

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

(WDC-2.0)1/2021-22: Barshitakli, Dist - Akola



**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.

Citation: H. Biswas, V.N. Parhad, A.O. Shirale, R.K. Naitam, P.C. Moharana, Ch. Jyotiprava Dash, Sirisha Adamala, B. Dash, M.S. Raghuvanshi, H.L. Kharbikar, U. Surendran and N.G. Patil (2026). 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: Barshitakli, Dist – Akola. ICAR-NBSS&LUP Publication No. 247, NBSS&LUP, Nagpur, 73 p.

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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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ACKNOWLEDGEMENTS

The publication titled “Land resource inventory for 14 selected watersheds of Maharashtra for land use planning using geo-spatial techniques (PMKSY 2.0). (WDC-2.0)1/2021-22: Barshitakli, Dist – Akola” is the result of the collaborative efforts of the officials from the ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP), Nagpur and the Vasundhara Watershed Development Agency (VWDA), Government of Maharashtra.

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.

We place on record our deep sense of gratitude to the Chief Executive Officer(s), Deputy Chief Executive Officer(s), technical and administrative staff of the VWDA for entrusting us with this important project and for their financial and logistic support from the beginning to the completion of the project.

The authors express their sincere gratitude to all the scientists and technical staff, the I/c PME Cell, I/c Library, Chief Administrative Officer, Chief Finance and Accounts Officer, Administrative Officer, Assistant Administrative Officers and all other administration, accounts and audit sections of ICAR-NBSS&LUP, Nagpur, who ensured that the project continued smoothly. Their valuable help and cooperation in all respects are gratefully acknowledged.

Finally, we heartfully thank to all the project staff involved in the PMKSY 2.0-Maharashtra project for their untiring and steadfast efforts in the successful implementation of the project through data collection, analysis and documentation of the report.

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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. Following the programme guidelines, the ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP) has been tasked with conducting LRI and providing technical support for watershed development planning.

Accordingly, ICAR-NBSS&LUP conducted Land Resource Inventory and watershed assessment for the Barshitakli Cluster-watershed located in Barshitakli Taluka of Akola District, Maharashtra. The Cluster-watershed forms part of the Purna River basin and represents the typical black cotton soil (Vertisol) terrain of the Deccan Plateau. Agriculture is the dominant land use in the watershed, primarily dependent on monsoon rainfall, with groundwater serving as a supplementary irrigation source.

The primary objectives of the study were to systematically characterize soil and land resources at the 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 Akola Barshitakli Cluster-watershed constitute 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:

District	Project name	Block	No. of MWS*	No. of villages	Area (ha)
Akola	Akola (WDC-2.0)1/2021-22	Barshitakli	11	8	4898.00
Buldhana	Buldhana (WDC-2.0)3/2021-22	Lonar	21	4	2498.59
Nandurbar	Nandurbar (WDC-2.0)4/2021-22	Nandurbar	5	14	3533.29
Nashik	Nashik (WDC-2.0)3/2021-22	Malegaon	7	7	2760.49
Osmanabad	Osmanabad (WDC-2.0)3/2021-22	Barshitakli	25	10	3380.00
Palghar	Palghar (WDC-2.0)6/2021-22	Dahanu	7	23	3926.27
Parbhani	Parbhani (WDC-2.0)3/2021-22	Gangakhed	8	9	3791.00
Raigad	Raigad (WDC-2.0)2/2021-22	Roha	3	11	3825.00

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

*MWS- Micro Watershed

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 Akola (WDC-2.0)/3/2021-22 sub-watershed located in Barshitakli 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.

CHAPTER 2

BARSHITAKLI WATERSHED AT A GLANCE

2.1 Location and Extent

The watershed (Fig. 2.1) is located in Barshitakli taluka, one of the administrative divisions of Akola District in the Maharashtra state of India. Barshitakli Taluka lies in the southeastern part of Akola District and experiences a semi-arid climate with moderate and irregular rainfall, typical of the Vidarbha region.

Geographically, the watershed falls approximately between 77.15° to 77.30° longitude and 20.35° to 20.50° latitude. The geology of the area is mainly composed of Deccan Trap basalt, representing the hard rock terrain widely found across the Deccan Plateau. Hydrologically, the watershed forms part of the Purna River basin, which ultimately drains into the Godavari River system.

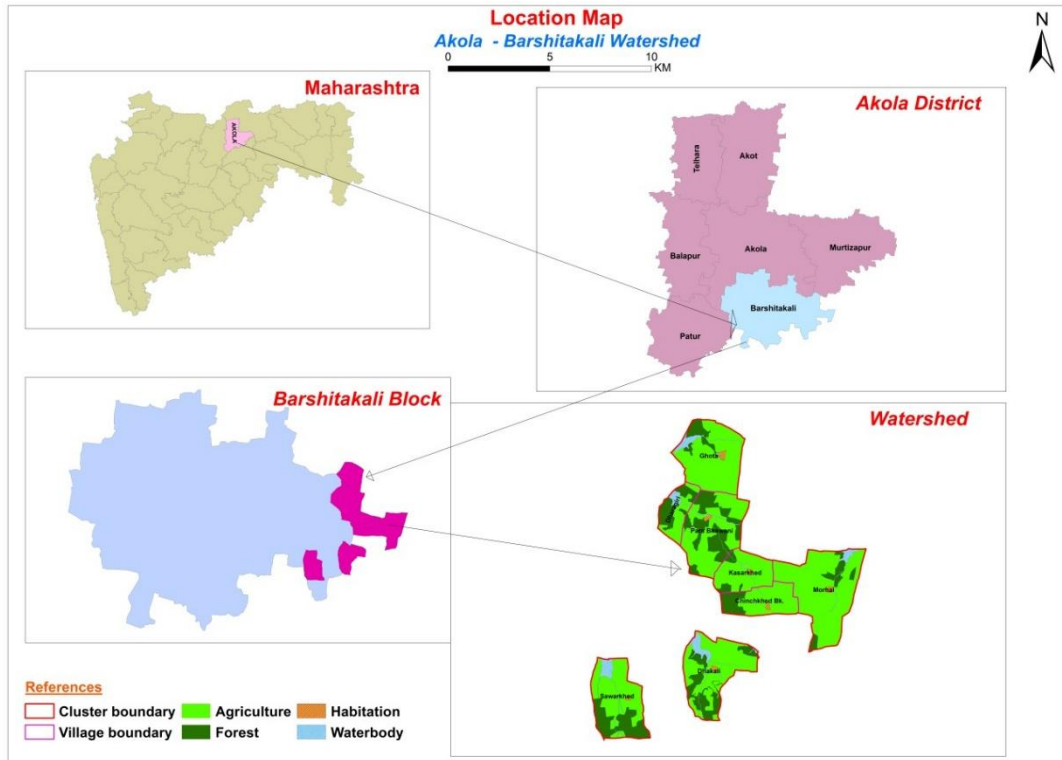


Fig. 2.1. Location map of the Akola-Barshitakli watershed

Barshitakli 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	Akola
2	Taluka	Barshitakli
3	Revenue Division	Amravati
4	Total sub-watershed Area	6274.30 ha
5	Villages	07 (Ghota, Dharagiri, Parabhavani, Sawarkhed, Kasarkhed, morhal, Dhakli)
6	Major River	Purna River
7	Climate	Hot, semi-arid climate
8	Average annual Rainfall	819 mm

2.2 Geology

Barshitakli, located in the southeastern part of akola district, lies within the deccan volcanic province, one of the largest continental flood basalt regions in the world. the area is predominantly underlain by cretaceous-eocene tholeiitic basaltic lava flows, forming the characteristic hard rock terrain of the Vidarbha region. these flows are generally massive, with occasional vesicular or amygdaloidal structures. thin intertrappean beds of sedimentary origin, such as clay, shale, or limestone, may be present between successive lava flows, reflecting quiescent periods during volcanic activity. the basaltic layers exhibit columnar jointing and spheroidal weathering, contributing to the formation of well-drained shallow to moderately deep black soils, with localized patches of red soils on higher elevations.

2.3 Geomorphology

Geomorphologically, Barshitakli lies in the eastern Deccan Plateau region, forming a transitional zone between the plateau uplands and the low-lying plains of the Purna River basin, a tributary of the Godavari River. The terrain is mostly undulating to gently rolling, interspersed with low basaltic hills and mesas, which are remnants of differential erosion of Deccan Trap lava flows. Elevations in the taluka generally range from 300 to 450 meters above mean sea level. The alluvial plains along the Purna River and its tributaries possess relatively deeper, more fertile soils, making them suitable for agriculture, while the plateau and upland areas have shallow soils, sparse vegetation, and moderate to severe soil erosion. The drainage network exhibits a dendritic pattern, characteristic of basaltic terrains. Distinct geomorphic units in the region include buttes, mesas, escarpments, hills and ridges, plateau tops, pediments, and pediplains.

2.4 Physiography and Soil

The geomorphic units of Barshitakli govern surface runoff patterns, soil distribution, and infiltration characteristics across the watershed. The underlying deccan trap basalt weathers to form soils whose depth and texture vary with slope position and degree of landscape dissection. Slope values in the taluka range from 0 to >70%, but the majority of the watershed exhibits gentle slopes below 6%, whereas steeper slopes are restricted to hills, ridges, escarpments, and mesa edges. Soils derived from basaltic parent material show

considerable variation in texture, depth, and physical properties depending on topographic position. Based on texture, the soils are predominantly loamy, with moderate fertility and good moisture-holding capacity, making them suitable for agriculture in plains and gentle slopes. However, during short-duration, high-intensity rainfall events, soils on steeper slopes are prone to surface sealing and runoff, which can trigger localized soil erosion.

2.5 Climate

The Barshitakli watershed experiences a semi-arid to sub-humid climate, typical of the eastern Deccan Plateau region. The climate is predominantly controlled by the southwest monsoon, which delivers most of the annual rainfall between June and September. The average annual rainfall ranges from 600 mm to 800 mm, with marked inter-annual and spatial variability. The monsoon contributes approximately 80–90% of total precipitation, making the watershed heavily dependent on seasonal rainfall for agriculture and groundwater recharge. The rainfall pattern is often erratic, leading to periodic droughts and water scarcity. Temperature variations are moderate to high throughout the year. Summers, from March to May, are hot and dry, with maximum temperatures frequently reaching 38–42°C, while winters, from November to February, are relatively cooler, with minimum temperatures occasionally dropping to 10–12°C. Relative humidity remains high during the monsoon season (above 70%) but drops significantly in summer. The region also experiences high evaporation rates, particularly during the pre-monsoon months, exacerbating water stress where irrigation infrastructure is inadequate.

2.6 Drainage

The Barshitakli watershed is part of the Purna River Basin, which ultimately drains into the Godavari River. The drainage network exhibits a dendritic pattern, typical of basaltic terrains, reflecting uniform lithology and relatively gentle slopes in the region. Several minor streams and rivulets traverse the watershed, converging into the main Purna River channel. The drainage density varies with topography and slope: flatter plateau areas and alluvial plains show lower drainage density, while hilly and escarpment zones demonstrate denser stream networks due to higher runoff. The surface runoff from rainfall events is largely controlled by the combination of slope, soil permeability, and geomorphic units. Seasonal streams dominate the network, with flow peaks during the monsoon, and minimal discharge during the dry months. The drainage system plays a critical role in irrigation, groundwater recharge, and soil conservation, and its characteristics influence the planning of watershed development interventions such as check dams, contour trenches, and percolation structures.

2.7 Water Resources, Cropping Patterns, and Demography and Socioeconomics

2.7.1 Surface Water

Surface water in the Barshitakli watershed primarily occurs in the form of seasonal streams, rivulets, and small ponds, which are fed by rainfall and runoff from the surrounding basaltic uplands. The watershed is part of the Purna River Basin, with the Purna River and its tributaries serving as the main drainage channels. During the monsoon season, these

streams carry substantial runoff, replenishing local water bodies and contributing to groundwater recharge. In addition to the river system, the watershed contains minor water harvesting structures such as farm ponds, check dams, and small reservoirs, which help store water for irrigation and livestock needs during the dry season. The availability of surface water is highly seasonal, with most flows occurring between June and September, while many smaller streams and ponds may dry up during the pre-monsoon and summer months. The spatial distribution of surface water is controlled by topography, drainage density, and slope, with low-lying alluvial plains and depressions accumulating larger water bodies, whereas the hilly and plateau regions exhibit rapid runoff and limited water retention. Effective watershed management in the area focuses on augmenting surface water storage, controlling runoff, and promoting percolation to maintain water availability throughout the year.

2.7.2 Groundwater

Groundwater in the Barshitakli watershed occurs primarily in fractures, joints, and weathered zones of the Deccan Trap basalt, as well as in alluvial deposits along the Purna River and its tributaries. The basaltic hard rock terrain exhibits low primary porosity, so groundwater storage is largely controlled by secondary porosity features such as fractures, joints, and vesicular zones. Recharge of groundwater is highly seasonal, mainly occurring during the monsoon months (June–September) through rainfall infiltration, seepage from streams, and percolation from small water harvesting structures like check dams and farm ponds. The depth to water table varies across the watershed: it is relatively shallow in the alluvial plains and low-lying depressions, and significantly deeper in upland and plateau regions.

Groundwater quality is generally suitable for irrigation and domestic use, though localized variations in total dissolved solids (TDS) and hardness may occur depending on lithology and anthropogenic activity. The availability of groundwater is critical for sustaining agriculture during dry periods, particularly in areas where surface water is insufficient. Effective watershed interventions such as recharge structures, percolation tanks, and contour bunding play a key role in enhancing groundwater storage and maintaining water security in the region.

2.7.3 Irrigation and Water Management

Agriculture in the Barshitakli watershed largely depends on rainfed cultivation, given the semi-arid to sub-humid climate and seasonal rainfall variability. Irrigation facilities are limited, with minor canal systems, farm ponds, check dams, and percolation tanks providing supplementary water for crops during dry periods. Farmers primarily grow crops suited to monsoon rainfall, with irrigation supporting cash crops and high-value crops where available.

Water management in the watershed focuses on harvesting and conserving both surface and groundwater. Structures such as contour bunds, farm ponds, percolation tanks, and check dams help control runoff, reduce soil erosion, and improve groundwater recharge. These interventions are particularly important in upland and plateau areas, where shallow soils

and steep slopes result in high runoff and low water retention. Integrated water management practices in the watershed aim to maximize water use efficiency, enhance agricultural productivity, and mitigate drought and water scarcity risks. Proper maintenance of minor irrigation structures and adoption of soil moisture conservation techniques play a critical role in sustaining crop yields and ensuring water security in the Barshitakli region.

2.7.4 Cropping Pattern

Agriculture in the Barshitakli watershed is largely rainfed, influenced by the semi-arid to sub-humid climate, soil fertility, and availability of irrigation. The cropping pattern is predominantly seasonal, with kharif crops sown during the monsoon and rabi crops cultivated in the post-monsoon season where residual soil moisture or irrigation is available. Major Kharif crops include soybean, cotton, pigeon pea (tur), and sorghum (jowar), which are well-adapted to the rainfall variability and soil conditions of the region. Rabi crops such as wheat, chickpea, and safflower are grown in areas with supplemental irrigation or in well-drained soils on alluvial plains.

Crop selection is also influenced by topography and soil depth. The upland plateau and hilly areas with shallow, less fertile soils predominantly support drought-resistant crops like sorghum and pigeon pea, while low-lying alluvial areas with deeper black soils are used for more intensive cultivation of cotton, soybean, and wheat. Farmers increasingly adopt crop rotation and mixed cropping systems to maintain soil fertility, reduce pest incidence, and optimize water use. Efficient rainwater harvesting and minor irrigation structures further enhance the sustainability of the cropping system in the watershed.

2.7.5 Demographic and Socioeconomic Status

The demographic landscape of Barshitakli taluka is predominantly rural, with a majority Hindu population and smaller communities of Muslims and other minorities. The population is primarily engaged in agriculture and allied activities, reflecting the semi-arid, rainfed nature of the region. Indigenous tribal communities are present in small pockets, contributing to the cultural diversity of the taluka. Education levels in Barshitakli are moderate, with literacy rates improving steadily due to government initiatives and local schools. However, the gender ratio remains slightly skewed towards males, especially in rural areas, reflecting broader regional trends in Vidarbha.

Economically, the taluka is largely agriculture-dependent, with limited industrial activity. Major sources of livelihood include crop cultivation, livestock rearing, and small-scale trade. Migration from upland and drought-prone areas occurs seasonally, primarily to nearby towns and cities for labour and employment opportunities. Overall, Barshitakli represents a rural agricultural economy with moderate literacy, gender imbalances, and dependence on seasonal rainfall, differing from the urbanized and industrialized profile seen in Barshitakli.

2.8 Constraints

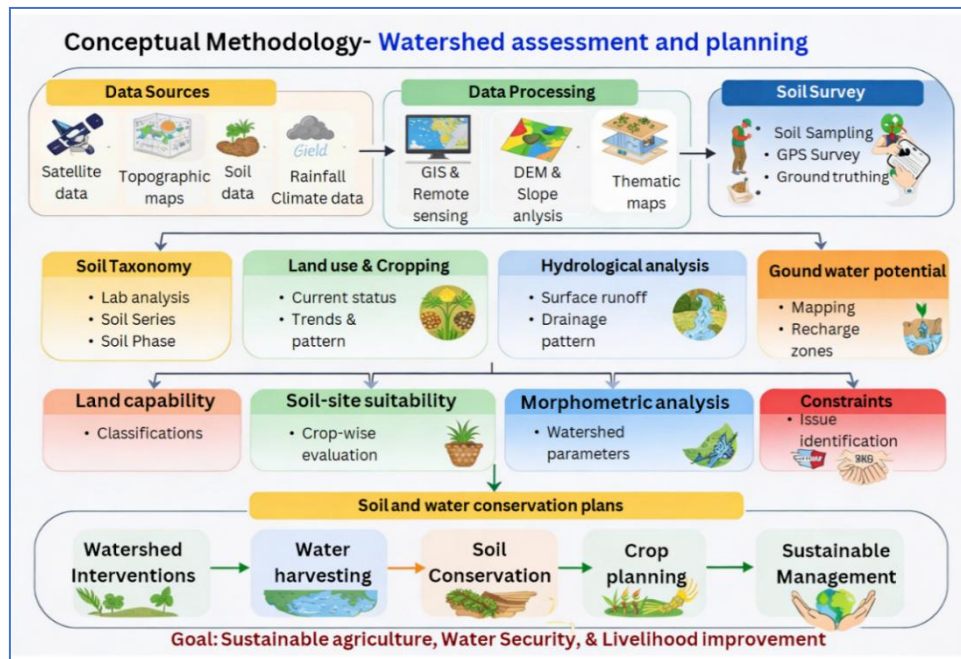
The following key issues were observed in the cluster villages, both through field surveys (2024-2025) and community consultations:

- 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 Barshitakli 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 Barshitakli 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 Barshitakli 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 unbunded 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 210 farmers 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 Barshitakli cluster of District Akola reveals a strong dependence on wells, which account for 38% of irrigation sources across surveyed villages. Borewell contribute 16%. Notably, 45% of households have no irrigation source, indicating high exposure to rainfall variability. Villages such as Dharagiri Sawarkhed, Chinchkhed Bk. almost entirely on wells. 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 Barshitakli 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. To reduce vulnerability and improve irrigation reliability, the cluster requires broader adoption of rainwater harvesting, farm ponds, and micro-irrigation technologies.

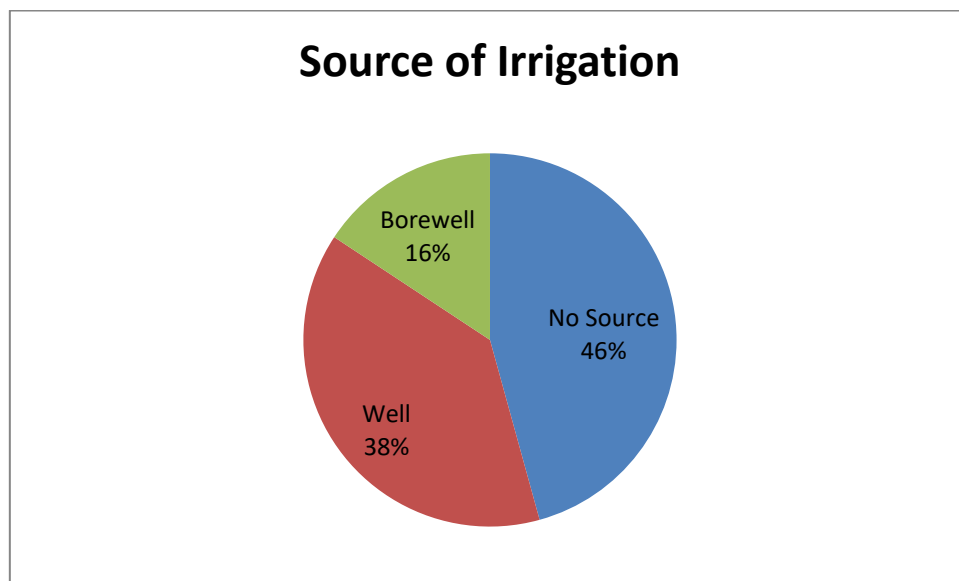


Fig. 4.1. Break-up of irrigation Sources in the Akola-Barshitakli watershed

4.1.2 Cropping Pattern

Cropping in the watershed is largely dependent on monsoon rainfall, and the agricultural system follows the kharif and rabi seasonal pattern. During the kharif season, the major crops cultivated by farmers are soybean, tur, and cotton, whereas gram (chickpea) and wheat are the main crops grown during the rabi season. Based on the data obtained from 210 farmers in the study area, soybean is the dominant kharif crop, cultivated by 210

farmers over an area of 259.45 ha with a productivity of 1657.35 kg ha⁻¹. Tur is grown by 137 farmers covering 42.82 ha, with a productivity of 135.80 kg ha⁻¹. Cotton is cultivated by 25 farmers on 18.74 ha, recording a productivity of 1611.27 kg ha⁻¹. These crops mainly depend on monsoon rainfall and form the backbone of kharif season agriculture. During the rabi season, gram and wheat are the major crops grown in the watershed. Gram is cultivated by 79 farmers on an area of 82.66 ha, with a productivity of 1527.95 kg ha⁻¹. Wheat is grown by 53 farmers covering 53.36 ha and records the highest productivity among all crops at 2217.77 kg ha⁻¹. Overall, the cropping pattern of the watershed indicates that soybean occupies the largest cultivated area during the kharif season, while wheat shows the highest productivity during the rabi season. The farming system in the area is largely rainfed, with limited irrigation available mainly for rabi crops. This cropping pattern reflects farmers' adaptation to the semi-arid climatic conditions, focusing on crops that ensure both food security and stable farm income.

