table 4.25. Relationship between rainfall and runoff.

Year	Rainfall (mm)	Runoff (mm)	No. of Runoff Events	Runoff (%)
2014	504.2	3.9	3	0.8
2015	496.9	29.6	3	6.0
2016	514.5	48.1	4	9.3
2017	527.0	8.8	7	1.7
2018	366.1	27.1	3	7.4
2019	866.5	43.3	12	5.0
2020	956.7	117.2	21	12.2
2021	926.1	158.8	17	17.1
2022	886.6	112.1	18	12.6
2023	505.3	9.9	1	2.0
2024	846.4	63.9	9	7.5
Average	672.4	56.6	9	8.4

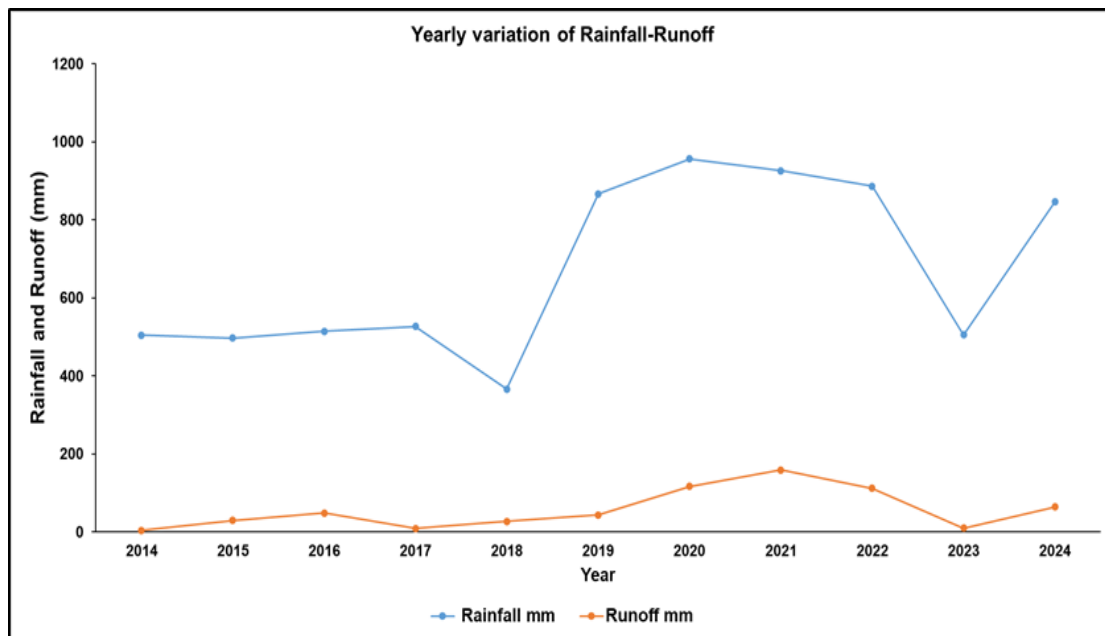


Fig 4.22: Yearly variation of rainfall-runoff in Malegaon watershed

4.7 Mapping of Groundwater Potential Zones

Groundwater is a crucial resource that supports various socio-economic activities within a watershed, including agriculture, industry, and domestic water supply. Its role in sustaining these activities makes it essential for ensuring the livelihoods of the communities living in these regions. However, the availability and distribution of groundwater are not uniform across different areas, as it varies spatially and temporally. This uneven distribution poses significant challenges for effective groundwater management, particularly in regions where the demand for water exceeds the natural supply. The Malegaon watershed, which covers seven villages, represents a region where groundwater management is especially important due to its varied potential for groundwater availability. Mapping of groundwater potential zones was done within the Malegaon watershed,

The results of the assessment indicate that the groundwater potential varies significantly across the watershed. According to the final groundwater potential map (Fig. 4.23), 13.8 % of the region is classified under “very poor groundwater potential”, 24.3 %, under “poor groundwater potential”, 28.2 % under “moderate groundwater potential”, 28.9 % under “good groundwater potential” and 4.9 % under “very good groundwater potential”. Therefore, approximately 33.8% of the watershed area exhibits good to very good groundwater potential. The assessment concludes that the integrated approach utilizing AHP and the weighted sum method facilitates a systematic assessment of groundwater potential, aiding in the identification of priority areas for conservation, recharge, and sustainable utilization of groundwater resources.



Fig. 4.23. Ground water potential zones in 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) representing current or 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) 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 Sorghum (jowar) Cultivation

The soils of the watershed were evaluated for jowar cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.26. The results indicate that 1239.5 ha (18.6% of the total geographical area, TGA) are classified as highly suitable (S1) for jowar cultivation, providing favorable soil and site conditions for optimal crop growth.

The moderately suitable (S2) category covers 372.1 ha (5.6% of TGA), where minor soil and environmental constraints may moderately influence crop productivity. A substantial portion of the watershed, 2648.5 ha (39.7% of TGA), falls under the marginally suitable (S3) class, reflecting moderate to severe limitations related to soil fertility, soil physical properties, and terrain, which may restrict yield potential unless appropriate agronomic management practices are adopted.

Table 4.26 Area under different suitability sub-classes for sorghum cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Highly Suitable (S1)	1239.5	18.6
2	Moderately Suitable (S2)	372.1	5.6
3	Marginally Suitable (S3)	2648.5	39.7
4	Not Suitable (N)	2217.0	33.2
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
Total area		6670.0	100.0

2217.0 ha (33.2% of TGA) of the study area is classified as not suitable (N) for jowar cultivation due to severe soil and site constraints. Overall, the evaluation suggests that nearly one-fourth of the watershed is highly to moderately suitable for jowar cultivation,

whereas a significant proportion is marginally suitable or unsuitable, emphasizing the importance of appropriate land-use planning and soil and water management interventions.

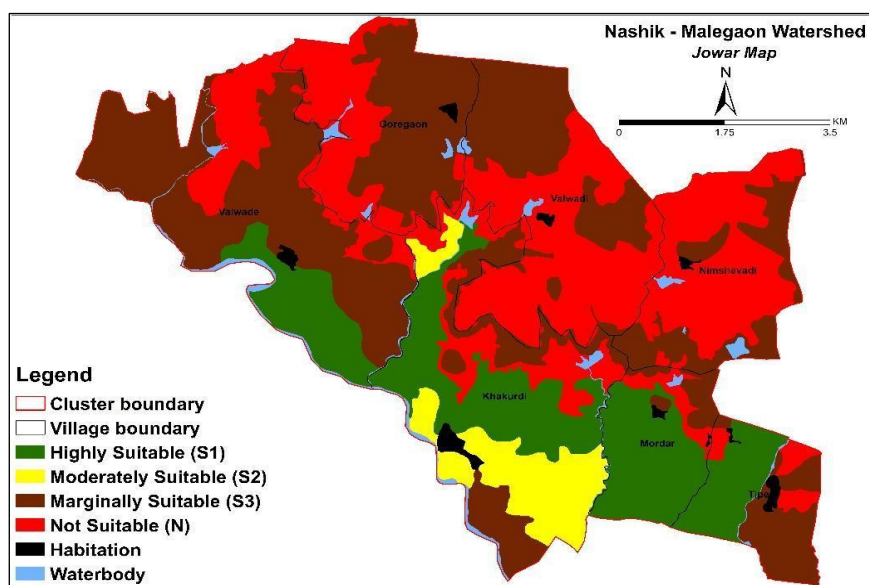


Fig. 4.24 Soil site suitability map for sorghum (jowar) Cultivation

4.8.2 Soil-Site Suitability for Maize Cultivation

The soil site suitability analysis for maize cultivation indicates that 676.3 ha (10.1% of the total geographical area, TGA) is classified as highly suitable (S1), providing optimal conditions for crop growth and productivity. Moderately suitable (S2) areas cover 372.1 ha, accounting for 5.6% of the TGA, where minor soil and environmental limitations may moderately influence crop performance.

A major portion of the study area, amounting to 3102.2 ha (46.5% of TGA), falls under the marginally suitable (S3) category. These areas are constrained by moderate to severe limitations related to soil fertility, soil physical properties, and terrain, which may restrict yield potential without appropriate management interventions. In contrast, 2326.5 ha (34.9% of TGA) are classified as not suitable (N) for maize cultivation due to severe constraints such as unfavorable soil conditions, slope, and drainage limitations.