Table 4.1. Crop Cultivation Pattern across the Akola-Barshitakli Cluster

Sr. No.	Crop	Farmers interviewed (n)	Season	Area (ha)	Productivity (kg ha ⁻¹)
1	Soybean	210	Kharif	259.45	1657.35
2	Tur	137	Kharif	42.82	135.80
3	Cotton	25	Kharif	18.74	1611.27
4	Gram	79	Rabi	82.66	1527.95
5	Wheat	53	Rabi	53.36	2217.77

4.1.3 Socioeconomic Status

4.1.3.1 Land holding pattern

The distribution of land holdings in the watershed indicates a strong dominance of small and marginal farmers, which reflects the fragmented nature of agricultural land in the study area. Based on the data collected from 210 farmers, the farmers were categorized into five groups according to their landholding size. The small farmer category (1–2 ha) constitutes the largest proportion of the farming community, with 107 farmers representing 50.95% of the total respondents. The average landholding size in this category is 1.56 ha. This indicates that most farmers in the watershed operate on relatively small agricultural land, which may limit their production capacity but encourages efficient land use practices. The marginal farmers (<1 ha) form the second-largest group, consisting of 74 farmers (35.23%) with an average landholding of 0.81 ha. These farmers generally rely on small-scale cultivation and are more vulnerable to climatic variability and resource limitations. The semi-medium farmers (2–4 ha) account for 25 farmers (11.90%), with an average landholding of 3.03 ha. This group has comparatively better access to land resources and may adopt improved agricultural practices more easily. The medium farmer category (4–10 ha) represents only 4 farmers (1.90%), with an average landholding of 5.19 ha, indicating that relatively few farmers possess larger operational holdings in the watershed. Notably, no farmers were recorded in the large farmer category (>10 ha). Overall, the

findings highlight that the watershed is predominantly characterized by small and marginal landholdings, which together account for over 86% of the total farmers. This pattern emphasizes the importance of sustainable land and water management practices, improved irrigation, and efficient resource utilization to enhance agricultural productivity and livelihood security in the region.

Table 4.2. Land holding pattern in Akola-(Barshitakli) watershed

Category	Criteria Land (ha)	No. of Farmers Interviewed (n)	Farmers (%)	Average Land holding (ha)
Marginal Farmers	<1	74	35.23%	0.81
Small Farmers	1-2	107	50.95%	1.56
Semi-Medium Farmers	2-4	25	11.90%	3.03
Medium Farmers	4-10	4	1.90%	5.19
Large Farmers	>10	0	0%	0.00

4.1.3.2 Income distribution

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

Table 4.3. Average annual income of farmers in Akola-Barshitakli watershed

Name of crops	No. of Farmers interviewed (n)	Crop area (%)	Average Income (Rs.)
Soybean	210	259.45	102380.95
Tur	137	42.82	24006.56
Cotton	25	18.74	84546.00
Gram	79	82.66	83134.10
Wheat	53	53.36	55801.88

The income pattern of major crops grown in the watershed indicates variations in crop profitability and their contribution to farmers' livelihoods. Based on the data collected from farmers, five major crops—soybean, tur, cotton, gram, and wheat—are cultivated across kharif and rabi seasons. During the kharif season, soybean occupies the largest cultivated area of 259.45 ha and is grown by 210 farmers, making it the dominant crop in the watershed. It provides an average income of Rs 2047.62, indicating its importance as a major income-generating crop for farmers. Tur is cultivated by 137 farmers over 42.82 ha, but it generates a relatively lower average income of Rs 400.11, suggesting lower profitability compared to other crops. Cotton, although cultivated by only 25 farmers on 18.74 ha, provides a comparatively higher average income of Rs 1207.81, indicating its potential as a cash crop. In the rabi season, gram is cultivated by 79 farmers on 82.66 ha, generating an average income of Rs 1598.73, which contributes significantly to farmers' seasonal earnings. Wheat, grown by 53 farmers on 53.36 ha, records the highest average

income of Rs 2232.83 among the listed crops, highlighting its economic importance during the rabi season. Overall, the income pattern indicates that soybean dominates in terms of cultivated area, while wheat and gram contribute substantially to farm income during the rabi season. Although crops like tur and cotton occupy relatively smaller areas, they still play a role in crop diversification and income stability. The cropping system thus reflects a balance between food crops and cash crops, helping farmers maintain both economic returns and food security in the watershed.

4.1.3.3 Education

The educational status of farmers in the watershed shows moderate levels of educational attainment with noticeable variation among villages. Education plays a crucial role in influencing farmers' awareness, decision-making ability, and adoption of improved agricultural technologies. Among the villages, Chinchkhed Bk has 23.33% illiterate respondents, while 30% of the farmers have completed secondary education, indicating a moderate level of schooling. In Dharagiri, the illiteracy rate is relatively low (6.6%), and the majority of respondents have attained higher secondary education (40%), with 20% completing higher studies, indicating comparatively better educational development. In Ghota village, the largest proportion of respondents (33.33%) have completed primary education, while 26.66% have higher secondary education. Morhal village shows a balanced educational distribution, with 26.66% having higher secondary education and 23.33% having secondary education. Parabhavani village demonstrates relatively higher educational attainment, with 36.66% of respondents having higher secondary education and 23.33% completing higher studies, which is the highest proportion of higher education among the villages. Kasarkhed village has the highest percentage of secondary education (50%), although only 6.6% of respondents have higher studies. In Sawarkhed village, primary education (26.66%) and secondary education (23.33%) dominate, while 16.6% of respondents have completed higher studies, showing moderate educational progress.

Table 4.4. Education profile of villages in Akola-Barshitakli watershed by population

Village	No Education (%)	Primary (%)	Secondary (%)	Higher Secondary (%)	Higher Studies (%)
Chinchkhed Bk	23.33	26.66	30	13.33	6.6
Dharagiri	6.6	6.6	26.66	40	20
Ghota	10	33.33	23.33	26.66	6.6
Morhal	13.3	16.66	23.33	26.66	13.33
Parabhavani	6.6	3.3	26.66	36.66	23.33
Kasarkhed	16.6	6.6	50	20	6.6
Sawarkhed	16.6	26.66	23.33	16.6	16.6

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 4565.73 hectares, and constitutes approximately 72.77% of the total area (Table 4.5 and Fig. 4.2). Forested land cover accounts for 22.09% of the landscape, indicating a moderate presence of natural vegetation. Habitation represents 0.88% of the area, which may indicate land degradation or areas unsuitable for cultivation. Waterbodies are limited to 267.22 ha, making up 14.26 % 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 Barshitakli watershed

Sr. No.	Land Use	Area (ha)	Percent (%)
1	Agriculture	4565.73	72.77
2	Forest	1386.18	22.09
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

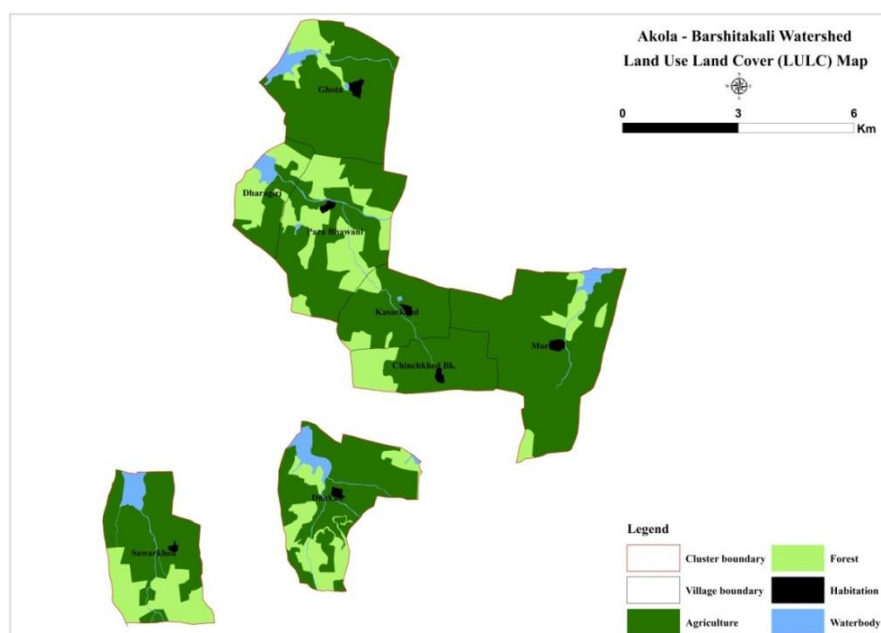


Fig. 4.2. Land-use/land-cover map Akola-Barshitakli

4.3 Landform Delineation

The landform analysis of the study area indicates a diverse geomorphological setting with several distinct landform units (Table 4.6). Among them, the middle pediment occupies the largest area, covering 1447.28 ha (23.07%) of the total watershed area. This is followed by the upper pediment, which extends over 1380.26 ha (22.00%), indicating the dominance of gently sloping erosional surfaces in the region. Pediplains cover 722.73 ha (11.52%), while escarpments account for 698.05 ha (11.13%), representing steep slopes and breaks in the terrain. Hills occupy 688.13 ha (10.97%), reflecting the presence of elevated and rugged

terrain. The lower pediment covers 591.98 ha (9.44%), and valleys extend over 307.62 ha (4.90%), indicating areas influenced by fluvial processes. Water bodies occupy 267.22 ha (4.26%), while plateau tops cover 113.79 ha (1.81%) of the total area. Habitation areas account for 55.18 ha (0.88%), and butte/mesa landforms are very limited, covering only 2.06 ha (0.03%). Overall, the watershed is predominantly characterized by pediment and pediplain landforms, along with hills, escarpments, and valleys, reflecting a combination of erosional and depositional geomorphic processes. The landform map of the watershed is presented in Fig. 4.3.

Table 4.6. Landform features existing in Barshitakli watershed

Sr. No.	Landform	Area (ha)	Percent (%)
1	Plateau	113.79	1.81
2	Hill	688.13	10.97
3	Escarpment	698.05	11.13
4	Upper Pediment	1380.26	22.00
5	Middle Pediment	1447.28	23.07
6	Lower Pediment	591.98	9.44
7	Pediplain	722.73	11.52
8	Valley	307.62	4.90
9	Butte/Messa	2.06	0.03
10	Habitation	55.18	0.88
11	Waterbody	267.22	4.26
	Total	6274.30	100.00

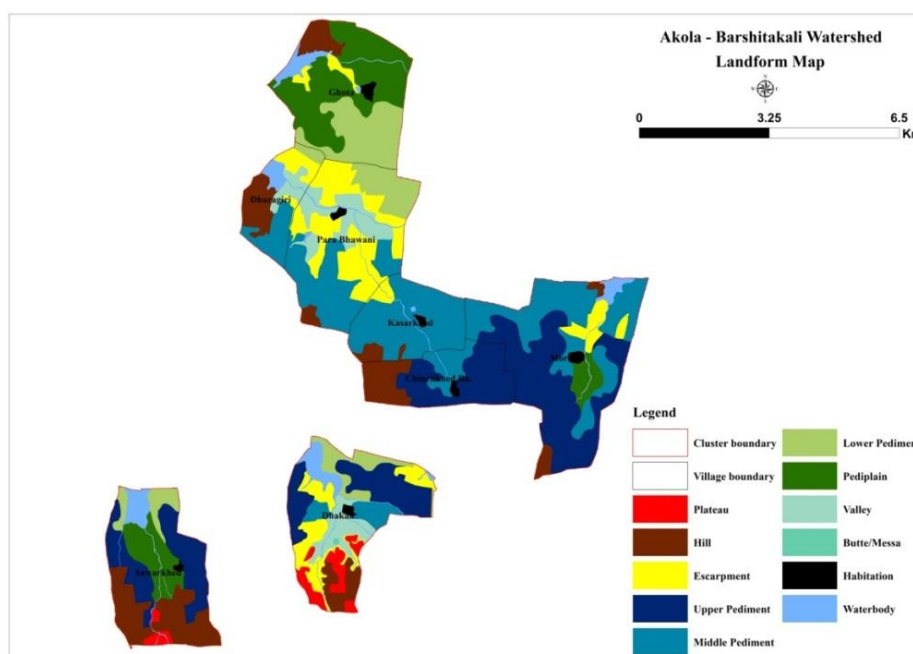


Fig. 4.3. Landform map of Akola-Barshitakli watershed

4.4 Soil series and phases

Eight soil series have been identified and mapped with 14 soil mapping units (14 phases of series) (Fig 4.4). The detailed descriptions of each series are given in Table 4.7, Table 4.8 and Fig.4.5.

Table 4.7. Dominant soil series identified in the watershed

Sr. No.	Series	Area (ha)	Percent (%)
1	Chinchkhed Bk.	282.57	4.50
2	Dhakali	344.60	5.49
3	Dharagiri	487.88	7.78
4	Ghota	2188.04	34.87
5	Kasarkhed	670.56	10.69
6	Morhal	31.35	0.50
7	Para Bhawani	942.68	15.02
8	Sawarkhed	1004.23	16.01
9	Habitation	55.18	0.88
10	Waterbody	267.22	4.26
	Total	6274.30	100.00

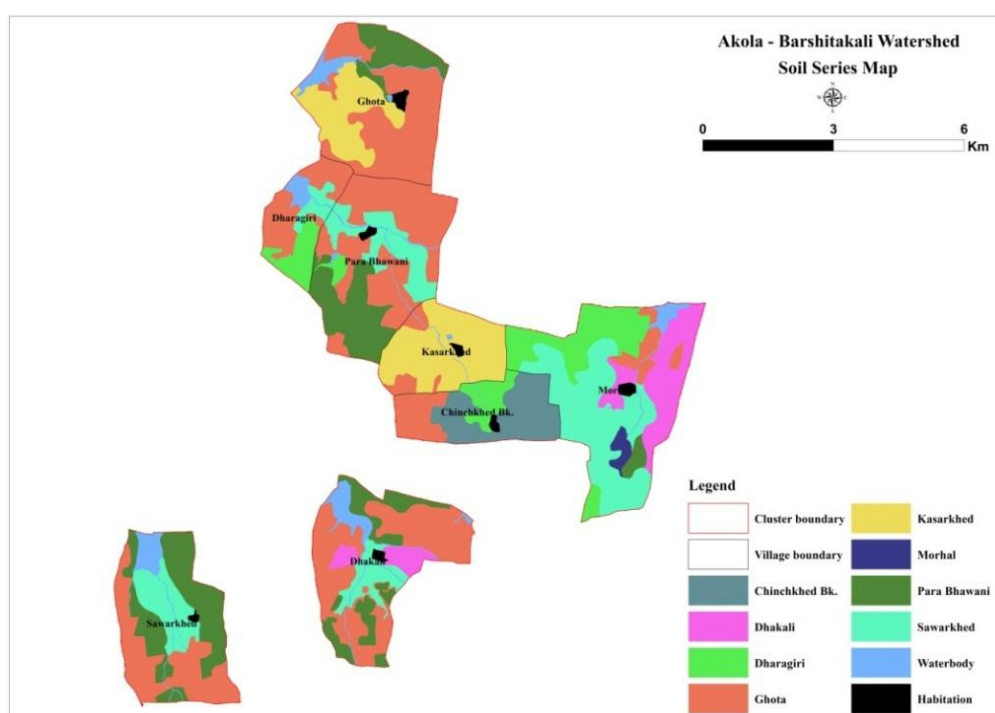


Fig. 4.4. Soil series map of Barshitakli watershed

Table 4.8 Soil phases existing identified in Barshitakli watershed

Sr. No.	Phase Class	Area (ha)	Percent (%)
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1	Chi4mB3	282.57141	4.50
2	Dha2mB3	358.669432	5.72
3	Dha2mC3	93.470155	1.49
4	Dha2mC4	380.341359	6.06
5	Gho1mC4	2188.035224	34.87
6	Kas5mB3	258.138171	4.11
7	Kas5mC3	412.424996	6.57
8	Mor2mC4	31.345989	0.50
9	Pab2mC3	163.665834	2.61
10	Pab2mC4	779.010703	12.42
11	Saw6mA2	33.861388	0.54
12	Saw6mB2	824.43622	13.14
13	Saw6mB3	99.545365	1.59
14	Saw6mC3	46.389586	0.74
15	Habitation	55.182869	0.88
16	Waterbody	267.21618	4.26
	Total	6274.30	100.00

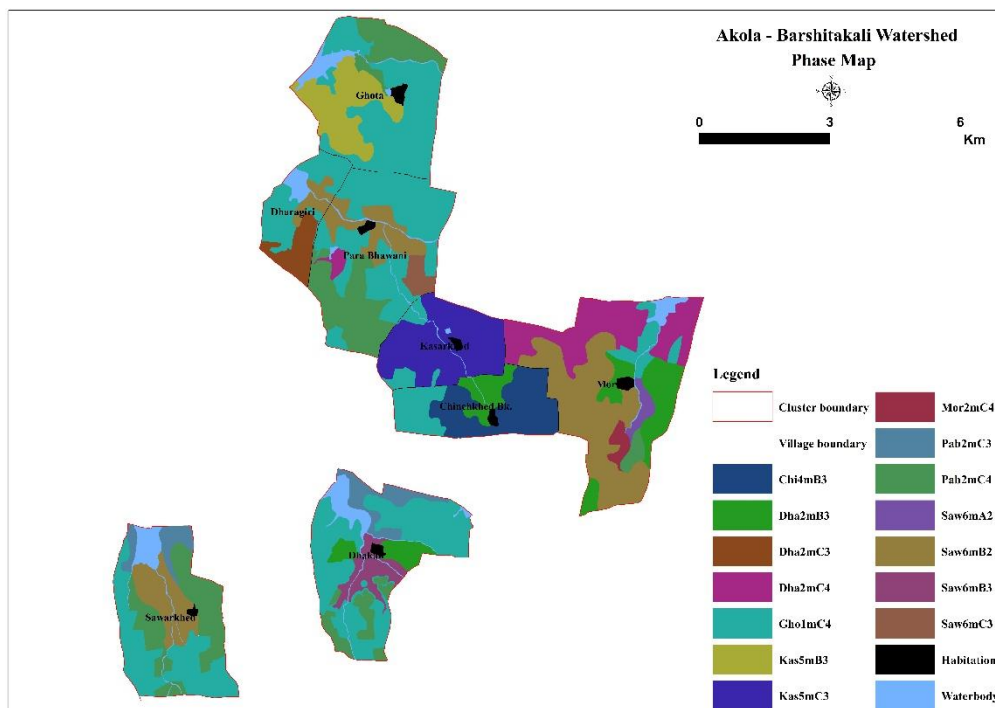


Fig. 4.5. Phase map of Akola-Barshitakli watershed

4.5 Soil Survey Interpretation

4.5.1 Slope

Land slope plays a crucial role in agriculture as it influences water drainage, soil erosion, and the ease with which crops can be cultivated. Steeper slopes generally experience higher surface runoff, which may lead to soil erosion and loss of fertile topsoil, ultimately affecting soil productivity and crop yields. In contrast, flat or gently sloping lands facilitate better water retention, efficient irrigation practices, and easier mechanization, which enhances agricultural productivity.

Slope also affects the microclimate of an area, as sloping terrains may experience variations in temperature, sunlight exposure, and moisture conditions. Considering the slope characteristics of land helps farmers adopt appropriate soil conservation practices such as contour farming, terracing, and bunding to reduce soil erosion and improve land management. Among the different slope classes (Table 4.9; Fig. 4.6), the maximum area of the watershed is under gently sloping terrain (3–8%), covering 65.26% of the total area.

This is followed by the very gently sloping class (1–3%), which accounts for 29.06% of the watershed area. The level to nearly level land (0–1%) occupies only 0.54% of the total area, indicating limited flat terrain in the study area. In addition, water bodies cover 4.26%, while habitation areas account for 0.88% of the watershed area.

Overall, the slope distribution indicates that the watershed is largely dominated by gently to very gently sloping terrain, which significantly influences runoff patterns, soil erosion processes, and land use practices. The slope map of the watershed is presented in Fig. 4.6.