Table 4.27 Area under suitability sub-classes for Maize Cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Highly Suitable (S1)	676.3	10.1
2	Moderately Suitable (S2)	372.1	5.6
3	Marginally Suitable (S3)	3102.2	46.5
4	Not Suitable (N)	2326.5	34.9
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
Total area		6670.0	100.0

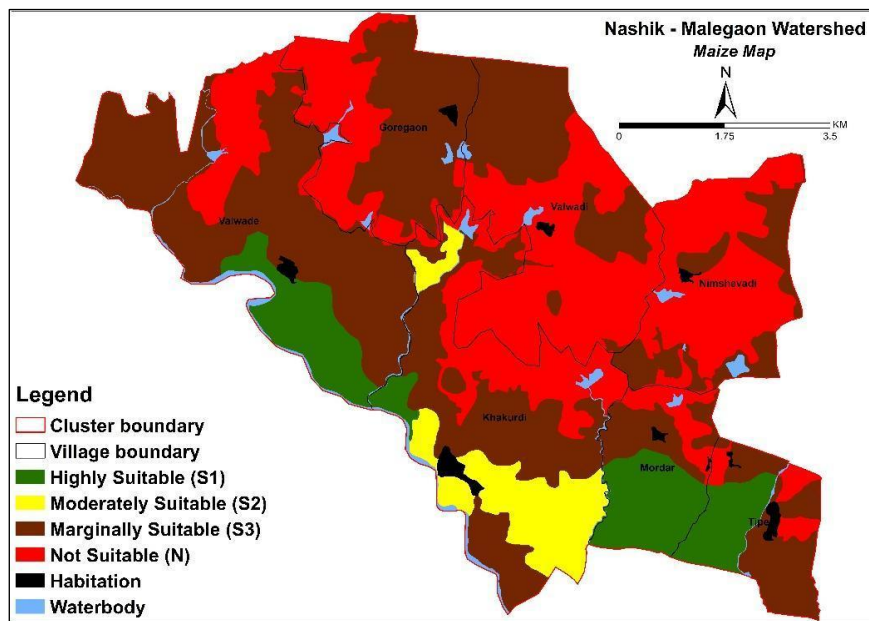


Fig. 4.25 Soil site suitability map for Maize Cultivation

4.8.3 Soil-Site Suitability for Pearl millet (bajra) Cultivation

The soils of the watershed were evaluated for bajra cultivation in accordance with crop-specific requirements. The distribution of suitability classes is presented in Table 4.28. The results indicate that 636.0 ha (9.5% of the total geographical area, TGA) are classified as highly suitable (S1) for bajra cultivation, offering favorable conditions for optimum crop growth and productivity.

A considerable portion of the study area, 1044.7 ha (15.7% of TGA), falls under the moderately suitable (S2) category, where certain soil and site-related limitations may moderately affect crop performance. The marginally suitable (S3) class occupies 2648.5 ha (39.7% of TGA), reflecting moderate to severe constraints primarily associated with soil and environmental factors, which may restrict yield potential without appropriate management practices.

Furthermore, 2147.9 ha (32.2% of TGA) of the watershed is categorized as not suitable (N) for bajra cultivation due to severe limitations. Overall, the assessment highlights that although a portion of the watershed is suitable for bajra cultivation, a significant share is marginally suitable or unsuitable, emphasizing the need for proper land-use planning and soil and water conservation measures.

Table 4.28 Area under suitability sub-classes for Pearl millet Cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Highly Suitable (S1)	636.0	9.5
2	Moderately Suitable (S2)	1044.7	15.7
3	Marginally Suitable (S3)	2648.5	39.7
4	Not Suitable (N)	2147.9	32.2
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
	Total area	6670.0	100.0

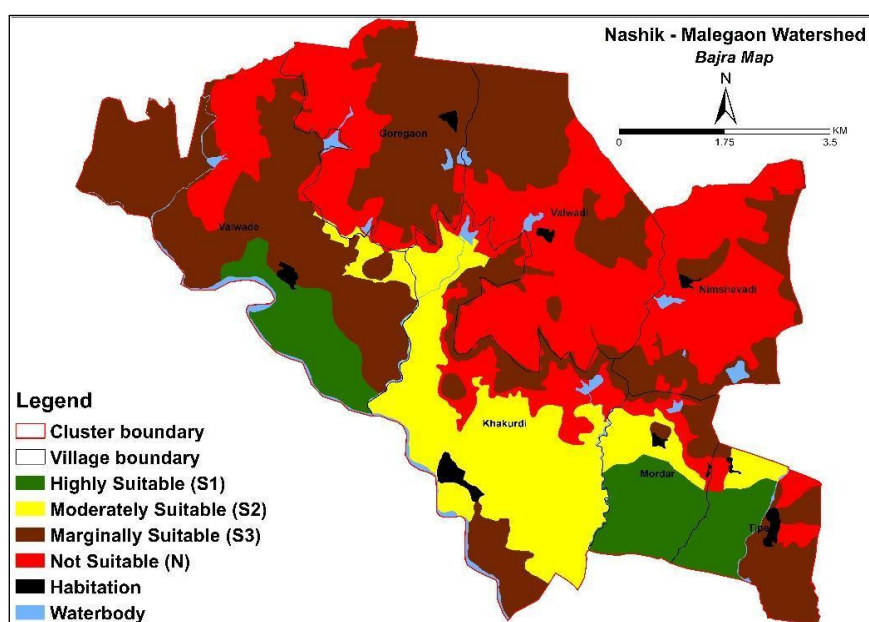


Fig. 4.26 Soil site suitability map for Pearl millet (bajra) cultivation

4.8.4 Soil-Site Suitability for Pigeon pea Cultivation

The soil-site suitability assessment for pigeon pea cultivation indicates that 1006.8 ha (15.1%) of the total geographical area is classified as moderately suitable (S2), representing areas with acceptable conditions for crop growth, though certain limitations may affect productivity.

The marginally suitable (S3) category covers 1018.9 ha (15.3%), reflecting moderate constraints that may restrict optimal crop performance. A dominant portion of the watershed, 4451.3 ha (66.7%), is classified as not suitable (N) for pigeon pea cultivation due to severe soil and site limitations. The assessment shows that a major share of the watershed is unsuitable for pigeon pea cultivation, whereas only about one-third of the area exhibits moderate to marginal suitability.

Table 4.29 Area under suitability sub-classes for pigeon pea cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1006.8	15.1
2	Marginally Suitable (S3)	1018.9	15.3
3	Not Suitable (N)	4451.3	66.7
4	Habitation	65.8	1.0
5	Waterbody	127.1	1.9
Total area		6670.0	100.0

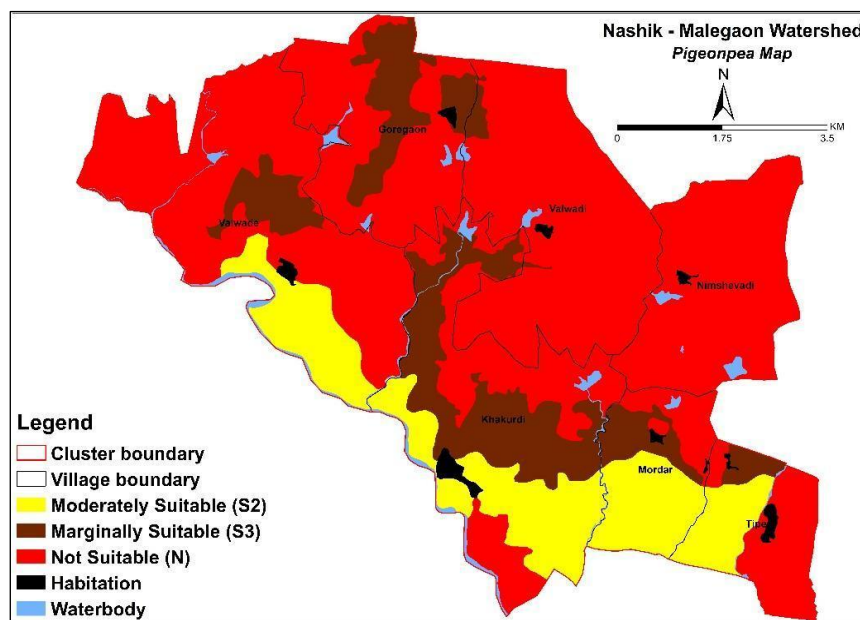


Fig. 4.27. Soil site suitability map for Pigeon pea (tur) Cultivation

4.8.5 Soil-Site Suitability for Soybean Cultivation

The land evaluation results for soybean cultivation show a varied distribution of suitability classes across the watershed (Table 4.30). Areas categorized as highly suitable (S1) cover 1239.5 ha, accounting for 18.6% of the total geographical area, indicating favorable soil and site conditions for achieving good crop performance.

The moderately suitable (S2) class occupies 1139.9 ha (17.1%), representing zones where soybean cultivation is feasible, although certain soil or site constraints may influence yield levels. The marginally suitable (S3) category extends over 1925.0 ha (28.9%), suggesting the presence of noticeable limitations that may restrict optimum crop growth.

A considerable portion of the watershed, 2172.7 ha (32.6%), falls under the not suitable (N) class, indicating areas with severe soil and environmental constraints that limit the scope for soybean cultivation. The classification highlights that nearly two-thirds of the watershed offers potential for soybean cultivation under varying degrees of suitability.