Table: 4.9. Land slope classes in Barshitakli watershed

Sr. No.	Slope Class	Area (ha)	Percent (%)
1	Level to nearly level (0-1)	33.86	0.54
2	Very gently sloping (1 - 3)	1823.36	29.06
3	Gently Sloping (3 -8)	4094.68	65.26
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

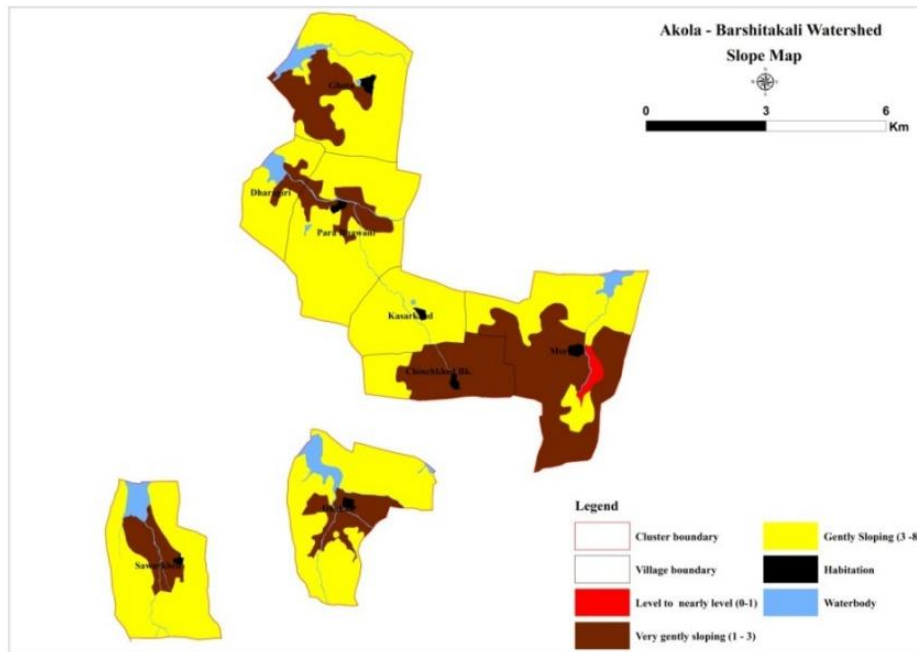


Fig. 4.6. Soil Slope map of Barshitakli watershed

4.5.2 Soil Erosion

Soil erosion, caused by water, wind, or human activities, removes the nutrient-rich top layer of soil and significantly affects soil fertility and land productivity. The loss of topsoil reduces the soil's capacity to retain moisture and nutrients, thereby decreasing agricultural productivity and making crops more vulnerable to drought stress, nutrient deficiencies, and pest infestations.

Furthermore, eroded soil particles are often deposited in nearby water bodies, leading to sedimentation, deterioration of water quality, and disturbance of aquatic ecosystems. Effective soil conservation practices such as maintaining crop cover, mulching, residue management, crop rotation, contour bunding, and terracing play an important role in controlling soil erosion and maintaining soil health.

The erosion analysis of the watershed (Table 4.10 Fig. 4.7) indicates that the very severe erosion class occupies the largest portion of the area, covering 53.85% of the total watershed area. This is followed by the severe erosion class, which accounts for 27.33%, while the moderate erosion class covers 13.68% of the total area. In addition, water bodies occupy 4.26% and habitation areas account for 0.88% of the watershed area. The dominance of severe to very severe erosion categories suggests that a large part of the watershed is vulnerable to significant soil loss, particularly in areas with higher slopes and limited vegetation cover.

Therefore, the implementation of appropriate soil and water conservation measures such as afforestation, contour bunding, check dams, and terracing is essential to reduce soil erosion and improve land sustainability in the watershed.

Table 4.10. Soil erosion status in the Barshitakli watershed

Sr. No.	Erosion Class	Area (ha)	Percent (%)
1	Moderate	858.30	13.68
2	Severe	1714.87	27.33
3	Very Severe	3378.73	53.85
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

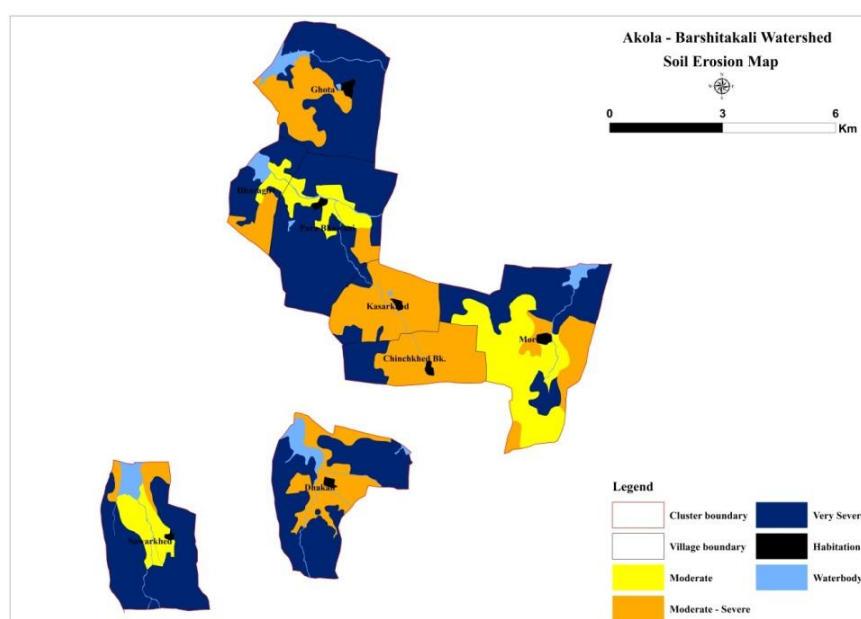


Fig. 4.7. Erosion map of Barshitakli watershed

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 influenced by landscape position and hydrological regime. Consequently, spatial variability in soil depth reflects not only the physical thickness of the soil profile but also broader gradients in soil fertility, water holding capacity, and ecosystem functioning across the terrain. Deeper soils generally provide more space for root penetration, better moisture storage, and enhanced nutrient availability, thereby supporting healthier plant growth and higher crop yields. In contrast, shallow soils restrict root development and reduce the availability of nutrients and moisture, particularly during dry periods, which can lead to lower productivity and increased vulnerability to drought stress. In areas with shallow soils, farmers may adopt management practices such as deep ploughing, addition of organic matter, and efficient irrigation to improve soil conditions and crop performance. Understanding soil depth therefore helps in making informed decisions regarding crop

selection, irrigation planning, and soil management for sustainable agricultural development.

The soil depth in the watershed (Fig. 4.8) varies from shallow (<25 cm) to very deep (>100 cm). The area-wise distribution of soil depth classes (Table 4.11) indicates that the maximum area is occupied by moderately deep soils (25–50 cm) covering 33.58% of the watershed. This is followed by shallow soils (<25 cm) accounting for 30.08% of the total area. Very deep soils (>100 cm) occupy 16.01%, while deep soils (75-100 cm) cover 11.08% of the watershed. Moderately deep soils (50-75 cm) constitute only 4.11% of the total area. In addition, water bodies account for 4.26% and habitation areas occupy 0.88% of the watershed area. The predominance of shallow to moderately deep soils indicate moderate soil development across the watershed, which has important implications for crop planning, soil moisture management, and sustainable land use practices.

Table 4.11. Soil depth classes in Akola-Barsitakli watershed

Sr. No.	Depth Class	Area (ha)	Percent (%)
1	Shallow (<25)	1887.50	30.08
2	Moderate (25-50)	2107.04	33.58
3	Moderately Deep (50-75)	258.14	4.11
4	Deep (75-100)	695.00	11.08
5	Very Deep (>100)	1004.23	16.01
6	Habitation	55.18	0.88
7	Waterbody	267.22	4.26
	Total	6274.30	100.00

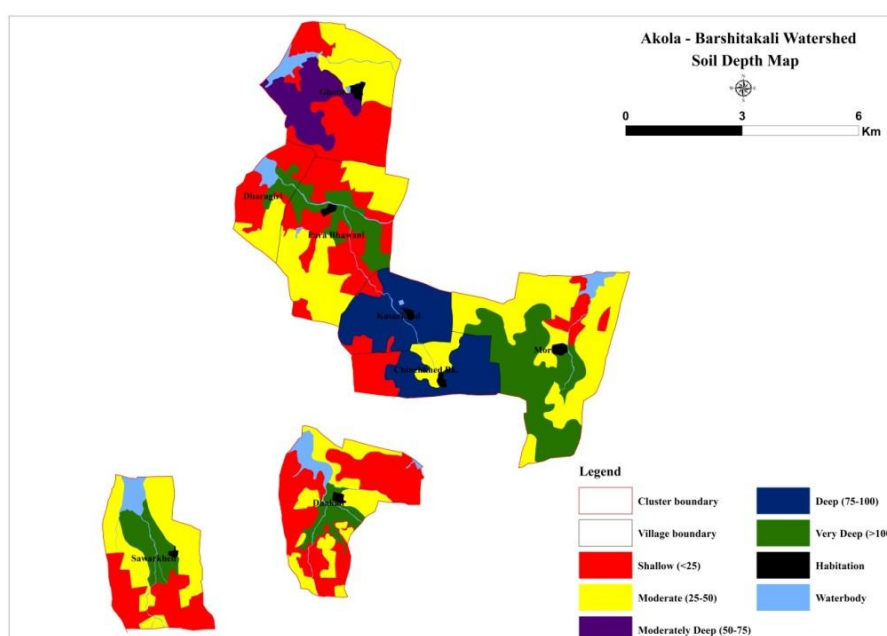


Fig. 4.8. Depth map of Akola-Barshitakli watershed

4.5.4 Surface texture:

Soil texture plays a vital role in agriculture by directly influencing water retention, root development, and nutrient availability for crops. Soils with finer textures, such as clay, generally have higher nutrient-holding capacity and moisture retention, whereas coarser soils, like gravely clay, may provide better drainage but lower water-holding ability. Understanding the soil texture of a region helps farmers make informed decisions regarding crop selection, irrigation management, and the use of soil amendments to enhance fertility and productivity.

The soil texture of the watershed (Table 4.12; Fig. 4.9) is predominantly composed of gravely clay, covering 3618.59 ha (57.67%) of the total area, followed by clay soils, which account for 2333.31 ha (37.19%). In addition, water bodies occupy 267.22 ha (4.26%), while habitation areas cover 55.18 ha (0.88%). The dominance of clay and gravely clay soils suggests that, despite the presence of coarse fragments in some areas, the soils generally have moderate to high fertility potential and can support a wide range of crops, particularly in the moderately deep to deep soil zones. Proper soil and water management practices, including mulching, organic amendments, and irrigation planning, are recommended to optimize crop productivity across the watershed.

Table 4.12. Soil texture distribution in Akola-Barshitakli watershed

Sr.No.	Texture	Area (ha)	TGA (%)
1	Clay	2333.31	37.19
2	Gravely Clay	3618.59	57.67
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

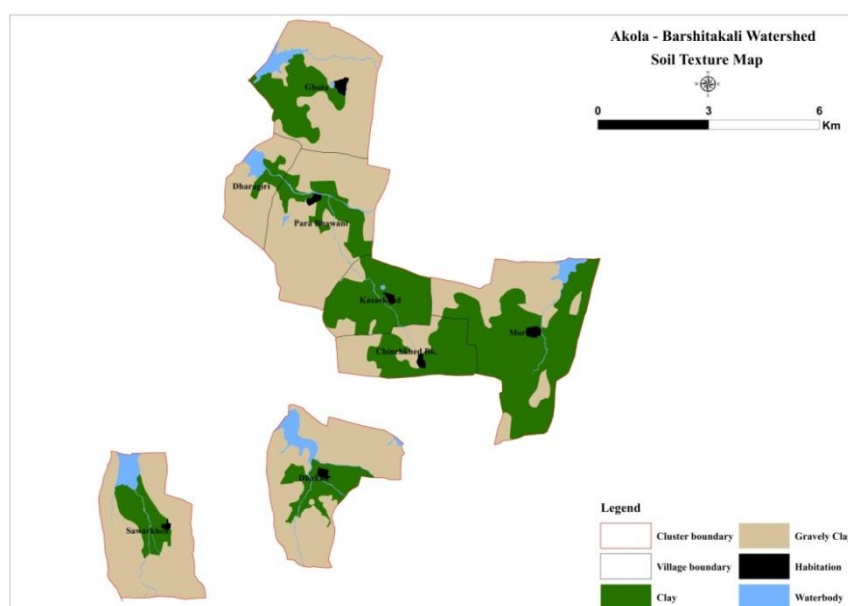


Fig. 4.9. Soil texture map of Akola-Barshitakli watershed

4.5.5 Soil reaction

Soil reaction, expressed as pH, is a critical parameter for plant growth and health, as it directly influences nutrient availability, microbial activity, and overall soil fertility, which in turn affect crop yields and land suitability. Knowledge of soil pH also guides the application of soil amendments to correct acidity or alkalinity, ensuring optimal soil conditions for agriculture.

The soils of the watershed have been grouped into different pH classes (Table 4.13; Fig. 4.10). The analysis reveals that the majority of soils are neutral (pH 6.5–7.5), covering 2850.25 ha (45.43%) of the watershed. This is followed by slightly alkaline soils (pH 7.5–8.0), which account for 2028.24 ha (32.33%), and moderately alkaline soils (pH 8.0–9.0), covering 707.94 ha (11.28%). Soils with slightly acidic reaction (pH 6.0–6.5) occupy 251.68 ha (4.01%), while moderately acidic soils (pH 5.0–6.0) are limited to 113.79 ha (1.81%) of the area. In addition, water bodies and habitation areas account for 4.26% and 0.88%, respectively.

Table 4.13. Soil pH distribution in Akola-Barshitakli watershed

Sr.No.	Soil pH	Area (ha)	TGA (%)
1	Moderately Acidic (5.0 - 6.0)	113.79	1.81
2	Slightly Acidic (6.0 - 6.5)	251.68	4.01
3	Neutral (6.5 - 7.5)	2850.25	45.43
4	Slightly Alkaline (7.5 - 8.0)	2028.24	32.33
5	Moderately Alkaline (8.0 - 9.0)	707.94	11.28
6	Habitation	55.18	0.88
7	Waterbody	267.22	4.26
	Total	6274.30	100

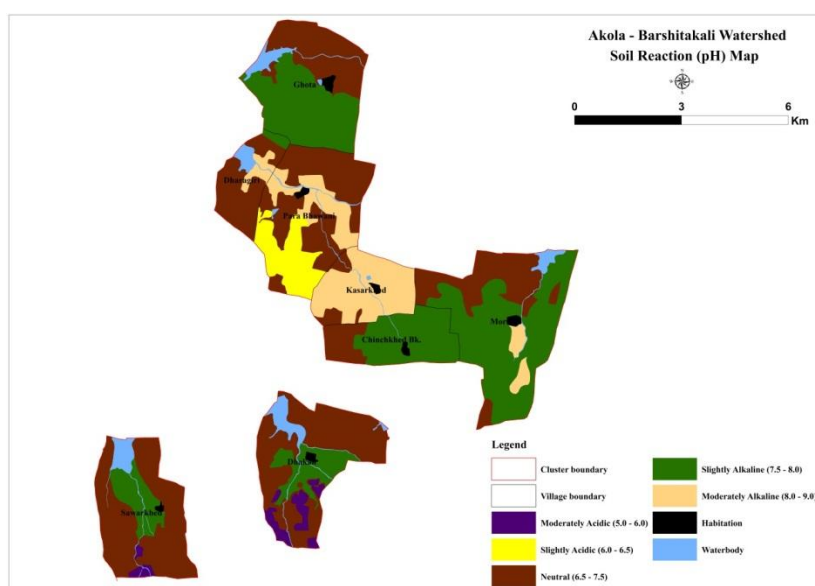


Fig. 4.10. Soil pH map of Akola-Barshitakli watershed

4.5.6 Soil salinity

Soil salinity, measured through the electrical conductivity of a solution within a unit distance, represents the content of soluble salts in the matrix. Soil conductivity is an index to measure soil water-soluble salt, which is an important indicator of mineral nutrients in the topsoil that can be quickly utilized by plants and is a factor to determine whether salt ions in soil limit crop growth. The EC of the soils of the watershed were well within the permissible limit of salinity (Table 4.14) and will not cause any detrimental effect on crop growth. Hence, the map is not shown here.

Table 4.14. Soil salinity classes in the Akola-Barshitakli watershed

Sr. No.	Electrical conductivity (dSm ⁻¹)	Area (ha)	TGA (%)
1	Normal (< 1)	5951.91	94.86
2	Habitation	55.18	0.88
3	Waterbody	267.22	4.26
	Total	6274.30	100.00

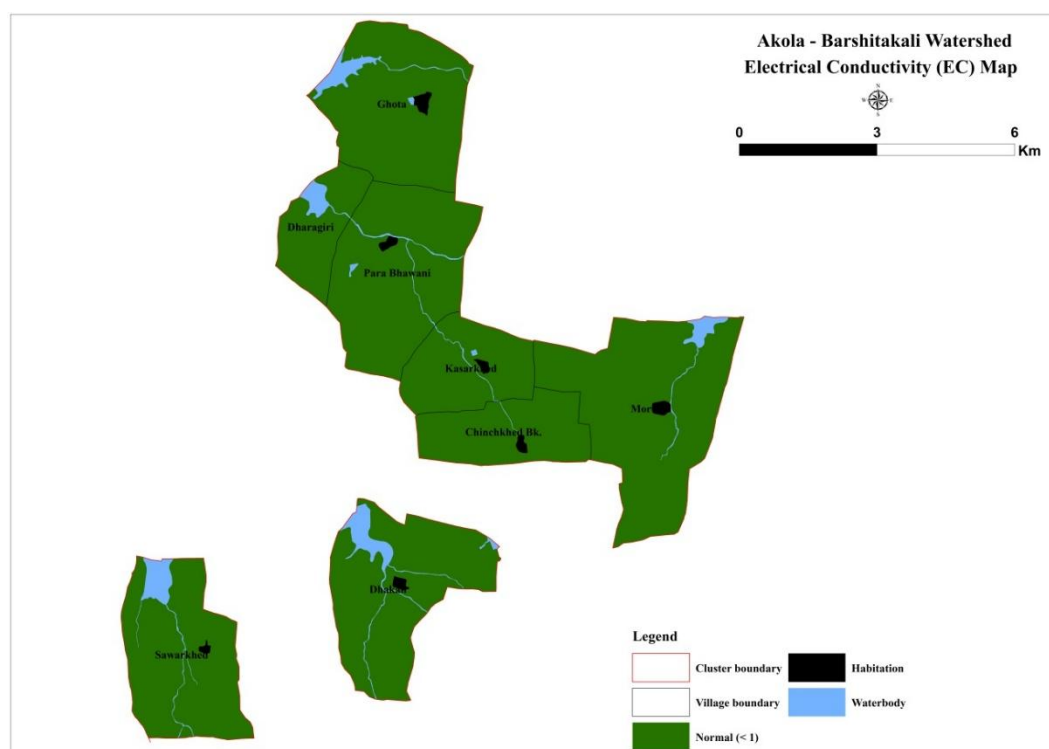


Fig.4.11 Status of soil salinity in Akola-Barshitakli watershed

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 (52.98 %) contains more than 10% CaCO₃ in soil, which could pose problems to normal crop growth.

Table 4.15. Extent of calcareousness in soils of Akola-Barshitakli watershed

Sr.No.	CaCO ₃ content (%)	Area (ha)	TGA (%)
1	Very Low (< 0.5)	3324.34	52.98
2	Moderately High (2.0 - 5.0)	692.87	11.04
3	High (5.0 - 10.0)	1419.43	22.62
4	Very High (> 10.0)	515.27	8.21
5	Habitation	55.18	0.88
6	Waterbody	267.22	4.26
	Total	6274.30	100.00

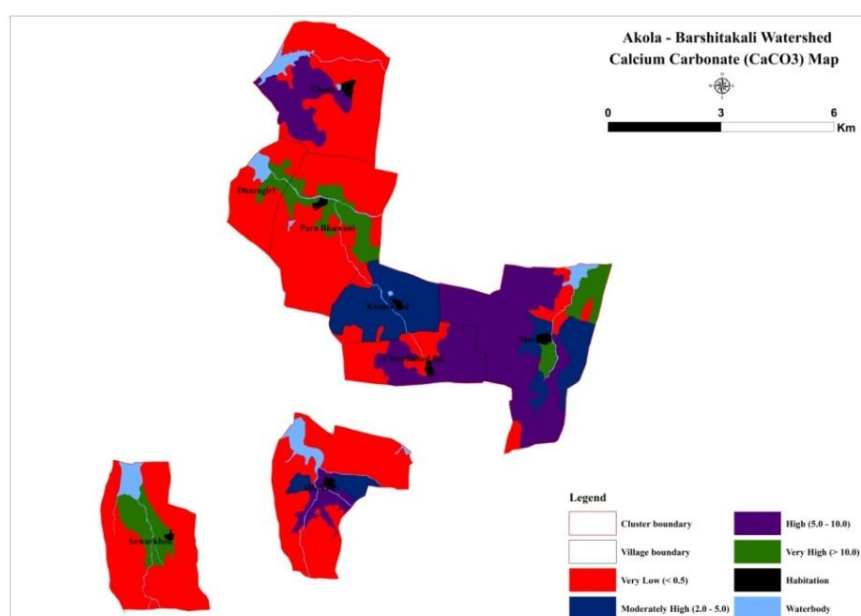


Fig. 4.12. Status of soil calcareousness in Akola-Barshitakli watershed

4.5.8 Soil organic carbon

Soil Organic Carbon (SOC) is a critical component influencing several ecological and soil processes. It is primarily derived from the decomposition of plant and animal residues such as leaves, roots, and dead organisms. SOC is considered an important indicator of soil health and fertility, as it plays a vital role in nutrient cycling, soil structure improvement, and biological activity. SOC significantly influences the soil's ability to retain and release essential nutrients, enhances water-holding capacity, and supports microbial activity, which collectively contribute to improved soil productivity. In addition, SOC acts as a major reservoir for carbon sequestration, thereby helping to mitigate climate change by removing carbon dioxide from the atmosphere and storing it in the soil. Monitoring SOC levels is therefore essential for sustainable land use and soil management. The depletion of SOC due to practices such as deforestation, excessive tillage, and intensive agricultural practices can lead to soil degradation, reduced agricultural productivity, and increased greenhouse gas emissions. Adoption of climate-smart agricultural practices, including the application of organic manures, crop residue incorporation, and conservation farming, can enhance

SOC levels and maintain long-term soil fertility. The soils of the watershed under study show moderately high to very high organic carbon content, as presented in Table 4.16 and Fig. 4.13. A large proportion of the watershed area falls under the high (0.80-1.00%) and very high (>1.00%) SOC categories, indicating generally good soil health and fertility status. This condition may be attributed to the presence of moderately deep soils and loamy soil texture, which favour the accumulation and stabilization of organic matter in the soil profile. However, a smaller portion of the area shows moderately high SOC levels, suggesting that there is still scope for improvement through better soil management practices. Therefore, there is a strong need for regular application of organic manures, compost, green manuring, and crop residue management by farmers in the watershed area to maintain and further enhance soil organic carbon levels.

Table 4.16. Soil organic carbon status of Akola-Barshitakli watershed

Sr. No.	OC Class	Area (ha)	Percent (%)
1	Moderately High (0.61 - 0.80)	489.86	7.81
2	High (0.80 - 1.00)	2642.92	42.12
3	Very High (> 1.00)	2819.13	44.93
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

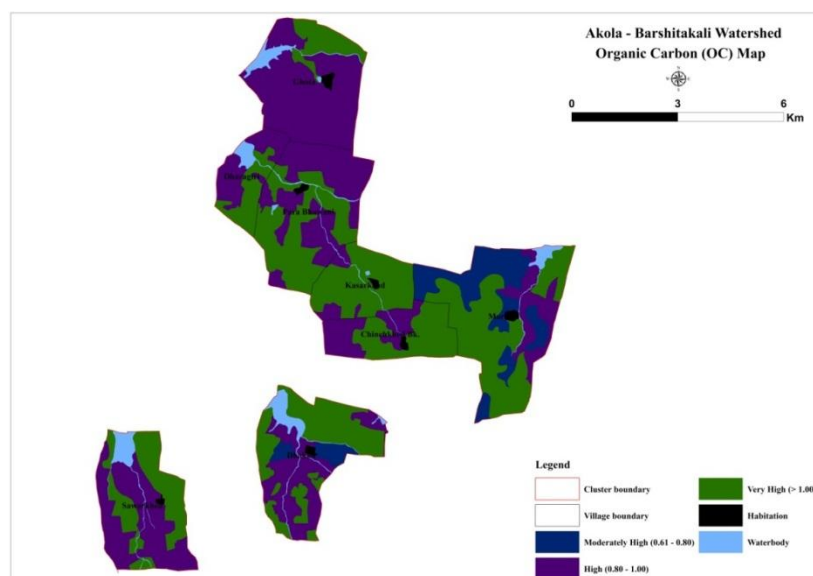


Fig. 4.13. Soil organic carbon map of Akola-Barshitakli watershed

4.5.9 Available nitrogen (N)

Available nitrogen (N) content in soils is a critical factor for plant growth, as it is a key component in the formation of proteins, amino acids, and chlorophyll, directly supporting photosynthesis, plant health, and crop yield. The agricultural soils of the watershed are largely deficient in nitrogen, which can limit crop productivity if not managed properly.

As shown in Table 4.17 and Fig. 4.14, the majority of the watershed area (55.52%) falls under the very low N class (<140 kg/ha), indicating widespread nitrogen deficiency. Soils with low N content (141–280 kg/ha) cover 37.53% of the area, while medium N content (281–420 kg/ha) is limited to 1.81%. Water bodies and habitation areas account for 4.26% and 0.88%, respectively.

Table 4.17. Available N content in soils of Akola-Barshitakli watershed

S. No.	N Class	Area (ha)	TGA (%)
1	Very Low (< 140)	3483.37	55.52
2	Low (141 - 280)	2354.74	37.53
3	Medium (281 - 420)	113.79	1.81
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

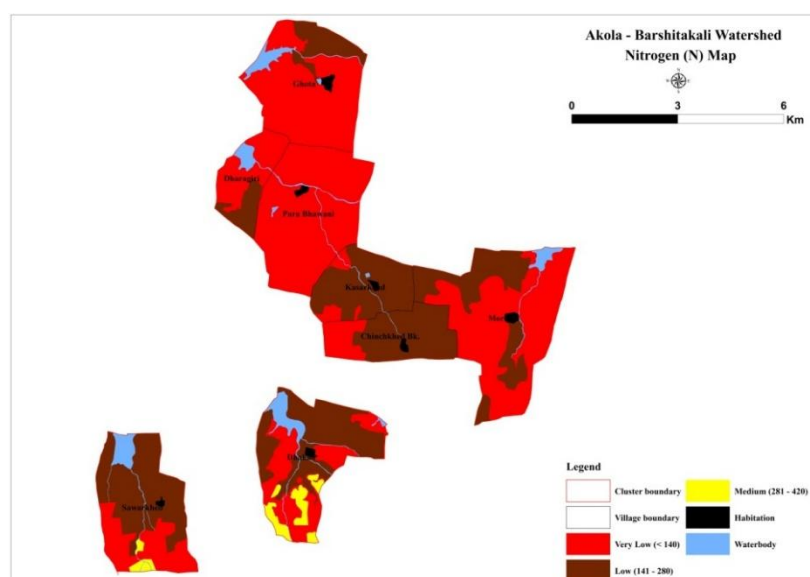


Fig. 4.14. Available soil nitrogen map of Akola-Barshitakli watershed

4.5.10 Available Phosphorous (P)

Among the three major nutrients, phosphorus (P) plays a crucial role in completing the life cycle of a plant, from stimulating root growth to supporting proper seed development and filling. Phosphorus is also essential in photosynthesis, carbohydrate metabolism, and energy transfer through ATP and ADP in various physiological processes. The phosphorus content of the agricultural soils in the watershed (Table 4.18, Fig. 4.15) ranges from very low (<15 kg/ha) to moderately high (51–65 kg/ha). The majority of the area (4298.10 ha, 68.50%) falls under the low P class (16–30 kg/ha), followed by very low P soils (<15 kg/ha) covering 1187.16 ha (18.92%). Soils with medium P (31–50 kg/ha) occupy 423.49 ha (6.75%), while moderately high P (51–65 kg/ha) is very limited at 43.16 ha (0.69%). The remainder includes water bodies (4.26%) and habitation areas (0.88%). The predominance of soils under very low to low P status (87.42%) indicates that farmers may not be

adequately applying phosphatic fertilizers, or that a substantial portion of applied phosphorus becomes fixed in the soils due to their calcareous nature. This underscores the need for efficient phosphorus management, including balanced fertilizer application and the use of phosphorus-solubilizing amendments, to improve nutrient availability and sustain crop productivity in the watershed.

Table 4.18. Available P content of soils of Akola-Barshitakli watershed

Sr. No.	P Class	Area (ha)	TGA(%)
1	Very Low (< 15)	1187.16	18.92
2	Low (16 - 30)	4298.10	68.50
3	Medium (31 - 50)	423.49	6.75
4	Moderately High (51 - 65)	43.16	0.69
5	Habitation	55.18	0.88
6	Waterbody	267.22	4.26
	Total	6274.30	100.00

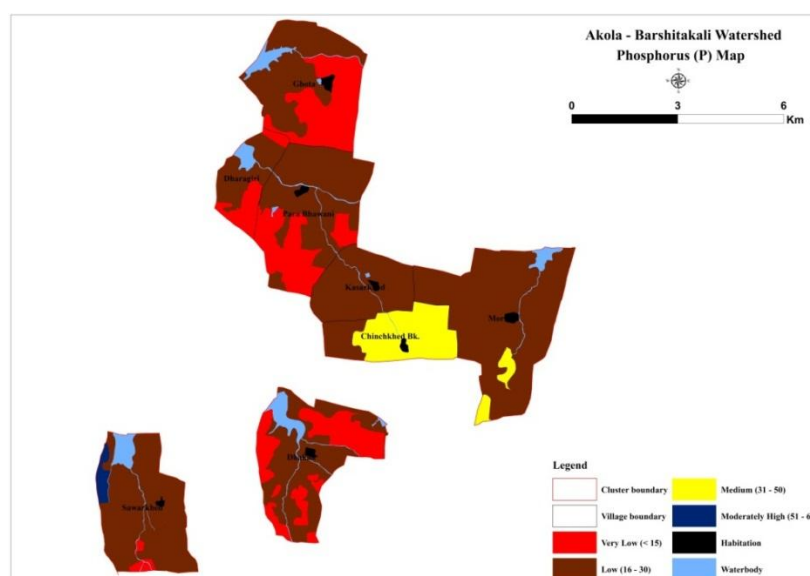


Fig. 4.15. Available soil phosphorus map of Akola-Barshitakli watershed

4.5.11 Available Potassium (K)

Potassium (K) is a vital macronutrient in agriculture, playing key roles in enzyme activation, water regulation, protein synthesis, and overall crop growth and stress tolerance. Exchangeable or available K is commonly used to assess soil K status and determine crop K requirements. The watershed soils exhibit five classes of available K (Table 4.19, Fig. 4.16). The analysis shows that the majority of the watershed (4786.68 ha, 76.29%) falls under the very high K class (>360 kg/ha), indicating that most soils are naturally rich in potassium. High K soils (301–360 kg/ha) occupy 618.74 ha (9.86%), while medium K (181–240 kg/ha) and low K (121–180 kg/ha) collectively account for only 272.66 ha (4.33%). Very low K (<120 kg/ha) covers 274.82 ha (4.38%), with habitation and waterbody areas representing the remaining 5.14%.

Table 4.19. Available K content of soils of Akola-Barshitakli watershed

Sr. No.	K Class	Area (ha)	TGA (%)
1	Very Low (< 120)	274.82	4.38
2	Low (121 - 180)	154.09	2.46
3	Medium (181 - 240)	117.57	1.87
4	Very High (> 360)	4786.68	76.29
5	High (301 - 360)	618.74	9.86
6	Habitation	55.18	0.88
7	Waterbody	267.22	4.26
	Total	6274.30	100.00

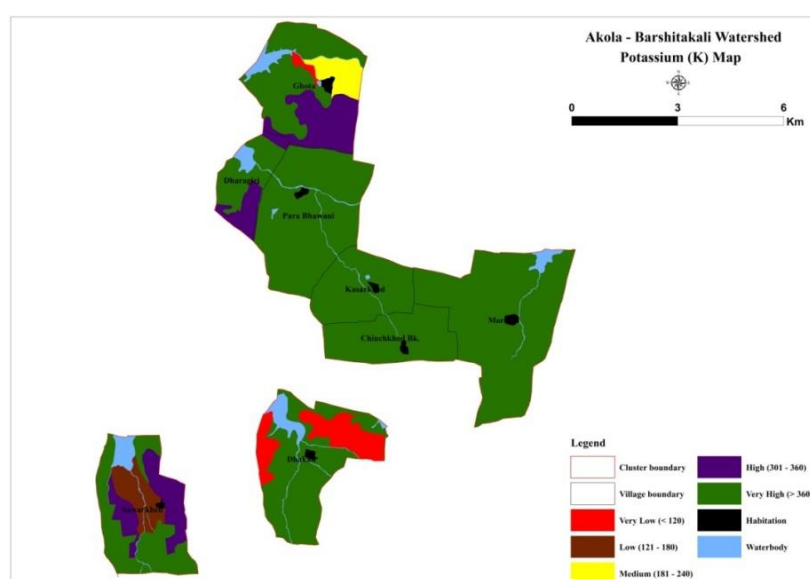


Fig. 4.16. Available soil potassium map of Akola-Barshitakli watershed

4.5.12 Micronutrient status of soils

Although required in small quantities, soil micronutrients-namely iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) are essential for vital plant processes such as photosynthesis, enzyme activation, and nitrogen fixation. Deficiencies in these micronutrients can result in poor plant growth, reduced crop yields, and lower quality produce. Proper micronutrient management is therefore crucial to maintain soil fertility and optimize the efficiency of applied fertilizers. The soils of the Akola-Barshitakli watershed exhibit five classes of DTPA-extractable iron (Fe).

Approximately 51.03% of the area-representing the very low to medium, indicating the need for soil or foliar Fe supplementation to improve crop nutrition. Conversely, about 12.53% of the watershed falls under the high to very high Fe category, reflecting localized zones of Fe abundance (Table 4.20, Fig. 4.17). The remaining areas show medium to moderately high Fe levels, suitable for most crops. These results highlight the importance of site-specific Fe management to ensure balanced micronutrient availability and optimize crop productivity across the watershed.

For other micronutrients, about 38.65% of the watershed is medium in plant-available Mn (Table 4.21, Fig. 4.18), while the remainder is varied from moderately high to very high. Soils throughout the watershed are very low in DTPA-extractable Cu (Table 4.22, Fig. 4.19).

However, over 92% of the soils are very low to low in bioavailable Zn (Table 4.23, Fig. 4.20), highlighting the need for targeted zinc fertilization to ensure optimal crop growth.

Table 4.20. Available Fe content in the soils of Akola-Barshitakli watershed.

Sr. No.	Fe Class	Area (ha)	TGA (%)
1	Very Low (< 2.5)	1336.76	21.31
2	Low (2.5 - 4.5)	1080.47	17.22
3	Medium (4.5 - 6.5)	784.23	12.50
4	Moderately High (6.5 - 8.5)	1964.12	31.30
5	High (8.5 - 10.5)	420.85	6.71
6	Very High (> 10.5)	365.47	5.82
7	Habitation	55.18	0.88
8	Waterbody	267.22	4.26
	Total	6274.30	100.00

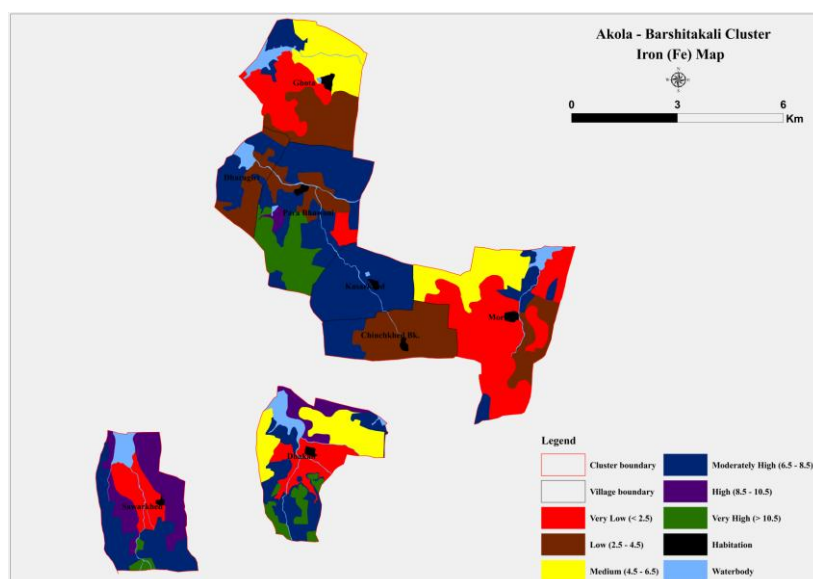


Fig. 4.17 DTPA-extractable soil Fe map of Akola-Barshitakli watershed

Table 4.21. Available Mn content in the soils of Akola-Barshitakli watershed

Sr. No.	Mn Class	Area (ha)	TGA (%)
1	Medium (1.3 - 5.0)	2424.91	38.65
2	Moderately High (5.0 - 7.0)	109.89	1.75
3	High (7.0 - 9.0)	806.46	12.85
4	Very High (> 9.0)	2610.64	41.61
5	Habitation	55.18	0.88
6	Waterbody	267.22	4.26
	Total	6274.30	100.00

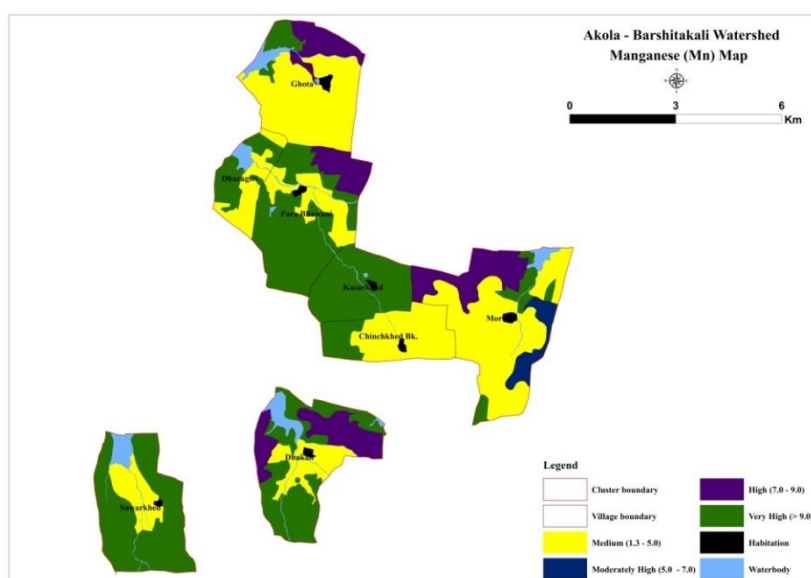


Fig. 4.18. DTPA-extractable soil Mn map of Akola-Barshitakli watershed

Table 4.22. Available Cu content in the soils of Akola-Barshitakli watershed

Sr. No.	Cu Class	Area (ha)	TGA(%)
1	Very Low (< 0.2)	5951.91	94.86
2	Habitation	55.18	0.88
3	Waterbody	267.22	4.26
	Total	6274.30	100.00

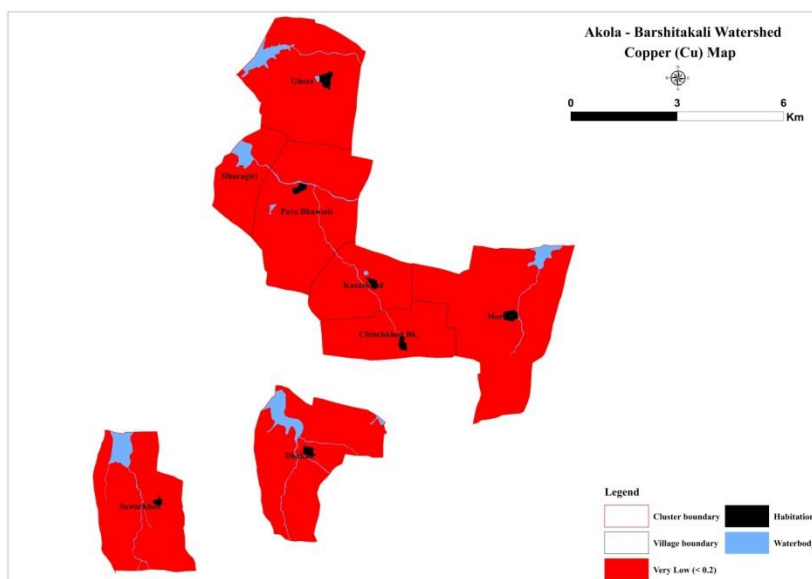


Fig. 4.19. DTPA-extractable soil Cu map of of Akola-Barshitakli watershed

Table 4.23. Available Zn content in the soils of Akola-Barshitakli watershed

Sr. No.	Zn Class	Area (ha)	Percent (%)
1	Very Low (< 0.3)	3163.82	50.42
2	Low (0.3 - 0.6)	2649.43	42.23
3	Medium (0.6 - 0.9)	138.66	2.21
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

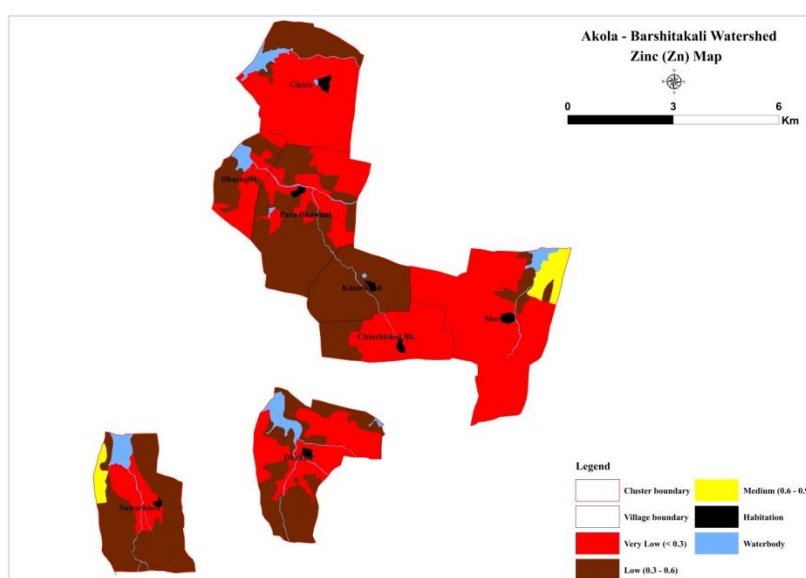


Fig. 4.20. DTPA-extractable soil Zn map of Akola-Barshitakli watershed

4.6 Surface Runoff

Runoff estimation is one of the most critical aspects of watershed hydrology, particularly in semi-arid basaltic regions where rainfall is relatively limited and water scarcity is a recurring challenge. Rainfall patterns alone do not explain the water shortage issues due to inadequate and uneven distribution. A more comprehensive understanding requires evaluating the partitioning of rainfall into infiltration, groundwater recharge, soil moisture storage, and surface runoff. Runoff estimation provides this clarity, quantifying the proportion of rainfall that escapes the landscape and identifying opportunities for conservation. High runoff percentages indicate locations where rainwater harvesting and soil and water conservation structures are critically required, whereas lower runoff values generally reflect areas with higher infiltration capacity that can be further strengthened through appropriate management practices. Seasonal variations in runoff also correspond closely with periods of increased erosion risk, as high-intensity storms generate rapid surface flow capable of removing fertile topsoil and reducing land productivity. Quantifying runoff therefore enables planners to identify critical periods particularly during peak monsoon months such as July and August, when intense rainfall events lead to the greatest soil and water losses. In addition, runoff analysis provides insight into inter-annual variability, demonstrating that wetter years often produce disproportionately higher runoff, whereas drier years reduce surface flow but may also limit groundwater recharge.