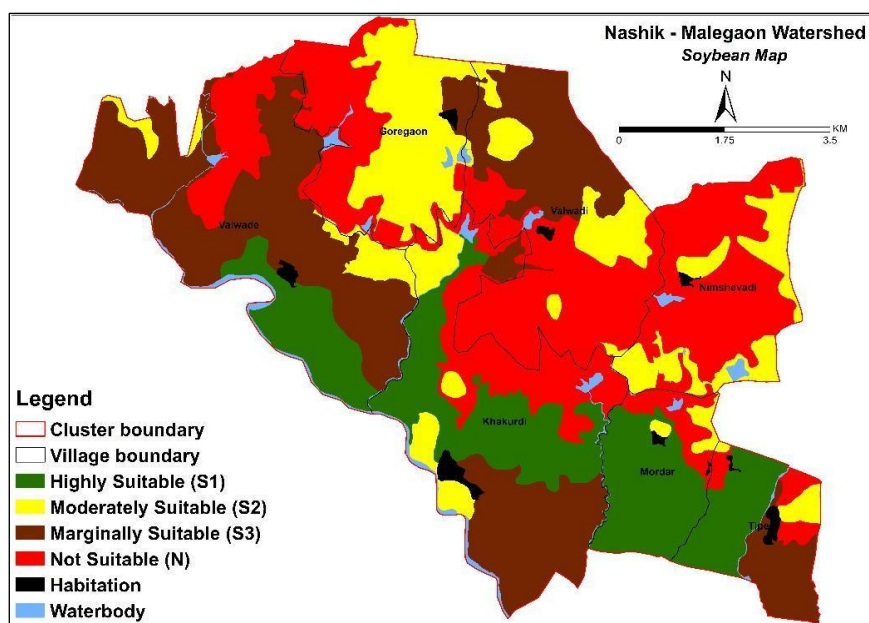


Fig. 4.28. Soil site suitability map for Soybean Cultivation

Table 4.30 Area under suitability sub-classes for Soybean Cultivation

Sr. No.	Suitability sub-classes	Area (Ha)	Percent (%)
1	Highly Suitable (S1)	1239.5	18.6
2	Moderately Suitable (S2)	1139.9	17.1
3	Marginally Suitable (S3)	1925.0	28.9
4	Not Suitable (N)	2172.7	32.6
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
Total area		6670.0	100.0

4.8.6 Soil-Site Suitability for Wheat Cultivation

The suitability assessment for wheat cultivation across the watershed reveals a broad range of land capability classes (Table 4.31). Areas classified as highly suitable (S1) cover 603.5 ha, representing 9.0% of the total geographical area, indicating zones with favorable soil and site conditions for wheat production.

The moderately suitable (S2) category extends over 1008.1 ha (15.1%), reflecting areas where wheat cultivation is feasible, although moderate limitations related to soil properties or terrain may influence productivity. A major share of the watershed, 2648.5 ha (39.7%), falls under the marginally suitable (S3) class, suggesting the presence of noticeable constraints that may restrict optimum crop growth and yields.

In contrast, 2217.0 ha (33.2%) of the area is classified as not suitable (N) for wheat cultivation due to severe soil and environmental limitations. Overall, the evaluation indicates that only a limited proportion of the watershed provides highly favorable conditions for wheat, while a substantial area exhibits marginal or poor suitability,

emphasizing the need for appropriate land-use planning and targeted management interventions.

Table 4.31 Area under suitability sub-classes for Wheat Cultivation

Sr. No.	Suitability sub-classes	Area (Ha)	Percent (%)
1	Highly Suitable (S1)	603.5	9.0
2	Moderately Suitable (S2)	1008.1	15.1
3	Marginally Suitable (S3)	2648.5	39.7
4	Not Suitable (N)	2217.0	33.2
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
Total area		6670.0	100.0

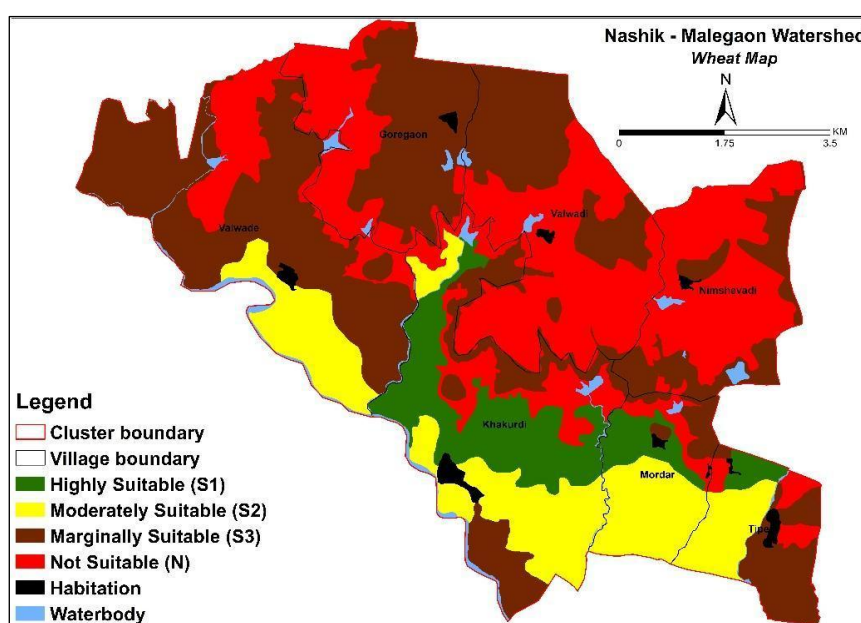


Fig. 4.29 Soil site suitability map for Wheat Cultivation

4.8.7 Soil-Site Suitability for Chickpea Cultivation

The soil-site evaluation for chickpea cultivation shows that 28.1% of the watershed area (1871.7 ha) falls under the moderately suitable (S2) class, indicating land where chickpea can be grown with manageable limitations. These areas provide relatively stable conditions for crop establishment and growth.

A larger proportion of the watershed, 36.8% (2457.5 ha), is categorized as marginally suitable (S3). This distribution highlights that chickpea cultivation across much of the area is constrained by soil and site factors, which may result in reduced productivity under normal management practices.

Further, 32.2% of the total area (2147.9 ha) is classified as not suitable (N) for chickpea cultivation, reflecting severe limitations that restrict successful crop production. The dominance of marginal and unsuitable land emphasizes the need for careful site selection when planning chickpea cultivation within the watershed.

Table 4.32 Area under suitability sub-classes for Chickpea Cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1871.7	28.1
2	Marginally Suitable (S3)	2457.5	36.8
3	Not Suitable (N)	2147.9	32.2
4	Habitation	65.8	1.0
5	Waterbody	127.1	1.9
Total area		6670.0	100.0

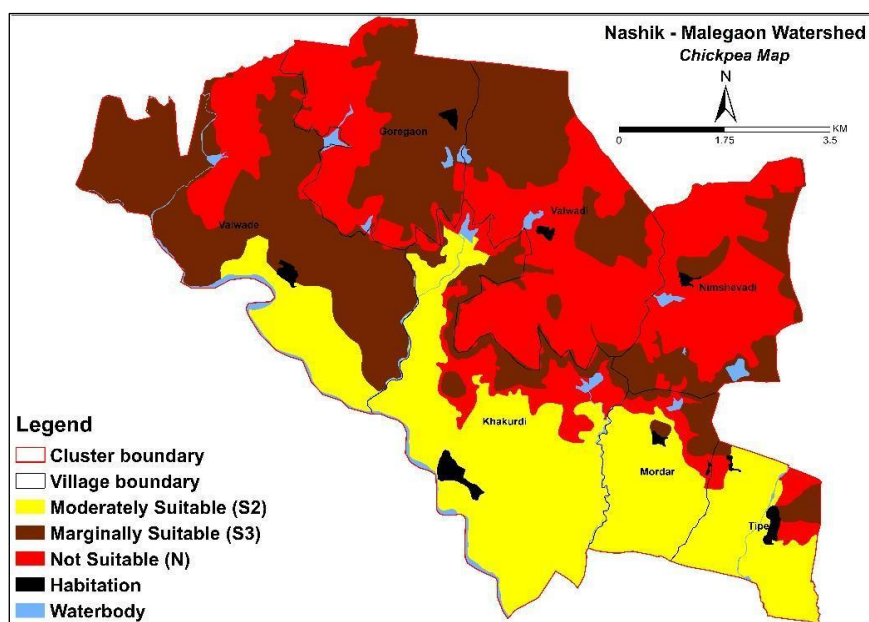


Fig. 4.30 Soil site suitability map for Chickpea Cultivation

4.8.8 Soil-Site Suitability for Cotton Cultivation

The soil-site evaluation for cotton cultivation shows that 1281.0 ha (19.2%) of the total geographical area is 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 2568.8 ha (38.5%), falls under the marginally suitable (S3) category, indicating the presence of moderate limitations that may restrict yield potential. Furthermore, 2627.4 ha (39.4%) of the area is categorized as not suitable (N) for cotton cultivation due to severe soil and site-related constraints. Overall, the assessment indicates that nearly two-fifths of the watershed is unsuitable for cotton cultivation, while about one-fifth of the area exhibits moderate suitability.

Table 4.33 Area under suitability sub-classes for Cotton Cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1281.0	19.2
2	Marginally Suitable (S3)	2568.8	38.5
3	Not Suitable (N)	2627.4	39.4
4	Habitation	65.8	1.0
5	Waterbody	127.1	1.9
Total area		6670.0	100.0

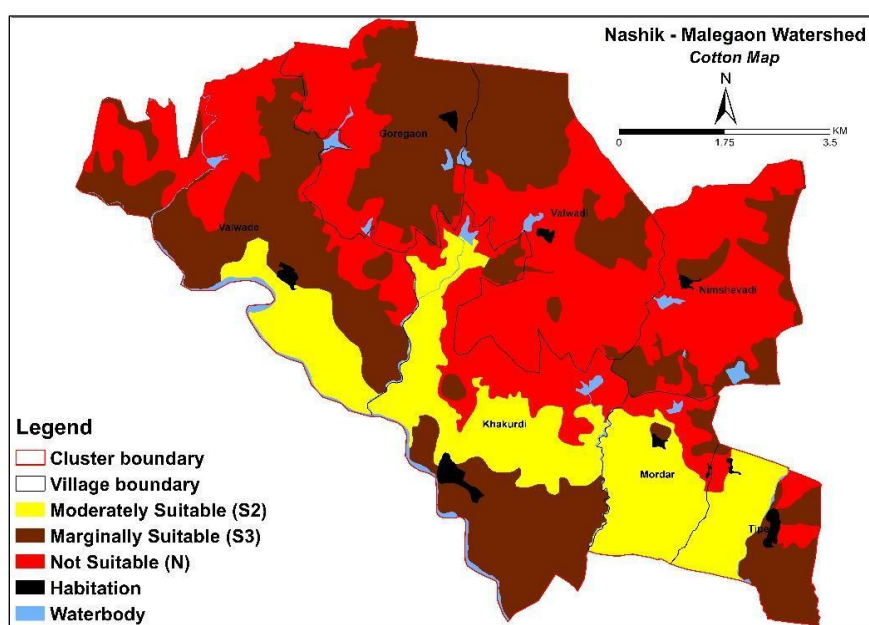


Fig. 4.31 Soil site suitability map for Cotton Cultivation

4.8.9 Soil-Site Suitability for Sugarcane Cultivation

The suitability classification for sugarcane cultivation reveals that 19.5% (1300.9 ha) of the total geographical area falls under the moderately suitable (S2) category. These areas represent zones where sugarcane cultivation can be practiced with moderate limitations.