In Barshitakli Taluka, where average annual rainfall is about 871 mm (lower than the state average), runoff estimation becomes especially important for planning interventions aimed at enhancing rainwater conservation, minimizing soil erosion, and improving the reliability of local water resources. For this study, the Soil Conservation Service (SCS)-Curve Number (CN) method was adopted, which is widely recognized for estimating direct runoff from storm rainfall (SCS, 1972; Subramanya & Sharma, 2024). The CN parameter reflects the combined influence of land use, soil type, and antecedent moisture conditions. Lower CN values indicate permeable soils and vegetated cover with higher infiltration capacity, while higher CN values correspond to impervious or degraded surfaces with limited infiltration. In practice, CN values are assigned by classifying soils into hydrologic groups (A, B, C, D) and matching them with land use categories such as cropland, forest, grassland, or settlements. In Barshitakli Taluka, Gravely clay and clay soils under rainfed agriculture fall into group D, with CN values are assigned reflecting their infiltration capacity.

Daily rainfall records for an 11 years period (2014–24) were compiled from Indian Meteorological Department (IMD). Land use and soil profiles were mapped using satellite imagery, field surveys, and farmer consultations. Curve Numbers were then assigned to each land cover-soil combination, adjusted for antecedent moisture conditions to reflect seasonal saturation. Using the SCS equation, runoff depth was calculated for each storm, aggregated monthly, and then summarized annually.

The monthly analysis of rainfall and runoff for 2014-24 years (Table 4.24) revealed that June and October months consistently produced minimum or negligible runoff despite receiving rainfall of 59-153 mm. This is attributed to dry antecedent conditions at the onset of the monsoon (June) and reduced storm intensity towards end of monsoon (October). Even when June rainfall exceeded 150 mm in several years, the resulting runoff remained comparatively low relative to subsequent monsoon months. This pattern highlights the critical role of antecedent soil moisture conditions in controlling effective runoff generation, as initially dry soils tend to absorb a larger proportion of early-season rainfall. July and August emerged as the dominant runoff months, accounting for the majority of surface runoff across the study period. Intense rainfall events in these months generated sharp peaks, with July 2016 producing over 118.3 mm of runoff and August 2015 exceeding 94 mm. These peaks correspond to short, high-intensity storms that overwhelm infiltration capacity and lead to rapid drainage. August runoff was particularly variable, ranging from negligible values in 2017 and 2023 to nearly 40 mm in 2024, reflecting both rainfall distribution and land surface conditions.

September also contributed significantly to runoff, especially in years with prolonged monsoon activity. For instance, 2014 recorded 56.8 mm and 2021 produced 75 mm of runoff, indicating that once soils are saturated, even moderate rainfall translates into substantial surface flow. In contrast, years with lower September rainfall, such as 2018 (44.7 mm rainfall, 0 runoff) and 2020 (123.7 mm rainfall, 0 runoff), produced minimal runoff, underscoring the sensitivity of late season hydrology to antecedent saturation.

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	21.3	0.0	262.8	72.6	214.7	34.4	167.9	56.8	8.2	0.0
2015	194.2	37.6	77.8	0.0	253.4	94.0	117.6	9.4	1.3	0.0
2016	158.5	3.0	407.4	118.3	139.2	29.5	152.5	2.0	117.9	2.9
2017	172.8	11.7	193.4	4.5	100.0	0.0	75.6	0.0	113.2	12.3
2018	373.2	73.5	271.5	66.5	198.1	40.6	44.7	0.0	0.0	0.0
2019	77.3	0.0	209.4	47.7	115.0	1.3	200.9	10.2	76.8	0.0
2020	187.2	5.4	254.6	11.3	150.4	1.7	123.7	0.0	54.5	1.2
2021	193.9	14.3	296.4	62.2	148.5	12.1	311.3	75.0	111.5	10.9
2022	98.0	0.0	312.9	66.9	174.7	33.0	170.9	11.4	131.3	12.7
2023	48.6	0.0	401.0	131.0	65.1	0.0	187.1	13.5	0.0	0.0
2024	162.8	0.5	268.5	2.8	218.8	40.1	160.8	19.2	39.9	0.0
Average	153.4	13.3	268.7	53.1	161.6	26.1	155.7	18.0	59.5	3.6

The annual relationship between rainfall and runoff confirms that runoff rarely exceeds 20% of seasonal rainfall, with an overall average of 13.5%. The highest runoff percentage was observed in 2014 (21.3%), while the lowest was in 2020 (2.5%). Wet years such as

2021 (1096.1 mm rainfall) produced nearly 174.5 mm of runoff, whereas moderate rainfall years like 2019 (701.1 mm rainfall) yielded only 59.2 mm. The number of runoff events averaged 15 per year, but ranged from as few as 7 in 2019 to as many as 23 in 2018, indicating that storm frequency and distribution strongly influence annual totals.

Table 4.25. Relationship between Rainfall and Runoff.

Year	Rainfall, mm	Runoff, mm	No. of Runoff Events	Runoff (%)
2014	770.1	163.8	16	21.3
2015	844.3	165.5	12	19.6
2016	1016.7	155.6	21	15.3
2017	658.7	28.5	9	4.3
2018	913.2	180.5	23	19.8
2019	701.1	59.2	7	8.4
2020	789.9	19.6	9	2.5
2021	1096.1	174.5	21	15.9
2022	888.0	123.9	19	14.0
2023	949.4	154.5	18	16.3
2024	948.1	62.6	15	6.6
Average	870.5	117.1	15	13.5

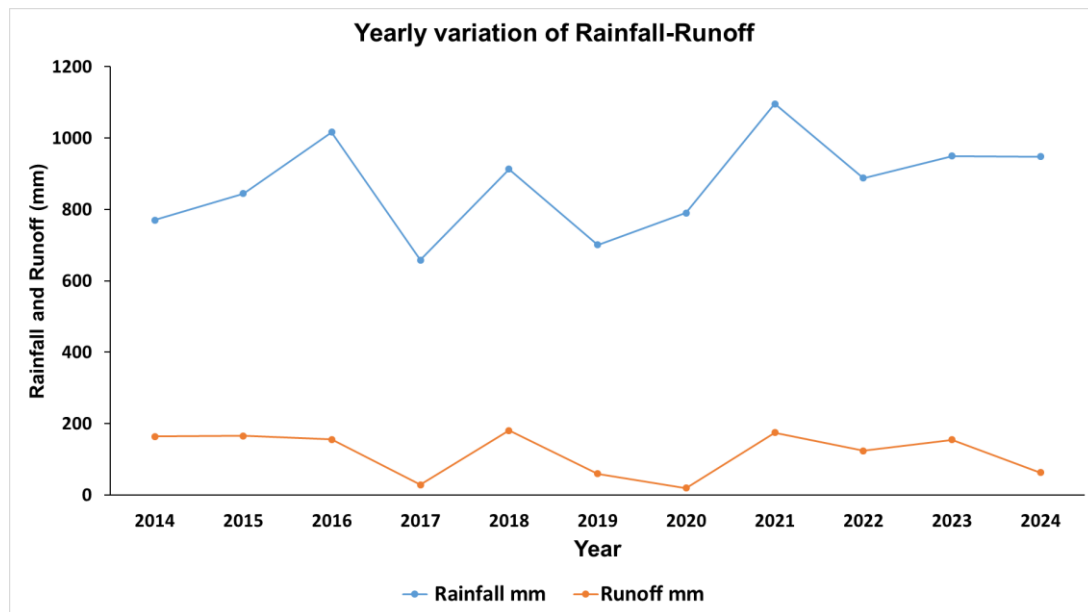


Fig 4.21. Yearly variation of Rainfall-Runoff

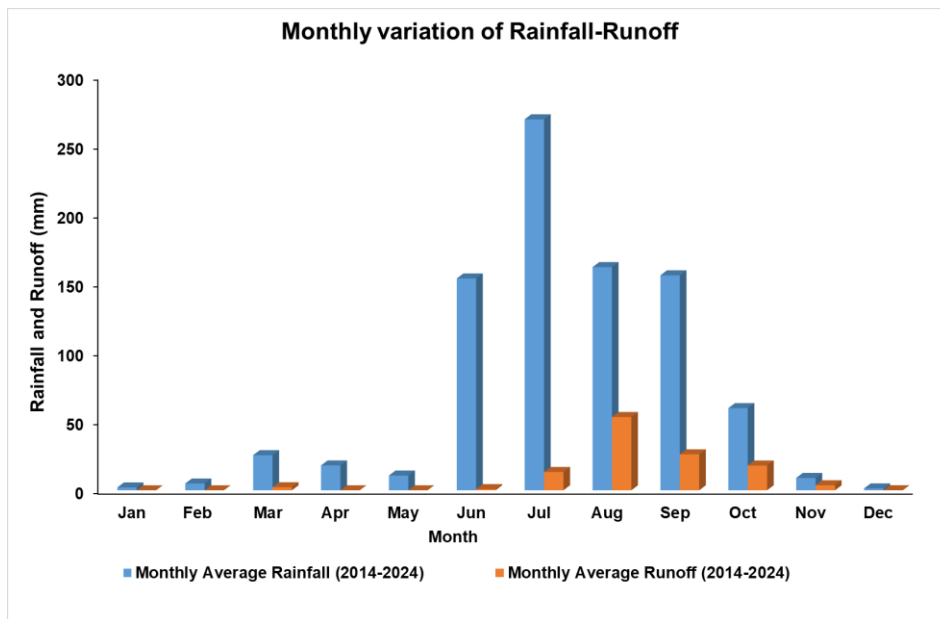


Fig 4.22. Monthly variation of Rainfall-Runoff

The results highlight several important patterns in rainfall-runoff dynamics within the Barshitakli watershed of Akola district. Runoff is strongly concentrated during the peak monsoon period (July-September), with July and August contributing the largest proportion of runoff and therefore representing the most critical months for water loss and soil erosion. Considerable interannual variability was also observed, where wetter years generated higher runoff percentages, whereas drier years produced reduced surface flow but also limited groundwater recharge. Although the overall runoff percentage remains relatively moderate indicating that a substantial portion of rainfall is either infiltrated or temporarily stored within the watershed. The magnitude of runoff during peak monsoon months remains significant and warrants appropriate management interventions. Furthermore, years characterized by extreme runoff peaks, such as 2016, 2018, 2021, and 2023, demonstrate an increased risk of erosion and localized flooding, underscoring the importance of implementing effective soil and water conservation measures.

4.7 Mapping of Groundwater Potential Zones

The study area consists of an eight-village cluster watershed containing four to five small reservoirs that capture monsoon runoff and contribute to aquifer replenishment. This hydrological setting distinguishes the watershed from other drought-prone areas of Akola district where groundwater demand is typically higher. Nevertheless, the recharge potential of these reservoirs is closely linked to rainfall variability; during low-rainfall years, reduced storage limits their recharge capacity and their ability to offset groundwater demand. To address these challenges, groundwater potential zone mapping was carried out using eight thematic factors: lithology, LULC, rainfall, landform, soil, slope, drainage density, and elevation. The influence of each factor on

groundwater occurrence was assessed using the Analytical Hierarchy Process (AHP), and the layers were integrated through a weighted overlay approach to produce a composite groundwater potential map. The resulting classification delineated five groundwater potential categories: very poor, poor, moderate, good, and very good. The analysis revealed that 11.1% of the area falls within very poor groundwater potential zones, 35.4% under poor, 24.0% under moderate, 25.3% under good, and 4.3% under very good categories. Overall, only 29.6% of the watershed exhibits favorable conditions for groundwater recharge, whereas the majority of the area (70.4%) ranges from moderate to very poor potential.

This assessment under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) helps in better planning of water resources by identifying areas where groundwater can recharge easily and areas where it is limited. The results show that local reservoirs play an important role not only in irrigation but also in recharging groundwater. The study also helps guide soil and water conservation works and encourages water-efficient farming in water-scarce areas. Overall, it provides useful information for improving water management and supporting sustainable agriculture in Barshitakli taluka of Akola district and other similar drought-prone regions.

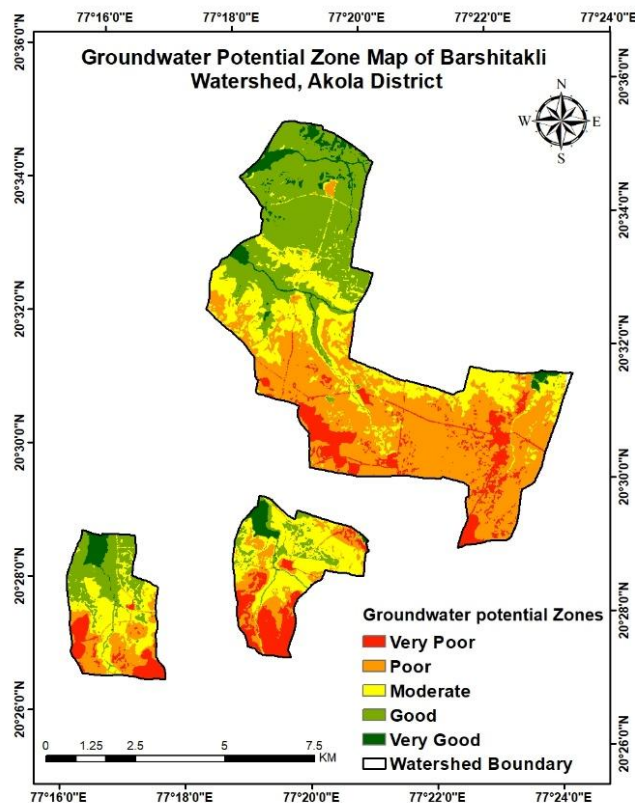


Fig 4.23. Groundwater potential zone map of the Barshitakli watershed, Akola district

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, including soil fertility, texture, depth, pH, and topography. The distribution of suitability classes is presented in Table 4.26. The results indicate that only 415.98 ha (6.63% of the total geographical area, TGA) are classified as highly suitable (S1), providing optimal soil and site conditions for Jowar growth. Moderately suitable (S2) areas cover 1541.39 ha (24.57% of TGA), where minor soil or environmental constraints may slightly influence crop productivity. The majority of the watershed, 3994.54 ha (63.67% of TGA),

falls under the marginally suitable (S3) class, reflecting moderate limitations related to soil fertility, texture, slope, and terrain that may restrict yield potential unless proper agronomic and soil management practices—such as fertilization, erosion control, or irrigation—are adopted.

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

Sr.No	Suitability Classes	Area (ha)	Area (%)
1	Highly Suitable (S1)	415.98	6.63
2	Moderately Suitable (S2)	1541.39	24.57
3	Marginally Suitable (S3)	3994.54	63.67
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

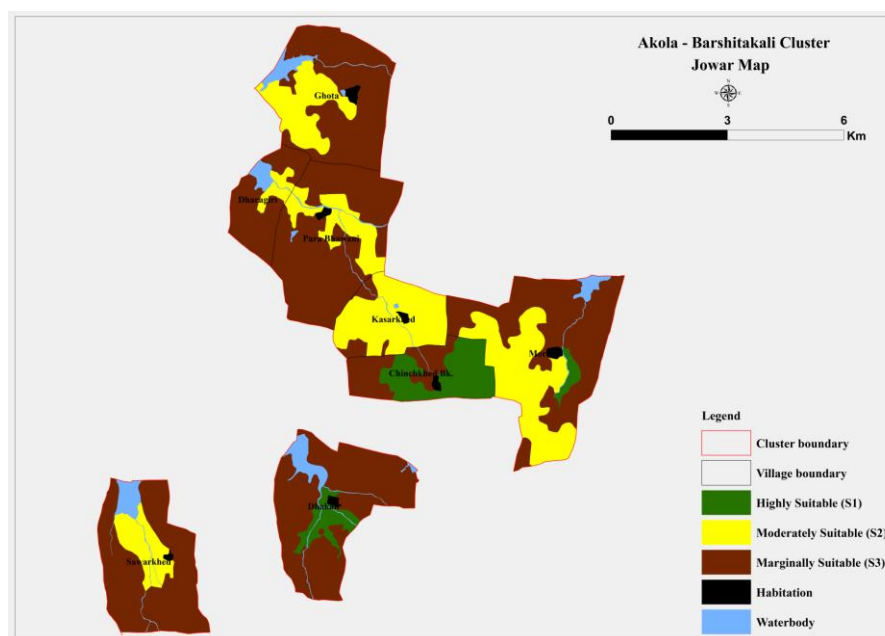


Fig. 4.24. Soil site suitability map for sorghum (jowar) Cultivation

4.8.2 Soil-Site Suitability for Pearl millet (Bajra) Cultivation

The soils of the watershed were evaluated for Bajra cultivation based on crop-specific requirements, including soil fertility, texture, drainage, and topography. The distribution of suitability classes is presented in Table 4.27.

The results indicate that the majority of the watershed (3994.54 ha, 63.67% of the total geographical area, TGA) is marginally suitable (S3) for Bajra cultivation, reflecting moderate limitations related to soil fertility, texture, slope, or drainage that may restrict yield potential unless appropriate agronomic management practices are adopted. Moderately suitable (S2) lands cover 1957.37 ha (31.20% of TGA), where minor soil or environmental constraints may slightly influence crop performance. Habitation and water bodies occupy 0.88% and 4.26% of the area, respectively.

Table 4.27. Area under suitability sub-classes for Bajra Cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Marginally Suitable (S3)	3994.54	63.67
2	Moderately Suitable (S2)	1957.37	31.20
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

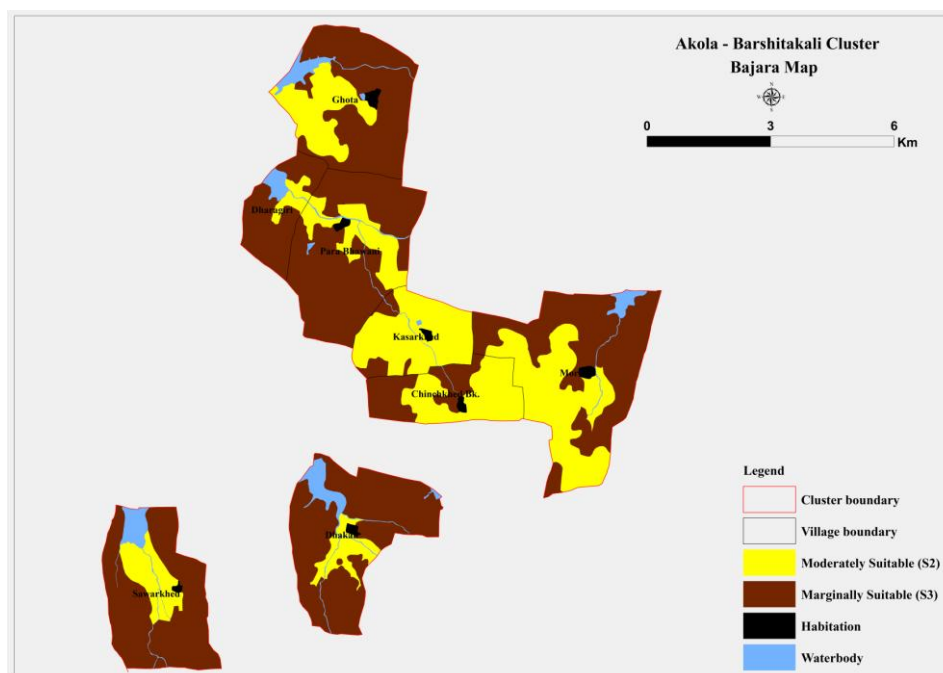


Fig. 4.25 Soil site suitability map for pearl millet (bajra) cultivation

4.8.3 Soil-Site Suitability for Pigeonpea Cultivation

The soil-site suitability assessment for Pigeonpea cultivation indicates that only 133.41 ha (2.13% of the total geographical area, TGA) is classified as highly suitable (S1), providing optimal conditions for crop growth. Moderately suitable (S2) areas cover 1153.40 ha (18.38% of TGA), where minor soil or site limitations may slightly affect crop productivity. Marginally suitable (S3) lands account for 2188.58 ha (34.88% of TGA), reflecting moderate constraints related to soil fertility, texture, depth, or terrain, which may restrict yields unless appropriate management practices are implemented.

A significant portion of the watershed, 2476.52 ha (39.47% of TGA), is not suitable (N) for Pigeonpea cultivation due to severe soil and site limitations. Habitation and water bodies occupy 0.88% and 4.26%, respectively.