About 15.4% (1027.3 ha) of the area is categorized as marginally suitable (S3), indicating the presence of noticeable constraints that may affect crop establishment and productivity. In contrast, a dominant share of the watershed, accounting for 62.2% (4148.9 ha), is classified as not suitable (N) for sugarcane cultivation, reflecting severe soil and site limitations. The distribution of suitability classes highlights that a large portion of the watershed does not support sugarcane cultivation, while comparatively smaller areas show moderate to marginal suitability.

Table 4.34 Area under suitability sub-classes for Sugarcane Cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1300.9	19.5
2	Marginally Suitable (S3)	1027.3	15.4
3	Not Suitable (N)	4148.9	62.2
4	Habitation	65.8	1.0
5	Waterbody	127.1	1.9
Total area		6670.0	100.0

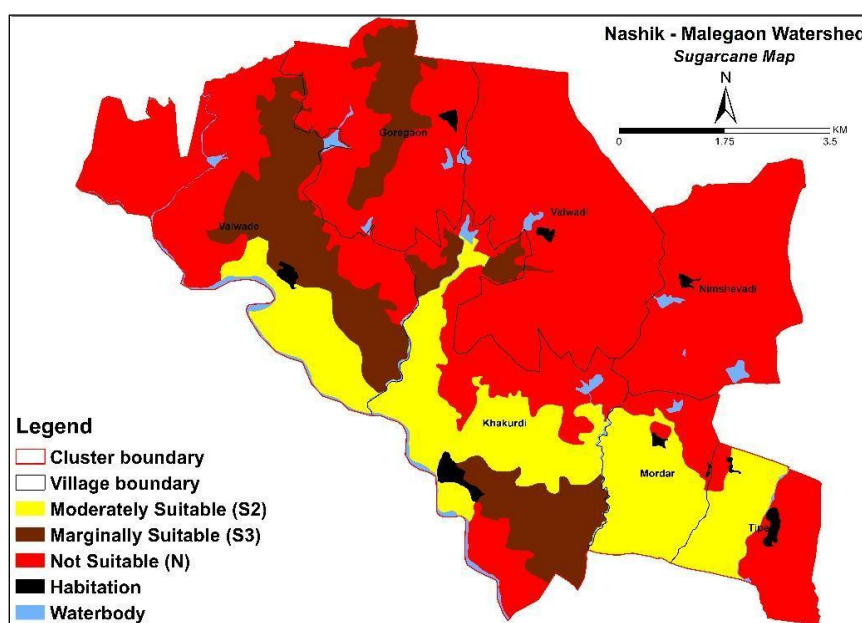


Fig. 4.32 Soil site suitability map for Sugarcane Cultivation

4.8.10 Soil-Site Suitability for Banana Cultivation

The soils of the study area were evaluated for their suitability for banana cultivation based on crop-specific requirements. The spatial distribution of suitability classes is presented in Table 4.35. The assessment indicates that a major portion of the total geographical area (TGA) is not suitable (N) for banana cultivation, covering 3387.7 ha, which accounts for 50.8% of the total area. These areas are constrained by factors such as soil limitations, topographic conditions, and moisture availability.

Areas classified as marginally suitable (S3) occupy 1849.9 ha, representing 27.7% of the TGA. These zones exhibit moderate to severe constraints, which may restrict optimal crop performance and require appropriate soil and water management interventions. Moderately suitable (S2) areas cover 1239.5 ha, accounting for 18.6% of the TGA, and offer relatively favorable conditions for banana cultivation, although certain limitations related to soil fertility, drainage, or terrain may still exist.

In addition, habitation areas account for 65.8 ha (1.0%), while water bodies occupy 127.1 ha (1.9%) of the total area. Overall, the evaluation suggests that nearly half of the study

area holds potential for banana cultivation under suitable management practices, particularly within the moderately and marginally suitable zones.

Table 4.35 Area under suitability sub-classes for Banana Cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1239.5	18.6
2	Marginally Suitable (S3)	1849.9	27.7
3	Not Suitable (N)	3387.7	50.8
4	Habitation	65.8	1.0
5	Waterbody	127.1	1.9
Total area		6670.0	100.0

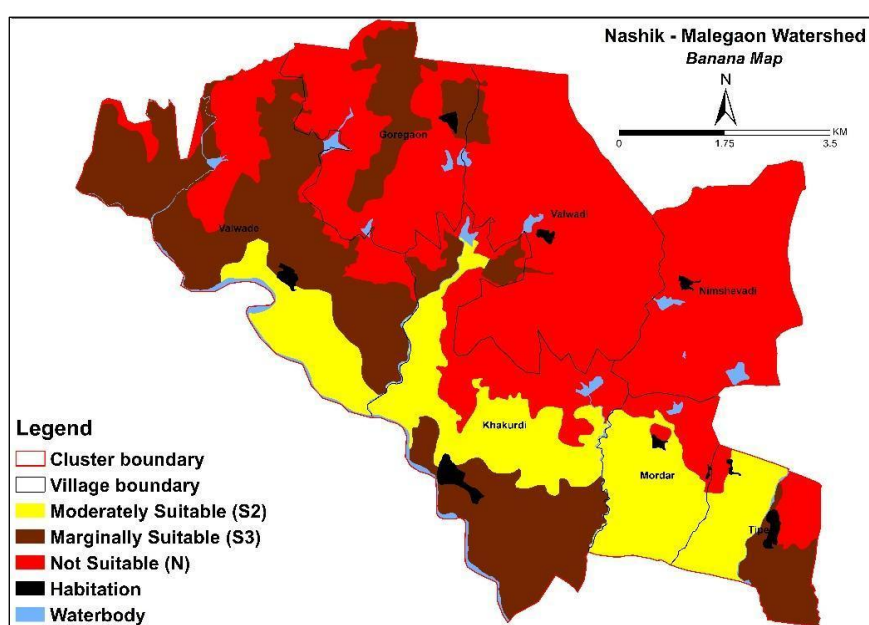


Fig. 4.33. Soil site suitability map for Banana Cultivation

4.8.11 Soil-Site Suitability for Grapes Cultivation

The soils of the watershed were evaluated for their suitability for grapes cultivation based on crop-specific requirements. The spatial distribution of suitability classes is presented in Table 4.36. The results indicate that a major proportion of the total geographical area (TGA) is classified as not suitable (N) for grapes cultivation, covering 3964.1 ha (59.4%) of the watershed.

The marginally suitable (S3) category occupies 1775.3 ha (26.6%), representing areas with moderate limitations that may restrict optimum crop growth and productivity. The moderately suitable (S2) class covers 737.7 ha (11.1%), indicating comparatively favorable conditions for grapes cultivation, though certain soil and site constraints may still exist. Overall, the assessment reveals that only a limited proportion of the watershed is suitable for grapes cultivation, while the majority of the area is either marginally suitable or not

suitable, highlighting the need for careful land-use planning and appropriate soil and water management practices.

Table 4.36 Area under suitability sub-classes for Grape Cultivation

Sr. No.	Suitability sub-classes	Area (Ha)	Percent (%)
1	Moderately Suitable (S2)	737.7	11.1
2	Marginally Suitable (S3)	1775.3	26.6
3	Not Suitable (N)	3964.1	59.4
4	Habitation	65.8	1.0
5	Waterbody	127.1	1.9
Total area		6670.0	100.0

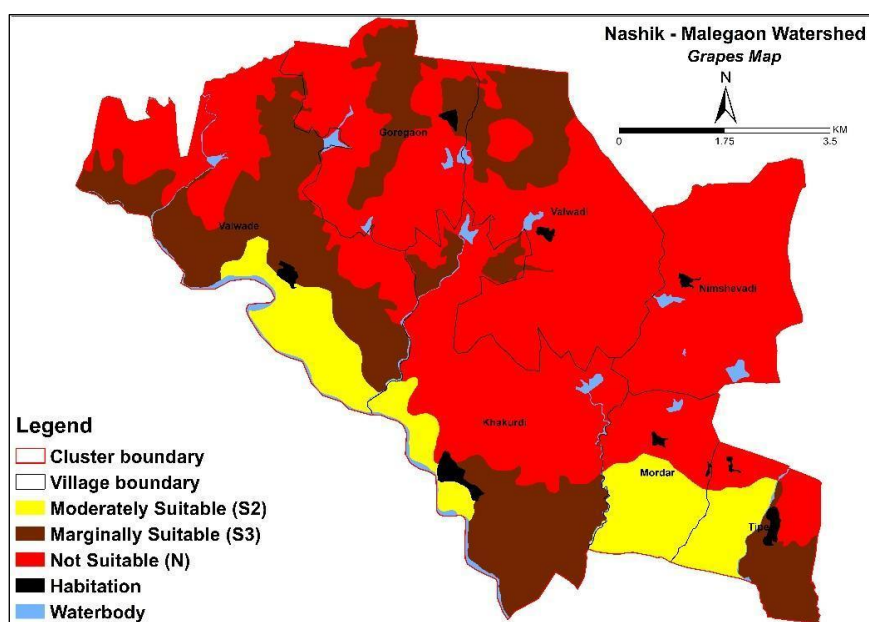


Fig. 4.34. Soil site suitability map for Grape Cultivation

4.8.12 Soil-Site Suitability for Pomegranate Cultivation

The soils of the watershed were evaluated for pomegranate cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.37. The results indicate that 1300.9 ha (19.5% of the total geographical area, TGA) are classified as highly suitable (S1), providing favorable conditions for pomegranate growth and productivity.

A relatively small area, 41.5 ha (0.6% of TGA), falls under the moderately suitable (S2) category, where minor soil and site limitations may moderately influence crop performance. A considerable portion of the watershed, 2176.0 ha (32.6% of TGA), is categorized as marginally suitable (S3), reflecting moderate to severe constraints related to soil properties and terrain, which may restrict yield potential unless appropriate management practices are adopted.

In contrast, 2958.7 ha (44.4% of TGA) of the study area is classified as not suitable (N) for pomegranate cultivation due to severe limitations associated with soil, topography, and moisture availability. Overall, the evaluation suggests that while nearly one-fifth of the

watershed is highly suitable for pomegranate cultivation, a major share of the area is either marginally suitable or unsuitable, highlighting the need for careful land-use planning and site-specific management interventions.

Table 4.37 Area under suitability sub-classes for Pomegranate Cultivation

Sr. No.	Suitability sub-classes	Area (Ha)	Percent (%)
1	Highly Suitable (S1)	1300.9	19.5
2	Moderately Suitable (S2)	41.5	0.6
3	Marginally Suitable (S3)	2176.0	32.6
4	Not Suitable (N)	2958.7	44.4
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
Total area		6670.0	100.0

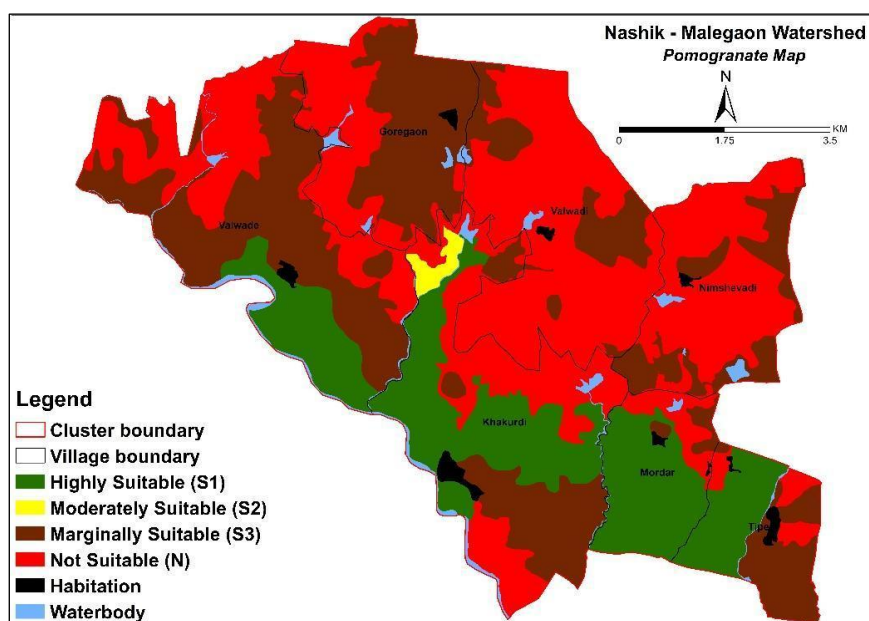


Fig. 4.35. Soil site suitability map for Pomegranate Cultivation

4.8.13 Soil-Site Suitability for Papaya Cultivation

The land suitability evaluation for papaya cultivation indicates that the watershed is largely constrained for this crop (Table 4.38). The marginally suitable (S3) class covers 2744.8 ha, accounting for 41.2% of the total geographical area, suggesting that papaya cultivation in these zones may be undertaken with considerable limitations that could affect crop growth and yield.

Table 4.38 Area under suitability sub-classes for Papaya Cultivation

Sr. No.	Suitability sub-classes	Area (ha)	Percent (%)
1	Marginally Suitable (S3)	2744.8	41.2
2	Not Suitable (N)	3732.3	56.0
3	Habitation	65.8	1.0
4	Waterbody	127.1	1.9
Total area		6670.0	100.0

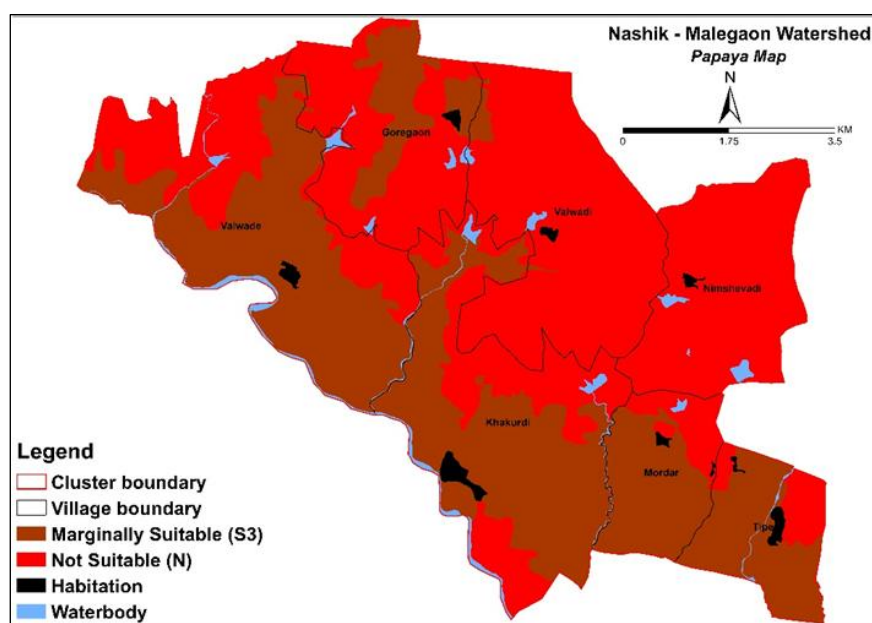


Fig. 4.36 Soil site suitability map for Papaya Cultivation

A dominant portion of the watershed, 3732.3 ha (56.0%), is categorized as not suitable (N) for papaya cultivation, reflecting severe soil and site-related constraints that significantly restrict the potential for successful crop production. Overall, the distribution of suitability classes highlights that the scope for papaya cultivation within the watershed is limited, with more than half of the area being unsuitable and the remaining portion exhibiting only marginal suitability.

4.8.14 Soil-Site Suitability for Onion Cultivation

The soil-site suitability analysis for onion cultivation reveals a wide variation in land capability across the watershed (Table 4.39). Areas identified as highly suitable (S1) extend over 1342.4 ha, constituting 20.1% of the total geographical area, indicating favorable soil and environmental conditions for onion production.

The moderately suitable (S2) category occupies the largest share, covering 2808.2 ha (42.1%), which reflects land with generally supportive conditions, though certain limitations may influence crop performance. The marginally suitable (S3) class accounts for 2326.5 ha (34.9%), suggesting the presence of notable soil and site constraints that may restrict optimal yield levels.

Overall, the classification demonstrates that a substantial proportion of the watershed is conducive to onion cultivation under moderate to high suitability conditions, while a significant area remains marginally suitable, highlighting the importance of appropriate soil and crop management practices.

Table 4.39 Area under suitability sub-classes for Onion Cultivation

Sr.No.	Suitability sub-classes	Area (Ha)	Percent (%)
1	Highly Suitable (S1)	1342.4	20.1
2	Moderately Suitable (S2)	2808.2	42.1
3	Marginally Suitable (S3)	2326.5	34.9
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
Total area		6670.0	100.0

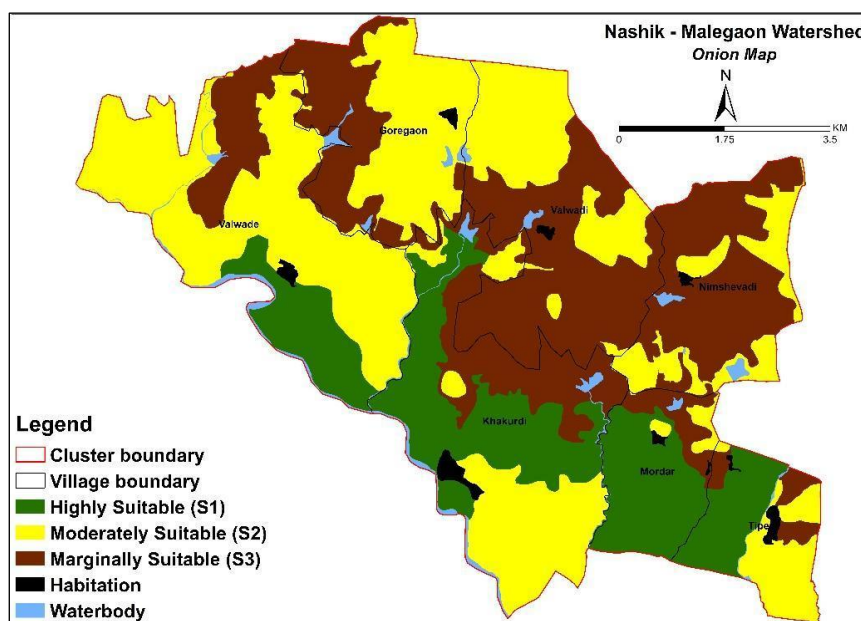


Fig. 4.37 Soil site suitability map for Onion Cultivation

4.8.15 Soil-Site Suitability for Tomato Cultivation

The soil-site suitability evaluation for tomato cultivation indicates that 1239.5 ha (18.6%) of the total geographical area is classified as highly suitable (S1), providing favorable conditions for tomato growth and productivity. A comparatively smaller area, 102.9 ha (1.5%), falls under the moderately suitable (S2) category, reflecting minor limitations.