Table 4.28. Area under suitability sub-classes for pigeonpea cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Highly Suitable (S1)	133.41	2.13
2	Marginally Suitable (S3)	2188.58	34.88
3	Moderately Suitable (S2)	1153.40	18.38
4	Not Suitable (N)	2476.52	39.47
5	Habitation	55.18	0.88
6	Waterbody	267.22	4.26
	Total	6274.30	100.00

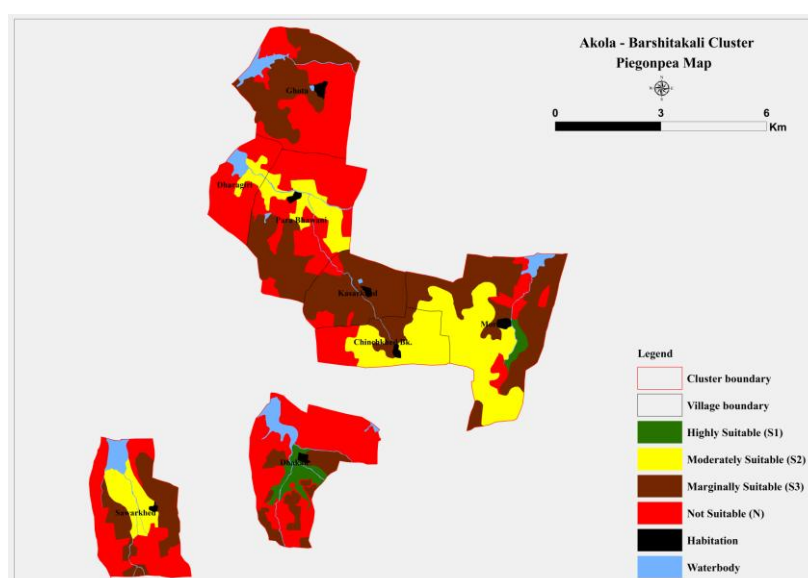


Fig. 4.26. Soil site suitability map for Pigeonpea (tur) Cultivation

4.8.4 Soil-Site Suitability for Soybean Cultivation

The watershed area demonstrates a predominance of marginally suitable lands (S3), covering 3994.54 ha (63.67% of total geographical area, TGA), which indicates that moderate limitations—such as soil fertility constraints, shallow soils, or slope issues—may restrict optimal crop productivity unless corrective measures are implemented. Moderately suitable lands (S2) account for 1957.37 ha (31.20%), providing conditions favorable for most crops, though minor management interventions may be required for optimal yields. Habitation (0.88%) and waterbody areas (4.26%) are excluded from agricultural use.

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

Sr. No.	Suitability Classes	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1957.37	31.20
2	Marginally Suitable (S3)	3994.54	63.67
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

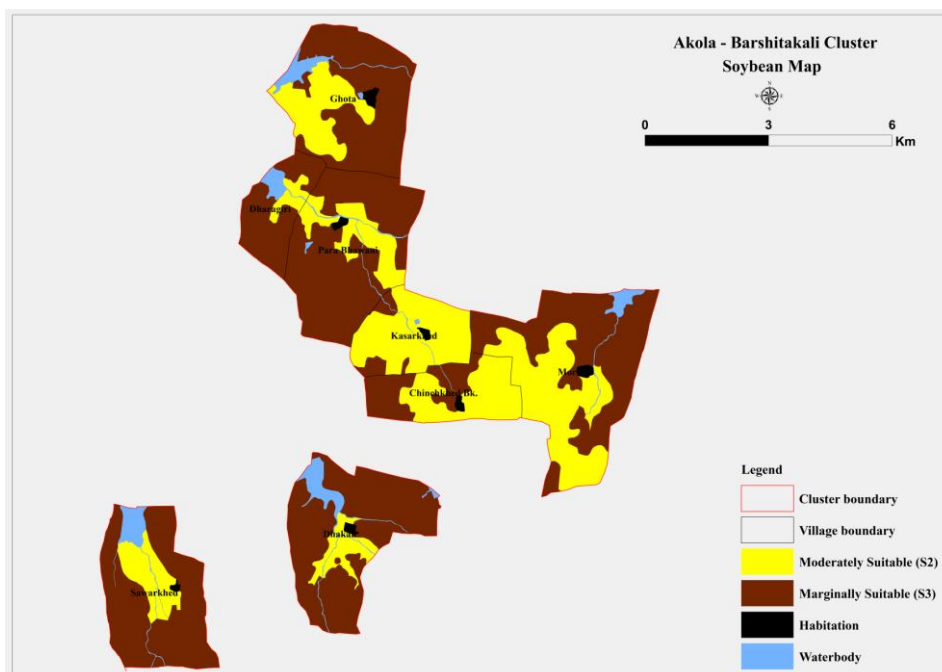


Fig. 4.27. Soil site suitability map for Soybean Cultivation

4.8.5 Soil-Site Suitability for Wheat Cultivation

The land suitability sub-class analysis provides insight into the distribution of agricultural potential within the watershed. The majority of the watershed, 3994.54 ha (63.67%), falls under the marginally suitable (S3) category, reflecting moderate limitations such as soil fertility constraints, shallow depth, or adverse slope conditions that may restrict crop productivity unless suitable management practices are applied.

The moderately suitable (S2) sub-class encompasses 1957.37 ha (31.20%), representing areas with minor limitations where crops can achieve relatively good yields under standard agronomic management. Habitation and water bodies occupy small portions of the watershed, 0.88% and 4.26% respectively.

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

Sr. No.	Suitability Classes	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1957.37	31.20
2	Marginally Suitable (S3)	3994.54	63.67
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

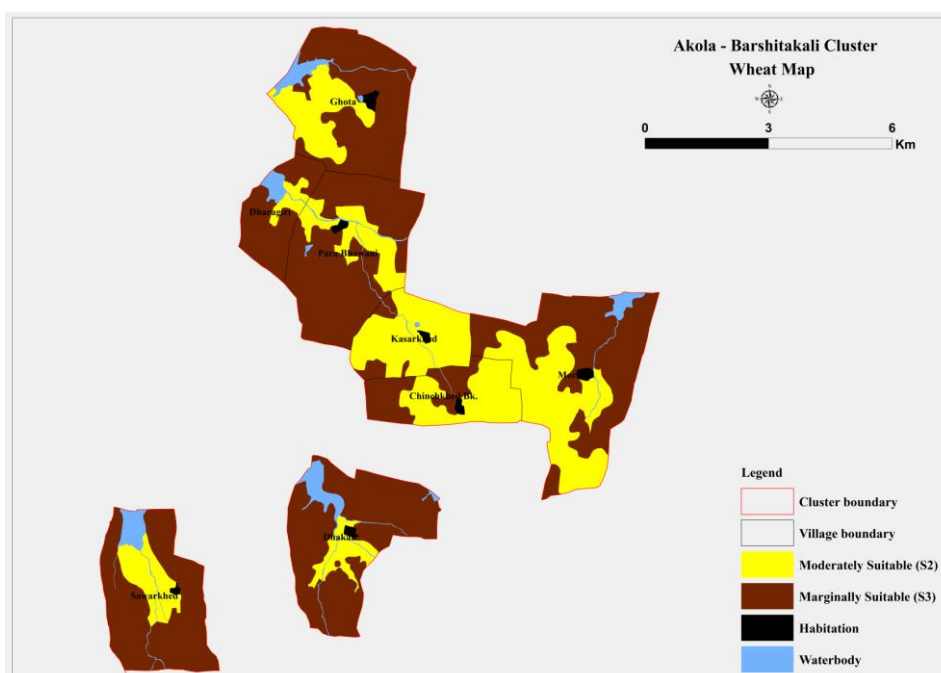


Fig. 4.28. Soil site suitability map for Wheat Cultivation

4.8.6 Soil-Site Suitability for Chickpea Cultivation

The land suitability assessment for chickpea cultivation shows that a dominant portion of the watershed, 4947.67 ha (78.86% of the total geographical area, TGA), falls under the marginally suitable (S3) category.

These areas exhibit moderate constraints such as shallow soils, low fertility, or unfavorable terrain, which could limit crop productivity unless proper agronomic measures—like fertilization, irrigation, and soil conservation—are applied. Moderately suitable (S2) lands cover 1004.23 ha (16.01% of TGA), representing areas with minor limitations where chickpea cultivation can achieve satisfactory yields under standard management practices. Habitation and water bodies occupy 0.88% and 4.26%, respectively.

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

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	1004.23	16.01
2	Marginally Suitable (S3)	4947.67	78.86
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

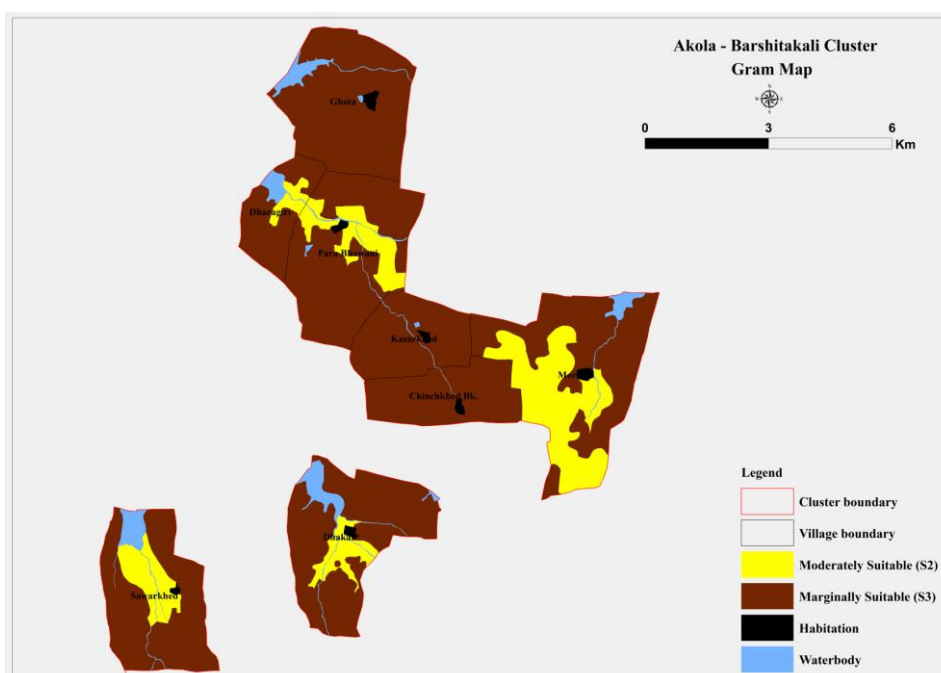


Fig. 4.29. Soil site suitability map for Chickpea Cultivation

4.8.7 Soil-Site Suitability for Cotton Cultivation

The land suitability assessment for cotton cultivation indicates a diverse distribution of suitability classes across the watershed (Table 4.32; Fig. 4.30). Areas classified as highly suitable (S1) cover 957.84 ha (15.27% of the total geographical area, TGA), reflecting zones with optimal soil fertility, texture, and site conditions conducive to high cotton yields. The moderately suitable (S2) category comprises 999.52 ha (15.93% of TGA), where cultivation is feasible but minor constraints—such as slight limitations in soil depth, nutrient availability, or drainage—may affect productivity. Marginally suitable (S3) lands extend over 1775.16 ha (28.29% of TGA), representing areas with moderate constraints that require targeted agronomic interventions, such as soil amendment, irrigation management, or erosion control, to sustain crop performance. A significant portion, 2219.38 ha (35.37% of TGA), is not suitable (N) for cotton cultivation due to severe limitations in soil quality, terrain, or drainage. Habitation and water bodies account for 0.88% and 4.26%, respectively.

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

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Highly Suitable (S1)	957.84	15.27
2	Moderately Suitable (S2)	999.52	15.93
3	Marginally Suitable (S3)	1775.16	28.29
4	Not Suitable (N)	2219.38	35.37
5	Habitation	55.18	0.88
6	Waterbody	267.22	4.26
	Total	6274.30	100.00

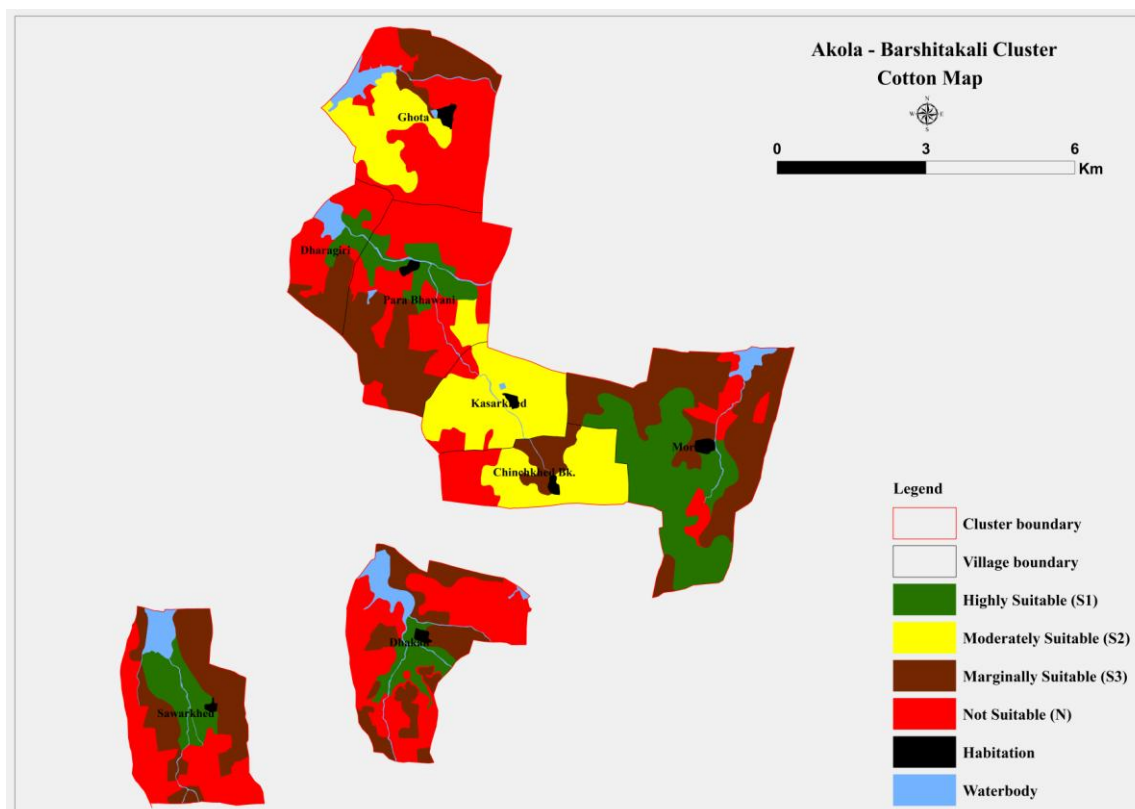


Fig. 4.30. Soil site suitability map for Cotton Cultivation

4.8.18 Soil-Site Suitability for Papaya Cultivation

The suitability assessment for papaya cultivation shows that a major portion of the watershed, 3994.54 ha (63.67% of the total geographical area, TGA), is not suitable (N) due to severe soil and environmental limitations, such as shallow soils, low fertility, poor drainage, or unfavorable slope conditions. Moderately suitable (S2) lands cover 1004.23 ha (16.01% of TGA), representing areas where papaya cultivation is feasible under good management practices, including soil fertility improvement and irrigation. The marginally suitable (S3) category occupies 953.13 ha (15.19% of TGA), indicating areas with moderate constraints that may restrict optimal growth unless proper interventions are applied. Habitation and water bodies account for 0.88% and 4.26%, respectively.

Table 4.33. Area under suitability sub-classes for Papaya Cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	1004.23	16.01
2	Marginally Suitable (S3)	953.13	15.19
3	Not Suitable (N)	3994.54	63.67
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

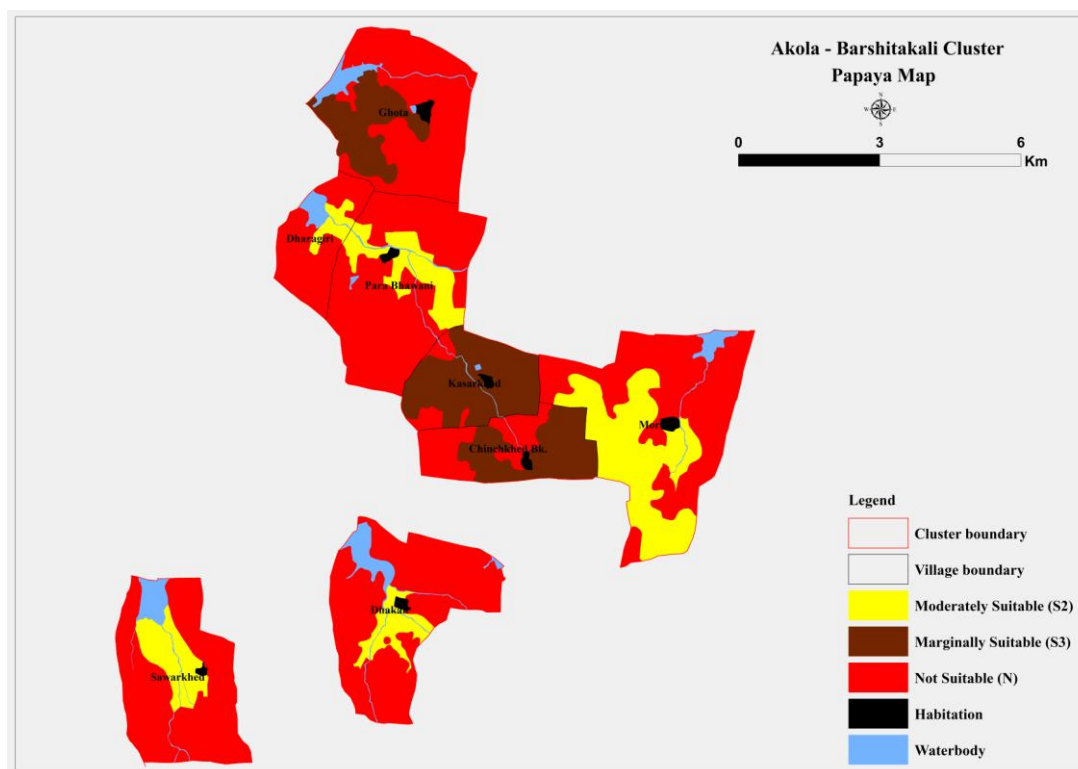


Fig. 4.31. Soil site suitability map for Papaya Cultivation

4.8.9 Soil-Site Suitability for Onion Cultivation

The land suitability assessment for onion cultivation indicates that a vast majority of the watershed, 5951.91 ha (94.86% of the total geographical area, TGA), falls under the moderately suitable (S2) category. These areas are well-suited for onion production, with favorable soil characteristics, adequate depth, and suitable drainage, allowing for good crop growth and productivity under standard agronomic practices.

Habitation and water bodies account for 0.88% and 4.26%, respectively. No areas were classified as highly suitable (S1) or marginally suitable (S3), suggesting that the existing moderate soil and environmental conditions can support onion cultivation effectively with standard management interventions. Overall, the assessment highlights that onion is the most widely suitable crop across the watershed, with nearly the entire area falling under moderately suitable lands, making it a viable option for large-scale cultivation and planning of horticultural activities.

Table 4.34. Area under suitability sub-classes for Onion Cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	5951.91	94.86
2	Habitation	55.18	0.88
3	Waterbody	267.22	4.26
	Total	6274.30	100.00

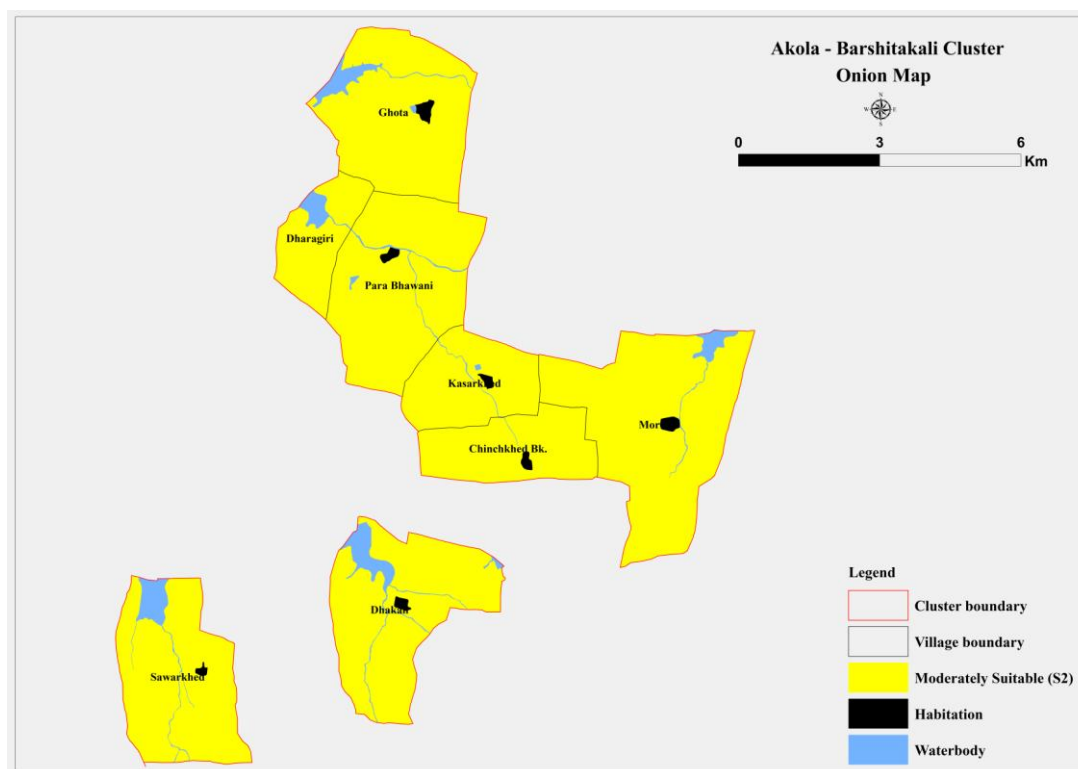


Fig. 4.32. Soil site suitability map for Onion Cultivation

4.8.10 Soil-Site Suitability for Tomato Cultivation

The land suitability assessment for tomato cultivation reveals that the majority of the watershed, 3994.54 ha (63.67% of the total geographical area, TGA), is classified as marginally suitable (S3). These areas are constrained by factors such as moderate soil fertility limitations, shallow depth, or suboptimal water retention, which may restrict optimal tomato growth unless proper management interventions—such as fertilization, irrigation, or soil amendments—are applied. The moderately suitable (S2) lands cover 1957.37 ha (31.20% of TGA), representing areas where tomato cultivation can be productive under standard management practices. Habitation and water bodies occupy 0.88% and 4.26%, respectively.