A substantial portion of the watershed, 2808.2 ha (42.1%), is categorized as marginally suitable (S3), suggesting the presence of moderate constraints that may restrict crop performance. In addition, 2326.5 ha (34.9%) of the area is classified as not suitable (N) for tomato cultivation due to severe soil and site limitations. Overall, the assessment shows that while nearly one-fifth of the watershed is highly suitable for tomato cultivation, a major share of the area falls under marginally suitable and not suitable categories.

Table 4.40 Area under suitability sub-classes for Tomato Cultivation

Sr. No.	Suitability sub-classes	Area (Ha)	Percent (%)
1	Highly Suitable (S1)	1239.5	18.6
2	Moderately Suitable (S2)	102.9	1.5
3	Marginally Suitable (S3)	2808.2	42.1
4	Not Suitable (N)	2326.5	34.9
5	Habitation	65.8	1.0
6	Waterbody	127.1	1.9
Total area		6670.0	100.0

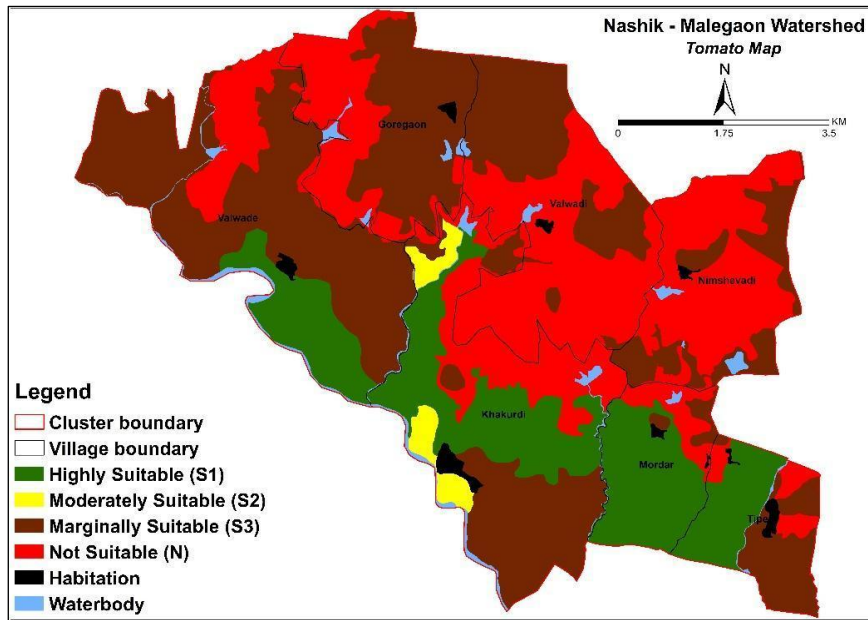


Fig. 4.38. Soil site suitability map for Tomato Cultivation

4.9 Soil and Water Conservation measures

Soil and water are vital resources that directly influence agricultural productivity, ecosystem stability, and long-term land sustainability. In Malegaon Taluka, village cluster watershed, the variation in landforms, soil textures, soil depth, and slopes creates conditions where soil erosion, surface runoff, and water scarcity are common, particularly in shallow and sloping lands. These challenges necessitate carefully planned soil and water conservation interventions to reduce erosion, retain moisture, enhance groundwater recharge, and maintain sustainable land use across agricultural and non-agricultural areas.

The conservation strategy for the village cluster watershed has been formulated based on the spatial distribution of land resources recorded in the dataset, including landform, soil texture, soil depth, land use/land cover, and slope. In cultivable lands consisting of loam, silt loam, clay loam, and silty clay soils, field bunds may be implemented or existing bunds strengthened with safe runoff disposal. Farm ponds may also be constructed in suitable locations to enhance water storage, while lined farm ponds are recommended in areas where improved water retention is required in soils with moderate depth. Broad bed and furrow systems combined with field bunds may be implemented to further enhance water

infiltration and regulate runoff in both shallow and moderately deep soils. Conservation bench terraces may be introduced in unbanded and sloping fields to effectively manage runoff and reduce soil erosion.

Non-cultivable lands, including wastelands, open scrub, plantation areas, and locations with tree cover, may be treated through afforestation and in-situ moisture conservation measures. In selected locations, percolation tanks are recommended to promote groundwater recharge, while runoff moderation and infiltration enhancement measures such as stone lines, micro-catchments on rock fractures, and assisted natural regeneration may be adopted in rocky or high-runoff areas, including hills, ridges, mesas, and inselbergs.

Watercourses, including rivers, nalas, and seasonal streams, may be supported with structural interventions such as cement and earthen nala bunds, along with repair and desilting works to maintain effective water flow. Stream bank plantation may also be undertaken along rivers and drainage channels to stabilize banks and prevent erosion. Seasonal and perennial waterbodies require renovation according to site-specific conditions, while rooftop rainwater harvesting systems in built-up areas can be promoted to capture and utilize surface runoff efficiently. Additional site-specific measures such as horticultural plantations with moisture conservation, afforestation combined with percolation tanks, and protection terraces are also suggested to further enhance soil moisture retention and water storage across diverse landforms.

Overall, the conservation interventions proposed for the village cluster watershed integrate both structural and vegetative measures to improve soil stability, enhance water retention, and promote groundwater recharge. By aligning conservation practices with landform characteristics, soil properties, land use patterns, and slope conditions, the plan addresses both erosion control and water management while supporting sustainable agricultural productivity and ecosystem resilience. The integration of field bunds, terraces, farm ponds, afforestation, and in-situ moisture conservation measures provides a comprehensive approach to managing soil and water resources, mitigating runoff, and improving the overall health and productivity of landscapes in Malegaon Taluka. During the implementation of conservation measures, farmers' opinions may be considered and appropriate designs may be adopted based on field conditions. If the site conditions are not suitable for the suggested measures, alternative interventions may be selected. The suggested polygon-wise soil and water conservation measures may consist of individual or combined treatments, with each polygon considered as an independent management unit. The specific soil and water conservation measures applied across all landforms and land use/land cover types are summarized in Table 4.41 and illustrated in Fig. 4.39.

Table 4.41 Proposed soil and water conservation (SWC) plan for Malegaon watershed.

Sr. No.	Proposed SWC Plan
1	Afforestation, In-situ Moisture Conservation Measures
2	Field bund/Strengthening of existing bund with safe disposal of runoff water
3	Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm Pond
4	Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm Pond with Lining
5	Runoff moderation and infiltration enhancement measures (e.g., stone lines, micro-catchments on rock fractures, assisted natural regeneration)
6	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm Pond with Lining
7	Conservation Bench Terrace in Unbunded Field/Field bund/Strengthening of existing bund with safe disposal of runoff water
8	In-situ Moisture Conservation Measures
9	Renovation of Waterbody as per the site condition
10	Rooftop Rainwater Harvesting
11	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water
12	Road
13	Afforestation, Silt Detention Trench in Downstream
14	Stream Bank Plantation
15	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm Pond
16	Renovation of Farm Pond as per the site condition
17	Horticultural Plantation, In-situ Moisture Conservation Measures
18	Afforestation, In-situ Moisture Conservation Measures, Percolation Tank
19	Cement Nala Bund, Earthen Nala Bund / Repairing of Cement Nala Bund and Desilting of Nallas
20	Puretocion Terrace
21	Horticultural Plantation, In-situ Moisture Conservation Measures, Farm pond
22	In-situ Moisture Conservation Measures, Farm pond with Lining
Total	

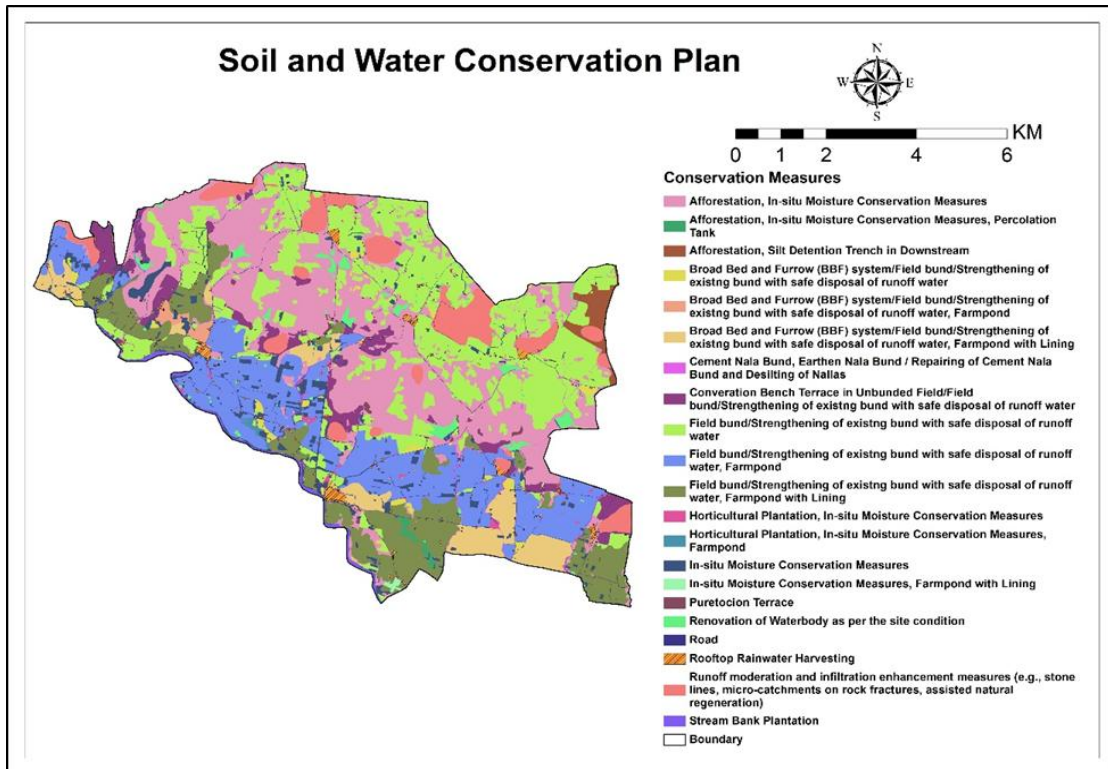


Fig. 4.39: Soil and Water Conservation measures proposed for Malegaon watershed.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

- The Malegaon watershed's economy is largely agriculture-based on a bajra/maize and commercial onion 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 crops like sorghum, bajra, and cotton, as well as commercial crops like onion, grape, and banana.

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 Nashik 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.

Morphometric analysis of the watershed reveals moderate relief and well-developed drainage networks, indicating considerable surface runoff during monsoon periods. The slope classification further suggests varying erosion potential across the watershed, necessitating location-specific interventions. The soil assessment highlights spatial variations in soil depth, texture, and erosion susceptibility, emphasizing the need for tailored land management and conservation practices. These factors collectively influence infiltration capacity, runoff generation, and groundwater recharge, thereby affecting overall watershed sustainability.

The land use and land cover analysis indicates the predominance of agricultural land, interspersed with fallow areas, scrublands, and built-up zones. This spatial distribution reflects the strong dependence of the local population on agriculture and allied activities. The identification of potential zones for water harvesting structures, recharge measures, and soil conservation treatments supports strategic planning aimed at optimizing resource utilization. The proposed interventions are designed to minimize land degradation, enhance water availability, and promote sustainable agricultural practices within the watershed.

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-I

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, Nashik

In this study, runoff estimation, groundwater potential zone (GWPZ) mapping, and soil and water conservation (SWC) planning were carried out at the village cluster level to enable site-specific assessment and practical implementation. However, morphometric analysis was conducted at the watershed level because morphometric parameters are controlled by natural drainage boundaries rather than administrative units.

Morphometric analysis quantitatively evaluates drainage network characteristics, basin geometry, slope, and relief, which influence runoff generation, erosion, and groundwater recharge. These parameters must be derived from a hydrologically closed unit bounded by

natural divides. A watershed represents such a unit, where streams develop hierarchically and drain toward a common outlet, ensuring reliable computation of indices such as drainage density, bifurcation ratio, stream frequency, form factor, and relief ratio.

Village clusters are administrative entities that do not coincide with complete drainage systems. Since streams often cross village boundaries, morphometric analysis at the cluster level would result in truncated stream networks and distorted basin geometry, leading to inaccurate hydrological interpretation.

Therefore, morphometric analysis was intentionally performed at the watershed level to maintain hydrological accuracy, while runoff estimation, GWPZ mapping, and SWC planning were undertaken at the village cluster level for effective local implementation. This integrated framework links natural hydrological processes with decentralized planning for sustainable water resource management.

The Malegaon village cluster, Nashik, Maharashtra, comprises seven villages. Together, these villages constitute the study cluster having 4 sub-watersheds (Fig. 1).

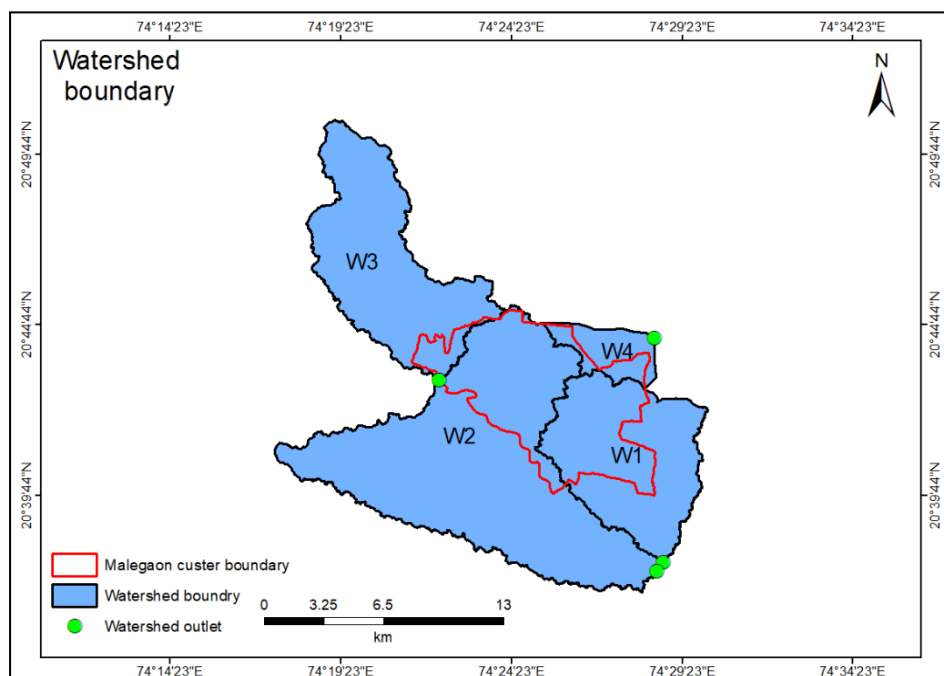


Fig. 1: Map of Malegaon cluster, Nashik depicted through sub-watershed

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

Sr. No.	Sub-watershed name	Sub-watershed order	Elevation (m)	Area (ha)	Flow origination
1	W1	5th	389-694	55.67	South-east
2	W2	5th	388-748	123.78	South-east
3	W3	5th	451-851	63.08	South-east
4	W4	4th	461-612	11.79	East

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

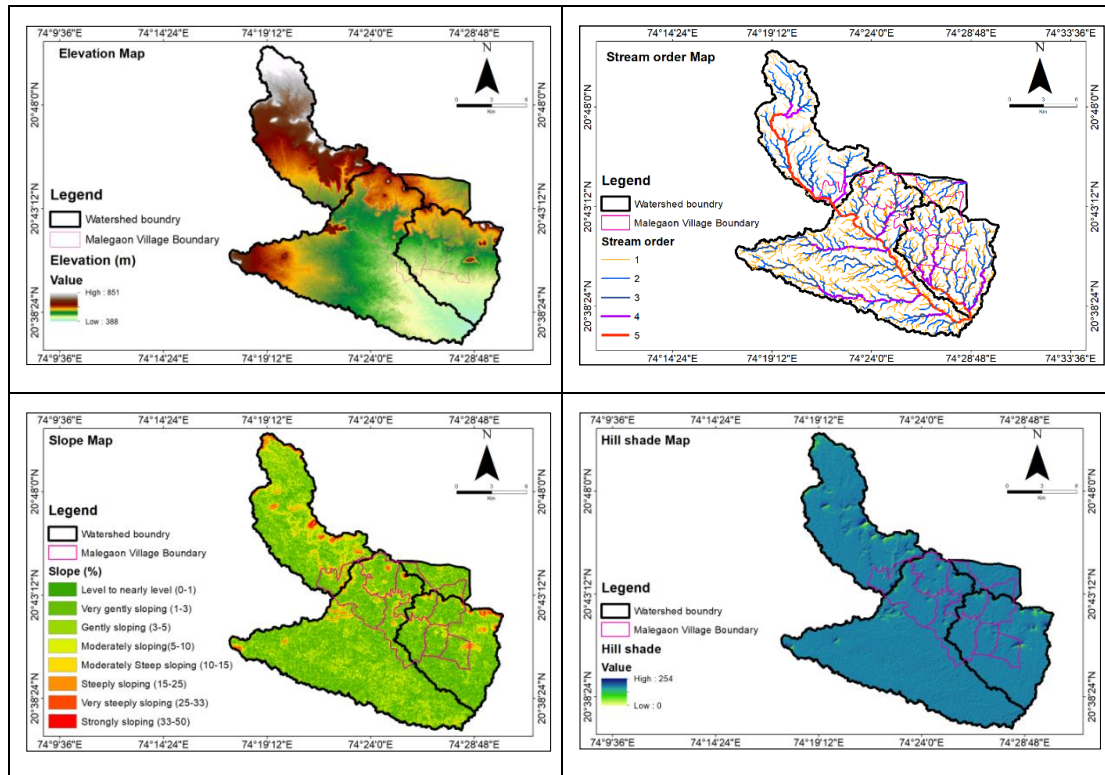


Fig. 2: Elevation, stream network, slope and hill shade map of sub-watershed

Linear aspect

Linear morphometric parameters focus on the stream network characteristics and its influence on runoff and watershed behavior. The morphometric analysis of the four sub-watersheds shows clear variation in drainage characteristics. W2 has the highest number of streams (848) and total stream length (352.3 km), indicating a well-developed drainage network, while W4 has the lowest values (Table 4.39). The bifurcation ratio ranges from 1.72 (W2) to 2.73 (W4), suggesting relatively greater structural influence in W4.