Table 4.35. Area under suitability sub-classes for Tomato Cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	1957.37	31.20
2	Marginally Suitable (S3)	3994.54	63.67
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

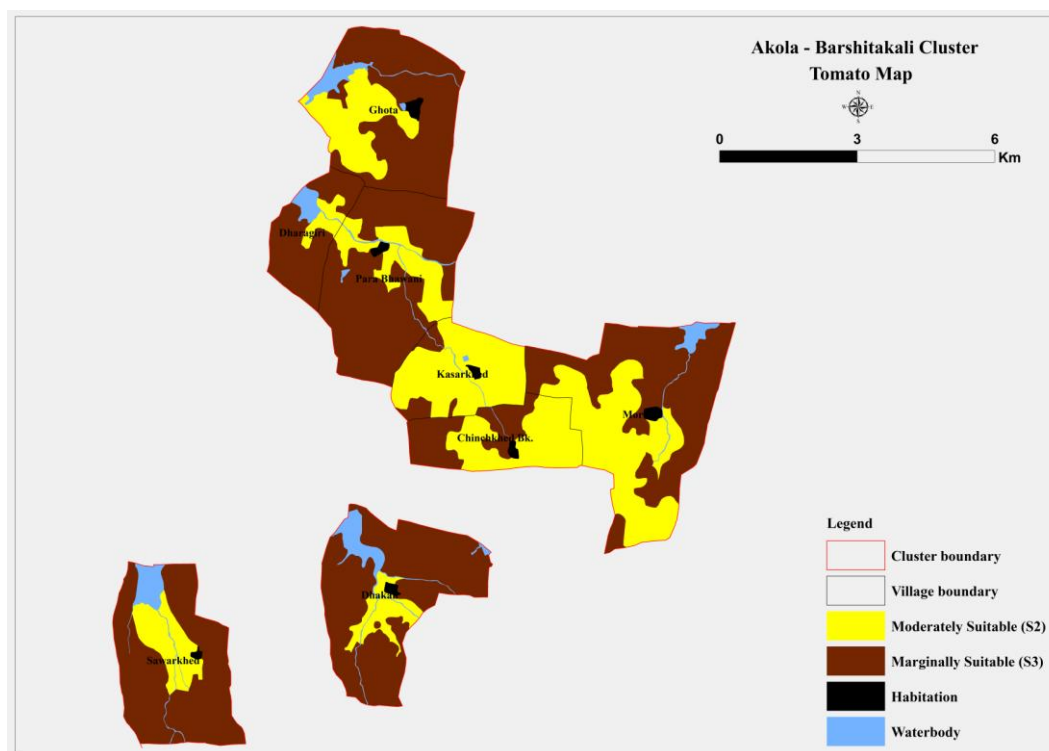


Fig. 4.33. Soil site suitability map for Tomato Cultivation

4.8.11 Soil-Site Suitability for Chilli Cultivation

The suitability assessment for chilli cultivation indicates that a large portion of the watershed, 3994.54 ha (63.67% of the total geographical area, TGA), is marginally suitable (S3). These lands face moderate constraints such as limited soil fertility, shallow soil depth, and uneven terrain, which may reduce chilli productivity unless proper management practices-like fertilizer application, irrigation, and soil amendments-are implemented. Moderately suitable (S2) lands cover 1957.37 ha (31.20% of TGA), representing areas where chilli cultivation can be productive under standard management. Habitation and water bodies occupy 0.88% and 4.26%, respectively.

Table 4.36. Area under suitability sub-classes for Chilli Cultivation

Sr.No	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	1957.37	31.20
2	Marginally Suitable (S3)	3994.54	63.67
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

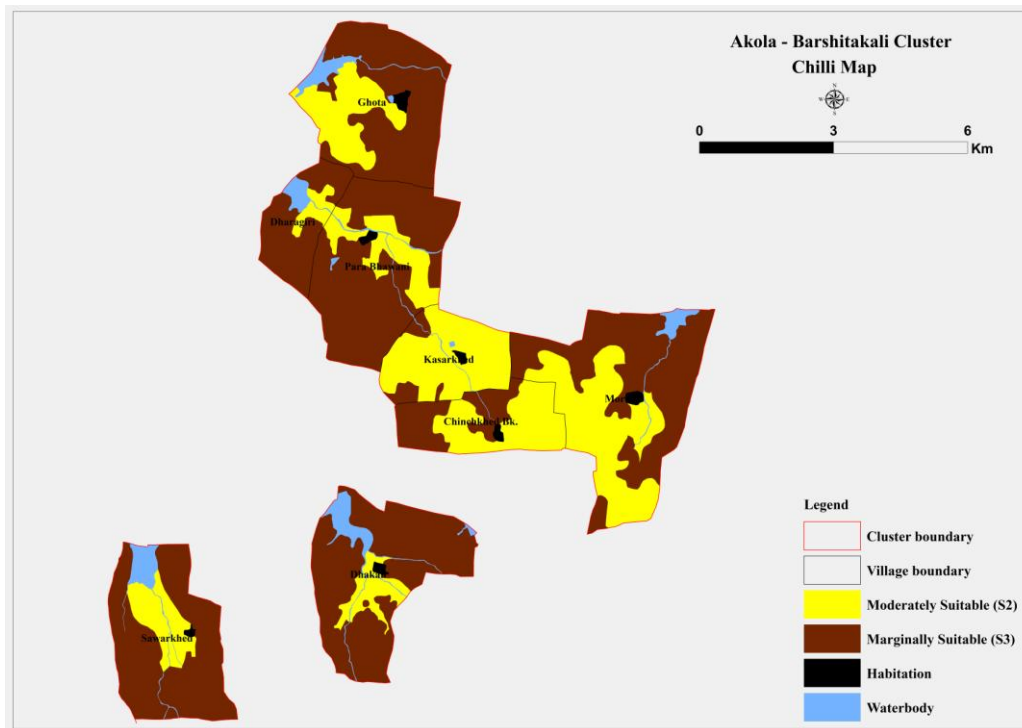


Fig. 4.34. Soil site suitability map for Chilli Cultivation

4.8.12 Soil-Site Suitability for Groundnut Cultivation

The land suitability assessment for groundnut cultivation indicates that a major portion of the watershed, 4947.67 ha (78.86% of the total geographical area, TGA), is marginally suitable (S3).

These areas are constrained by moderate limitations such as shallow soils, poor fertility, and uneven terrain, which may restrict optimal groundnut growth unless proper management practices-like soil amendments, irrigation, and nutrient management-are applied. Moderately suitable (S2) lands cover 1004.23 ha (16.01% of TGA), representing areas with acceptable conditions for groundnut cultivation, where yields can be satisfactory under standard agronomic management. Habitation and water bodies occupy 0.88% and 4.26%, respectively.

Table 4.37. Area under suitability sub-classes for Groundnut Cultivation

Sr.No	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	1004.23	16.01
2	Marginally Suitable (S3)	4947.67	78.86
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

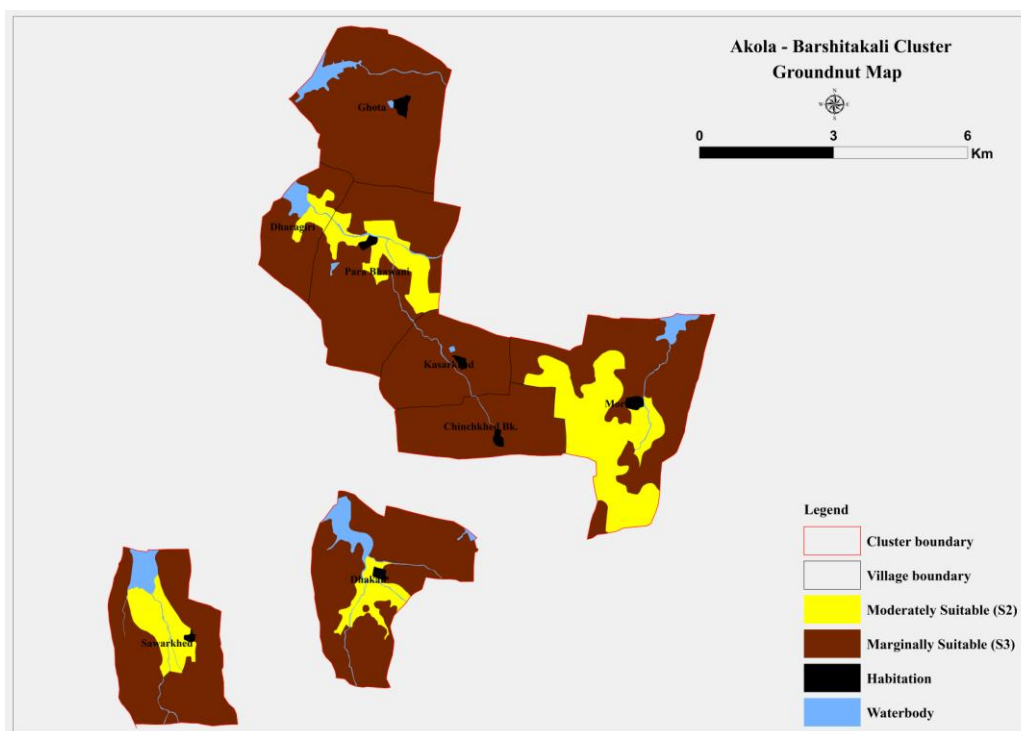


Fig 4.35. Soil site suitability map for Groundnut Cultivation

4.8.13 Soil-Site Suitability for Turmeric Cultivation

The land suitability assessment for turmeric cultivation indicates that the majority of the watershed, 3994.54 ha (63.67% of the total geographical area, TGA), is marginally suitable (S3). These areas face moderate constraints, including limitations in soil fertility, water retention, and terrain, which may restrict turmeric productivity unless proper soil and water management practices are implemented.

Moderately suitable (S2) lands cover 1957.37 ha (31.20% of TGA), representing zones where turmeric cultivation is feasible and can produce satisfactory yields under standard management practices. Habitation and water bodies account for 0.88% and 4.26%, respectively.

Table 4.38. Area under suitability sub-classes for Turmeric Cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	1957.37	31.20
2	Marginally Suitable (S3)	3994.54	63.67
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

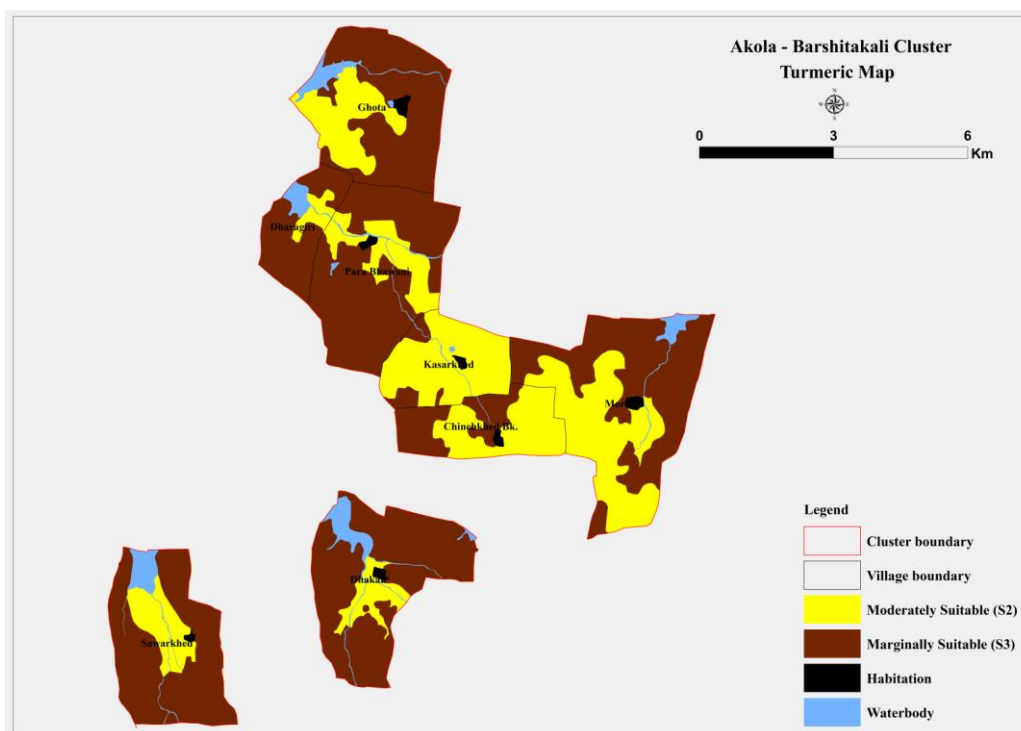


Fig 4.36. Soil site suitability map for Turmeric Cultivation

4.8.14 Soil-Site Suitability for Black gram Cultivation

The land suitability assessment for black gram cultivation indicates that the majority of the watershed, 3994.54 ha (63.67% of the total geographical area, TGA), falls under the marginally suitable (S3) category. These areas are constrained by moderate limitations such as soil fertility deficits, shallow soil depth, and terrain irregularities, which may restrict black gram growth and yield unless proper management interventions like fertilization, irrigation, and soil amendments are applied. Moderately suitable (S2) lands cover 1957.37 ha (31.20% of TGA), representing zones where black gram cultivation is feasible under standard agronomic practices. Habitation and water bodies account for 0.88% and 4.26%, respectively.

Table 4.39. Area under suitability sub-classes for Blackgram Cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	1957.37	31.20
2	Marginally Suitable (S3)	3994.54	63.67
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

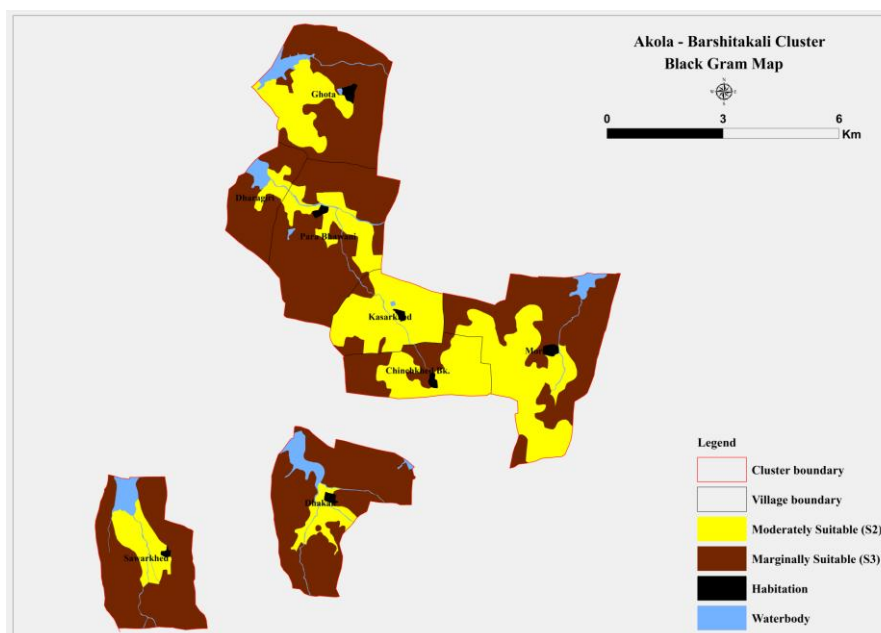


Fig 4.37. Soil site suitability map for Black gram Cultivation

4.8.15 Soil-Site Suitability for Green gram Cultivation

The land suitability assessment for green gram cultivation indicates that a majority of the watershed, 4525.74 ha (72.13% of the total geographical area, TGA), falls under the moderately suitable (S2) category. These lands have favorable soil and environmental conditions for green gram growth, with adequate soil fertility, depth, and moisture retention, allowing for good crop performance with standard agronomic practices.

Marginally suitable (S3) lands cover 1426.16 ha (22.73% of TGA), representing areas with moderate constraints such as lower fertility, shallow soils, or drainage issues, which may limit optimal yields unless management interventions like nutrient supplementation or irrigation are implemented. Habitation and water bodies account for 0.88% and 4.26%, respectively.

Table 4.40. Area under suitability sub-classes for Green gram Cultivation

Sr. No.	Green Gram	Area (ha)	Area (%)
1	Moderately Suitable (S2)	4525.74	72.13
2	Marginally Suitable (S3)	1426.16	22.73
3	Habitation	55.18	0.88
4	Waterbody	267.22	4.26
	Total	6274.30	100.00

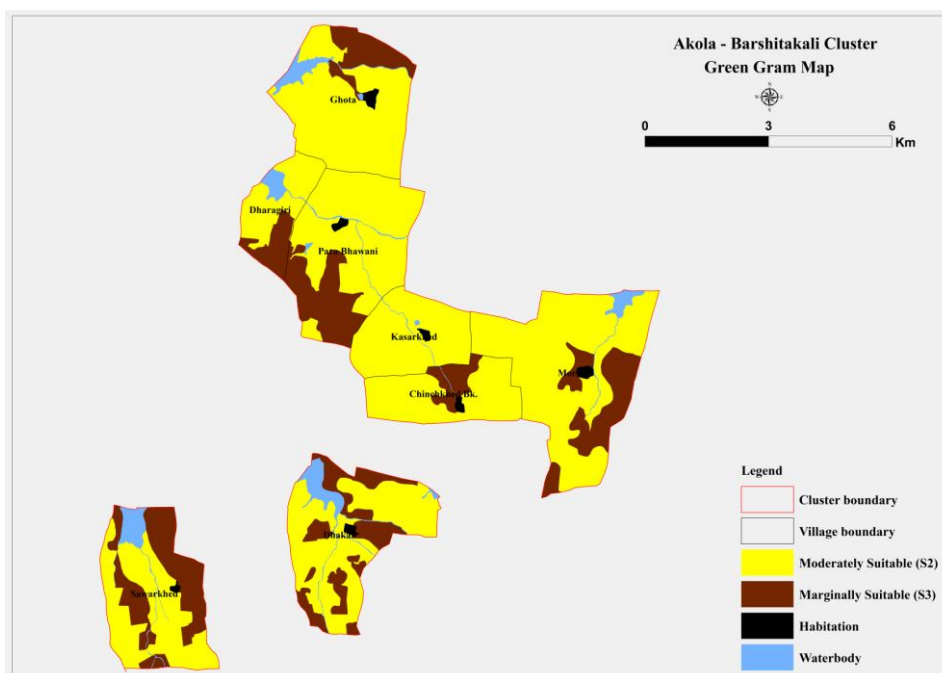


Fig 4.38. Soil site suitability map for Greengram Cultivation

4.8.16 Soil-Site Suitability for Mango Cultivation

The land suitability assessment for mango cultivation reveals that a major portion of the watershed, 4252.68 ha (67.78% of the total geographical area, TGA), is not suitable (N) due to severe limitations such as shallow soils, poor fertility, inadequate drainage, or terrain constraints that impede optimal mango growth. Moderately suitable (S2) lands cover 858.30 ha (13.68% of TGA), where mango cultivation is feasible with favorable soil and environmental conditions, while marginally suitable (S3) areas account for 840.93 ha (13.40% of TGA), where moderate limitations may restrict growth and yield unless proper management interventions like irrigation, soil amendments, and fertility enhancement are implemented.

Table 4.41. Area under suitability sub-classes for Mango Cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	858.30	13.68
2	Marginally Suitable (S3)	840.93	13.40
3	Not Suitable (N)	4252.68	67.78
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

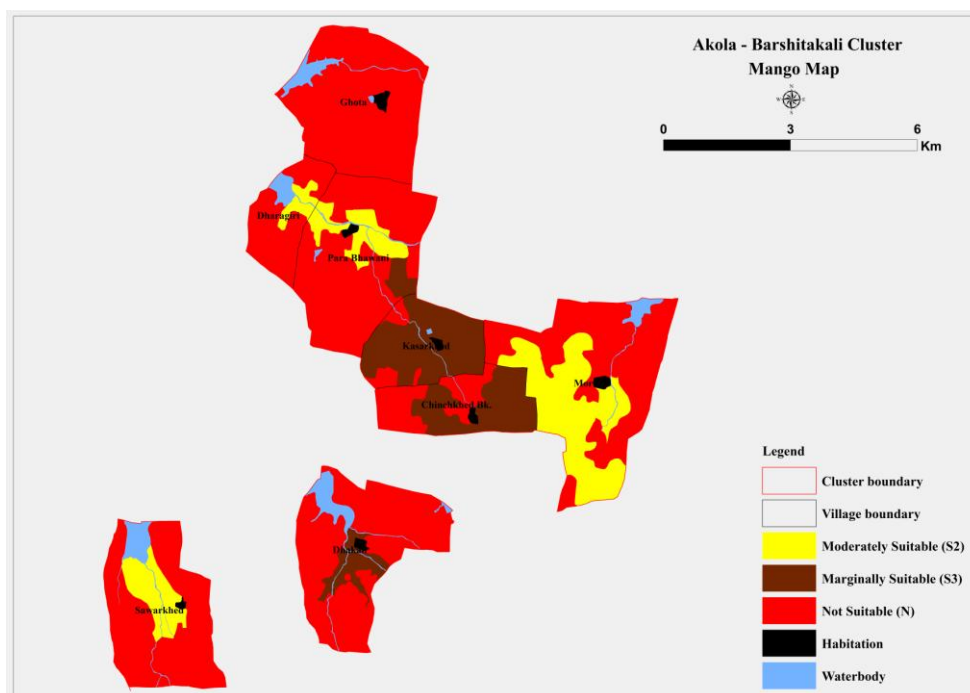


Fig 4.39. Soil site suitability map for Mango Cultivation

4.8.17 Soil-Site Suitability for Guava Cultivation

The land suitability assessment for guava cultivation shows that the majority of the watershed, 3994.54 ha (63.67% of the total geographical area, TGA), is not suitable (N) due to severe constraints such as poor soil fertility, shallow soils, inadequate water retention, or unsuitable terrain for guava growth. Moderately suitable (S2) areas cover 1699.23 ha (27.08% of TGA), representing lands where guava cultivation is feasible under favorable soil and site conditions, while marginally suitable (S3) lands account for 258.14 ha (4.11% of TGA), which may require management interventions like irrigation, soil fertility improvement, and drainage management to achieve satisfactory yields. Habitation and water bodies occupy 0.88% and 4.26%, respectively.