Mean channel length and valley length are highest in W2, reflecting more mature channel development, whereas W4 records the lowest values. Channel index is highest in W4 (1.52), indicating greater sinuosity. Basin perimeter is also largest in W2 (99.88 km), confirming it as the most extensive sub-watershed, while W4 is the smallest.

Table 2 Linear morphometric parameters of sub-watersheds, Malegaon cluster, Nashik

Sr. no.	Morphometric parameter	Symbol	Unit	W1	W2	W3	W4
1	No. of streams	Nu	No	366	848	423	63
2	Stream length	Lu	km	159.4	352.3	180.5	27.5
3	Bi-furcation ratio	Rb	-	1.81	1.72	1.77	2.73
4	Mean channel length	Cl	km	12.89	25.66	20.16	4.5
5	Valley Length	Vl	km	11.21	22.31	16.71	3.25
6	Channel Index	Ci	-	1.2	1.2	1.37	1.52
7	Minimum areal distance	Adm	km	10.7	20.58	14.7	2.97
8	Valley Index	Vi	-	1.04	1.1	1.14	1.09
9	Basin perimeter	P	km	49.02	99.88	64.42	21.25

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 four sub-watersheds. Basin area is highest in W2 (123.78 km²) and lowest in W4 (11.79 km²). Mean basin width is also greater in W2 (5.34 km). Form factor (Ff) and elongation ratio (Re) are highest in W4 (0.74 and 0.16), suggesting a comparatively more circular basin, whereas W2 and W3 show lower values, indicating elongated shapes. Circularity ratio (Rc) is maximum in W4 (0.33), while compactness coefficient (Cc) is highest in W2 (2.55), reflecting greater basin irregularity. Standard sinuosity index (Ssi) ranges from 1.15 (W1 and W2) to 1.38 (W4), indicating relatively higher channel sinuosity in W4.

Drainage parameters show that stream frequency (Fs) is highest in W2 (7.33 per km²) and lowest in W4 (5.43 per km²). Drainage density (Dd) is nearly similar in W1 and W3 (2.9 km/km²) but lower in W4 (2.3 km/km²). Drainage intensity (Di) follows a similar trend, with the highest value in W2 (2.57). Length of overland flow (Lg) is greatest in W2 (0.39 km) and lowest in W4 (0.04 km), indicating shorter runoff travel distance in W4.

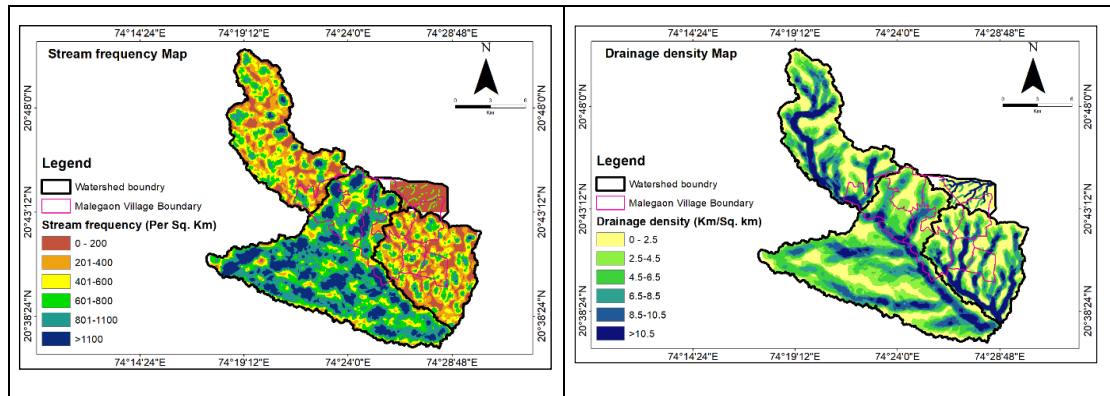


Fig. 3: Steam frequency and drainage density map of sub-watershed

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

Sr. No.	Parameter	Symbol	Method/Formula	Unit	W1	W2	W3	W4
1.	Mean basin width	Wb	$Wb = A/Lb$	km	5.0	5.34	3.44	2.9
2.	Basin area	A	GIS Analysis	km ²	55.67	123.78	63.03	11.79
3.	Relative perimeter	Pr	$Pr = A/P$	km	1.14	1.24	0.98	0.55
4.	Length area relation	Lar	$Lar = 1.4 * A^{0.6}$	km ²	15.61	25.22	16.82	6.15
5.	Lemniscate's	k	$K = Lb^2/A$	-	2.3	4.3	5.3	1.0
6.	Form factor	Ff	$Ff = A/Lb^2$	-	0.44	0.23	0.19	0.74
7.	Elongation ratio	Re	$Re = 2/Lb * (A/\pi)^{0.5}$	-	0.02	0.01	0.01	0.16
8.	Circularity ratio	Rc	$Rc = 12.57 * (A/P^2)$	-	0.29	0.16	0.19	0.33
9.	Compactness coefficient	Cc	$Cc = 0.2841 * P/A^{0.5}$	-	1.87	2.55	2.31	1.76
10.	Standard sinuosity index	Ssi	$Ssi = Ci/Vi$	-	1.15	1.15	1.21	1.38
11.	Stream frequency	Fs	$Fs = Nu/A$	Per km ²	7.15	7.33	7.14	5.43
12.	Drainage Density	Dd	$Dd = Lu/A$	km/km ²	2.9	2.8	2.9	2.3
13.	Drainage Intensity	Di	$Di = Fs/Dd$	-	2.49	2.57	2.49	2.33
14.	Length of Overland Flow	Lg	$Lg = A/2 * Lu$	km	0.17	0.39	0.20	0.04

Relief Aspects

The maximum basin height (Z) is highest in W3 (851 m) and lowest in W4 (612 m), while total basin relief (H) is also maximum in W3 (398 m) and minimum in W4 (151 m) (Table 4). Relief ratio (R_{hl}) is highest in W4 (43.1), indicating steeper terrain conditions, whereas W2 shows the lowest value (15.4).

Relative relief ratio (R_{hp}) is greatest in W4 (710.6), followed by W1 and W3, suggesting higher relief intensity in W4. The ruggedness number (R_n) is maximum in W3 (1.14), reflecting more dissected and erosion-prone terrain, while W4 has the lowest value (0.35). Similarly, the Melton ruggedness number (MR_n) is highest in W3 (50.1), indicating comparatively higher susceptibility to runoff and erosion processes.

Table 4: Relief morphometric parameters of sub-watersheds, Malegaon cluster, Nashik

Sr. No	Parameters	Symbol	Methods /Formula	W1	W2	W3	W4
1.	Height of at basin mouth (m)	z	DEM	390	391	453	461
2.	Maximum height of the basin (m)	Z	DEM	694	748	851	612
3.	Total basin relief (m)	H	$H = Z - z$	304	357	398	151
4.	Relief ratio	R_{hl}	$R_{hl} = H / L_b$	27.1	15.4	21.7	43.1
5.	Relative relief ratio	R_{hp}	$R_{hp} = H * 100 / P$	620.2	357.4	617.8	710.6
6.	Ruggedness number	R_n	$R_n = D_d * (H/1000)$	0.87	1.02	1.14	0.35
7.	Melton Ruggedness number	MR_n	$MR_n = H / A^{0.5}$	40.8	32.1	50.1	44.0

The slope distribution across the four watersheds (W1, W2, W3, and W4) indicates that the terrain is very gently sloping (1-3%) and gently sloping (3-5%) in all areas. In W1 and W2, nearly 39% and 38% of the total area fall under the very gently sloping class, respectively, followed by gently sloping lands. W3 shows a comparatively higher proportion of moderately sloping land (5-10%) at 21.5%, indicating relatively undulating terrain. In W4, very gently sloping land dominates (37.9%), while steep and very steep slope classes occupy only a negligible percentage in all watersheds.

The integrated morphometric and slope analysis reveals distinct hydrological and geomorphic behavior among the four sub-watersheds. W2, with the highest drainage density, stream frequency, basin area, and total stream length, indicates a well-developed drainage network and higher runoff potential, requiring priority management. W3 exhibits high basin relief, ruggedness number, and Melton ruggedness number, suggesting greater

susceptibility to erosion and sediment transport. W4, although smaller in area, shows higher circularity and relief ratio, indicating quicker runoff response despite lower drainage density. Overall, the predominance of gentle slopes supports agricultural use, but moderate to high relief and drainage intensity in specific sub-watersheds increase erosion risk.

Accordingly, W2 and W3 should be prioritized for soil and water conservation measures such as check dams, percolation tanks, contour bunding, and vegetative barriers to reduce runoff and enhance groundwater recharge. In higher relief areas of W3, afforestation, staggered contour trenches, and gully control structures are recommended to minimize erosion. In comparatively circular and quick-response basins like W4, small water harvesting structures and farm ponds can effectively moderate peak flow. These integrated watershed management strategies will help improve runoff regulation, soil conservation, and sustainable water resource development.