Table 4.42. Area under suitability sub-classes for Guava Cultivation

Sr. No.	Suitability Classes	Area (ha)	Area (%)
1	Moderately Suitable (S2)	1699.23	27.08
2	Marginally Suitable (S3)	258.14	4.11
3	Not Suitable (N)	3994.54	63.67
4	Habitation	55.18	0.88
5	Waterbody	267.22	4.26
	Total	6274.30	100.00

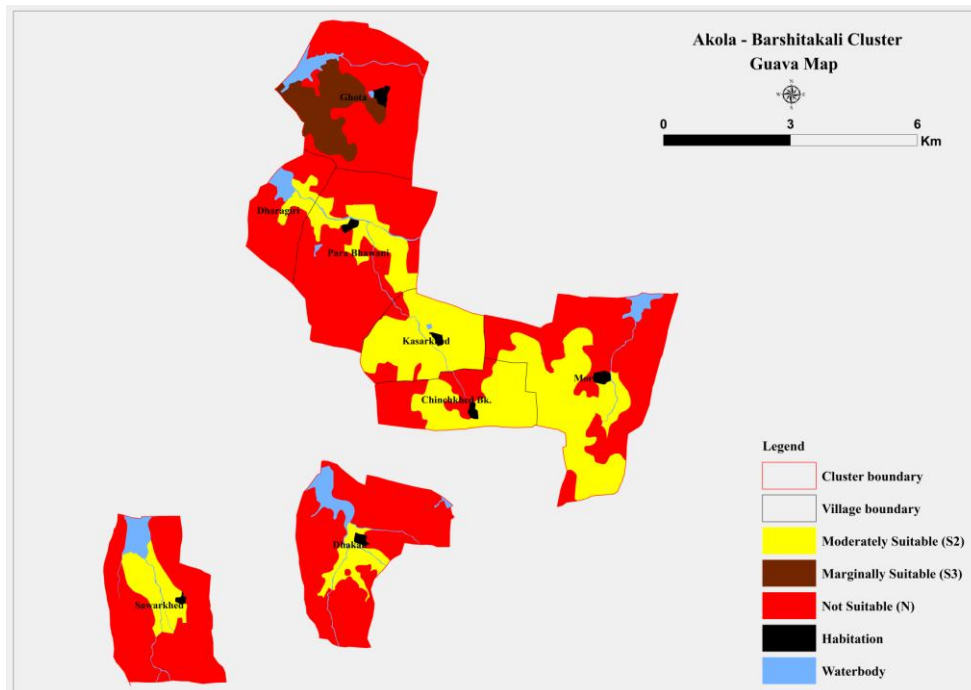


Fig 4.40. Soil site suitability map for Guava Cultivation

4.9 Soil and Water Conservation measures

Soil and Water Conservation (SWC) planning plays an essential role in improving land productivity and regulating surface runoff in areas where terrain, soil depth, and land use patterns influence water availability and soil erosion. Effective conservation planning becomes necessary in landscapes dominated by cultivation, where uncontrolled runoff and insufficient moisture retention can restrict agricultural performance. By applying appropriate conservation measures, soil health can be protected, infiltration can be increased, and land degradation can be minimized. The planning process depends on actual physical parameters such as landform characteristics, soil texture and depth, slope categories and land use/land cover distribution, which together determine the suitability of interventions across different land units.

The watershed under study comprises a cluster of eight villages falling within Barshitakli Taluka. Agriculture is the primary livelihood activity here, but the region faces recurring challenges of erratic rainfall, soil erosion, and declining water availability. The average annual rainfall of about 871 mm is relatively low, and its uneven distribution across the monsoon months often results in both dry spells and sudden runoff peaks. These conditions, combined with shallow soils and undulating terrain, have led to land degradation and reduced crop productivity in the cluster.

The landscape of the watershed is diverse, with hills, escarpments, pediments, plateaus, and pediplains forming the major landforms. Severe soil loss is observed in degraded forest patches, open scrub, wastelands, and unbunded agricultural fields located on steeper slopes. Gullies originating in the hills extend into foothill zones and agricultural lands, causing

further damage. Stream bank erosion is also evident along seasonal nalas, while siltation of farm ponds and reservoirs reduces their storage capacity. In contrast, valley and pediplain areas with deeper soils show relatively less erosion but suffer from poor drainage and declining groundwater recharge.

To address these issues, a comprehensive set of soil and water conservation measures has been proposed for the eight villages cluster. The largest share of interventions is in cultivable lands, where construction and strengthening of field bunds along with farm ponds will help harvest runoff and improve soil moisture. In shallow soils, farm ponds with lining are recommended to reduce seepage losses and ensure reliable storage. These measures together form the backbone of the plan, reflecting the importance of agricultural land management in the watershed.

In degraded forest and escarpment zones, afforestation combined with silt detention trenches is suggested to stabilize slopes and reduce downstream siltation. In open scrub and wastelands, afforestation with in situ moisture conservation practices will help arrest erosion and improve soil moisture. These vegetative measures are critical for restoring ecological balance in non-arable lands.

Waterbody renovation is also prioritized, focusing on desiltation and repair of small reservoirs and seasonal waterbodies to restore their capacity. In pediplains and middle pediments, broad bed and furrow systems are recommended along with bund strengthening and farm ponds to improve drainage and reduce waterlogging. On unbunded fields in escarpments and plateau zones, conservation bench terraces are proposed to reduce slope length and control runoff velocity.

Additional measures include rooftop rainwater harvesting in built up areas, stream bank plantation along rivers and nalas to stabilize banks, and cement or earthen nala bunds with desilting in seasonal streams to enhance recharge. Smaller interventions such as horticultural plantations in fallow lands, road drainage works, and localized in situ moisture conservation practices are also part of the plan.

Altogether, the proposed measures cover more than six thousand hectares across the eight villages. The plan integrates structural works like bunds, farm ponds, terraces, and nala bunds with vegetative measures such as afforestation, horticulture, and stream bank stabilization. By directly addressing erosion hotspots and water scarcity issues identified in the cluster, the plan aims to reduce runoff, conserve soil, and enhance water availability.

In conclusion, the soil and water conservation plan for the eight villages watershed provides a holistic framework to combat land degradation and water scarcity. It emphasizes capturing monsoonal runoff, reducing erosion, and enhancing groundwater recharge. The interventions are designed to protect existing water harvesting structures, improve crop yields, and strengthen the resilience of farming communities. By implementing this plan, the watershed can move towards sustainable management, ensuring long term ecological stability and socio-economic development for the villages.

Table 4.43. Proposed soil and water conservation (SWC) plan for Barshitakli watershed.

Sr. No.	Proposed SWC Plan
1	Field bund/Strengthening of existing bund with safe disposal of runoff water, Farmpond
2	Field bund/Strengthening of existing bund with safe disposal of runoff water, Farmpond with Lining
3	Afforestation, Silt Detention Trench in Downstream
4	Afforestation, In-situ Moisture Conservation Measures
5	Field bund/Strengthening of existing bund with safe disposal of runoff water
6	Renovation of Waterbody as per the site condition
7	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water, Farmpond
8	Conservation Bench Terrace in Unbunded Field/Field bund/Strengthening of existing bund with safe disposal of runoff water
9	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water, Farmpond with Lining
10	Rooftop Rainwater Harvesting
11	Horticultural Plantation, In-situ Moisture Conservation Measures
12	Stream Bank Plantation
13	Road
14	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existng bund with safe disposal of runoff water
15	Cement Nala Bund, Earthen Nala Bund / Repairing of Cement Nala Bund and Desilting of Nallas
16	In-situ Moisture Conservation Measures

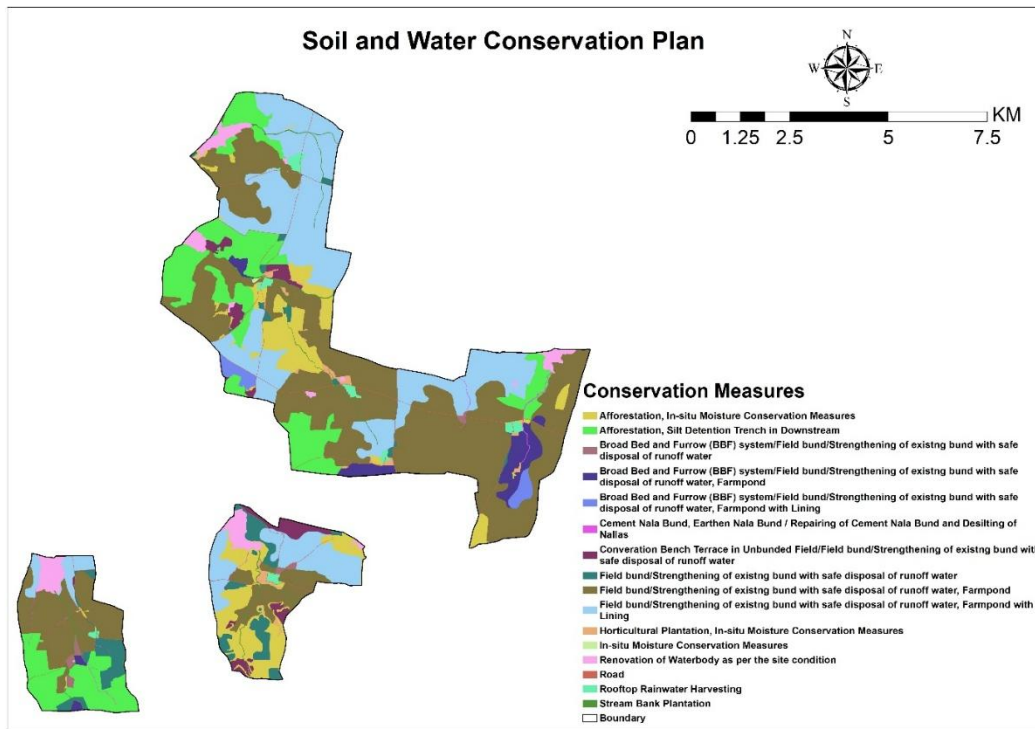


Fig 4.41. Soil and Water Conservation measures proposed for Barshitakli watershed, Akola district.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

- The Barshitakli watershed's economy is largely agriculture-based on a cotton, soybean, pigeon pea and chickpea 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.
- Runoff estimation in Barshitakli watershed showed that most surface flow occurs during July-September, with July and August contributing the highest runoff due to intense monsoon storms. Annual runoff averaged 13.5% of seasonal rainfall, indicating that a substantial share of rainfall is lost through infiltration, storage, or recharge.
- Groundwater potential mapping classified the Barshitakli watershed into very poor, poor, moderate, good, and very good zones using eight thematic factors. Only 29.6% of the watershed falls under good to very good groundwater potential, while 70.4% ranges from moderate to very poor. Small reservoirs play an important role in both irrigation support and groundwater recharge, especially during normal rainfall years.
- Proposed soil and water conservation measures for Barshitakli watershed include field bunds, farm ponds, nala bunds, terraces, afforestation, and stream bank stabilization. Structural and vegetative measures were planned according to landform, slope, soil depth, and land use.

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 Barshitakli watershed. The generation and interpretation of these thematic layers provide a scientific foundation for identifying priority areas and formulating appropriate soil and water conservation strategies.

The 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.

The assessment of fertility parameters indicated that the soil of the watershed possesses the multi-nutrient deficiencies like available nitrogen, phosphorus and zinc coupled with majority of the area under medium category of the organic carbon. This needs serious attention to optimized the productivity potential of the watershed soils. The farmers of the Barshitakli watershed should make aware about the balance application of the nutrients in order to sustain the soil health in long term. The farmers should also adopt a compulsory approach of utilizing the organic manures in their farm to maintain the soil organic carbon in their soil. The assessment of crop suitability in the watershed area revealed that the soils of watershed can support the crop diversification through agricultural and horticultural crops for enhancing the soil health and socio-economic conditions of the farmers. The study demonstrates that rainfall-runoff dynamics, groundwater availability, and land management practices are closely interconnected in the Barshitakli watershed. Runoff is mainly concentrated during peak monsoon months, increasing the risk of soil erosion and water loss, while early monsoon rainfall largely infiltrates into the soil. Groundwater potential mapping reveals that only a limited portion of the watershed has favourable recharge conditions, highlighting the need for careful water resource management. Small reservoirs play a key role in both irrigation and groundwater recharge. The proposed soil and water conservation measures provide a comprehensive approach to reduce runoff, improve infiltration, and enhance water availability, ultimately supporting sustainable agriculture and strengthening watershed resilience.

Overall, the integrated approach adopted in this study enables precise planning, prioritization, and implementation of watershed development activities. The recommended measures are expected to reduce surface runoff and soil erosion, enhance groundwater recharge, and improve crop productivity. Successful execution of these interventions will

contribute to long-term water security, environmental sustainability, and socio-economic development of the farming community. The study thus provides a robust scientific framework for sustainable watershed management and supports the broader objectives of the PMKSY programme in achieving efficient and equitable utilization of water resources.

ANNEXURE-1

Methodology for Morphometric Analysis

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

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

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

Morphometric analysis Barshitakali cluster, Akola

The 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 Barshitakali village cluster, Akola, Maharashtra, comprises eight villages. Together, these villages constitute the study cluster having 4 sub-watersheds (Fig. 1).

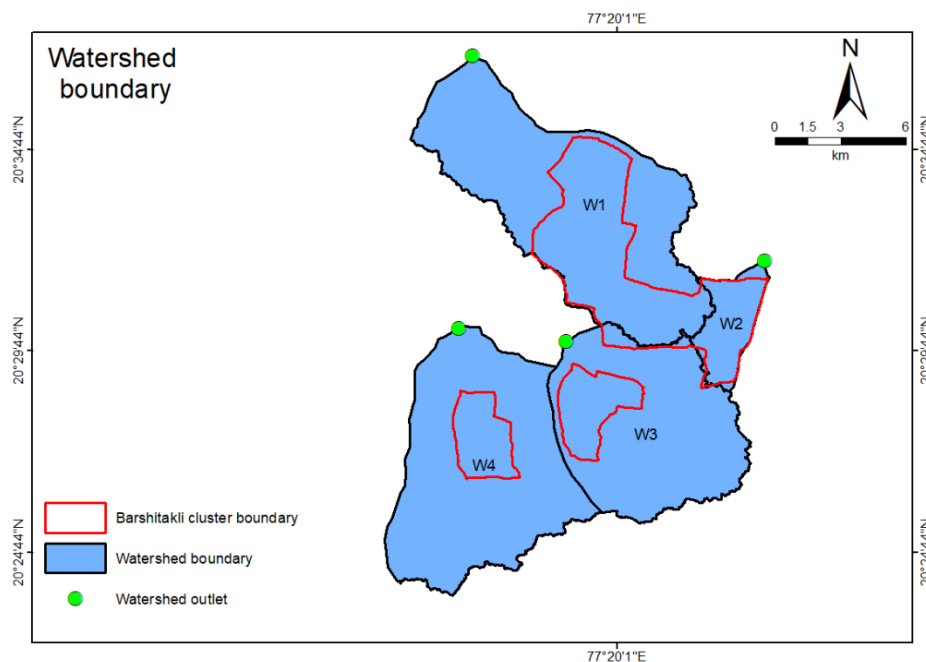


Fig. 1: Map of Barshitakali cluster, Akola, depicted through sub-watershed

Table 1: Distribution of area under different sub-watershed, Barshitakali cluster, Akola

Sr. No.	Sub-watershed name	Sub-watershed order	Elevation (m)	Area (km ²)	Flow origination
1	W1	5 th	231-346	80.27	South-east
2	W2	3 rd	298-354	10.69	East
3	W3	5 th	283-381	56.61	South-east
4	W4	5 th	269-392	70.09	South-east
			Total	217.66	

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.

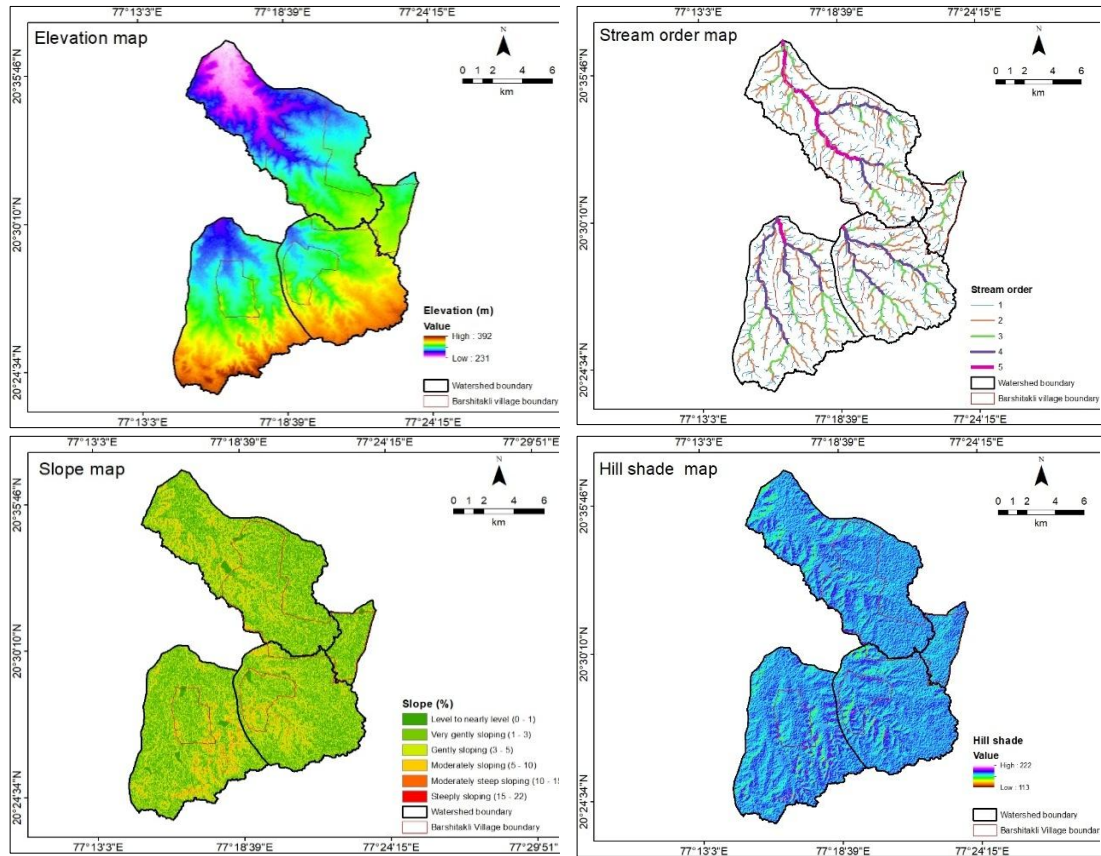


Fig. 2: Elevation, stream network, slope and hill shade map of sub-watershed

Linear aspect

Linear morphometric parameters focus on the stream network characteristics and its influence on runoff and watershed behaviour. The morphometric analysis of the four sub-watersheds shows clear variation in drainage characteristics. W1 has the highest number of streams (373) and total stream length (207.4 km), indicating a well-developed drainage network, while W2 has the lowest values (Table 2). The bifurcation ratio ranges from 4.1 (W1) to 7.9 (W2), suggesting relatively greater structural influence in W1.

Mean channel length and valley length are highest in W4, reflecting more mature channel development, whereas W2 records the lowest values. Channel index is highest in W2 (1.4), indicating greater sinuosity. Basin perimeter is also largest in W1 (57.88 km), confirming it as the most extensive sub-watershed, while W2 is the smallest.

Table 2: Linear morphometric parameters of sub-watersheds, Barshitakali cluster, Akola

Sr. no.	Morphometric parameter	Symbol	Unit	W1	W2	W3	W4
1	No. of streams	Nu	No	373	59	257	337
2	Stream length	Lu	km	207.4	26	142.2	187.2
3	Bi-furcation ratio	Rb	-	4.2	7.9	4.1	4.3
4	Mean channel length	Cl	km	12.37	7.08	10.16	13.89
5	Valley Length	Vl	km	11.01	6.12	9.42	12.03
6	Channel Index	Ci	-	1.2	1.4	1.3	1.3
7	Minimum areal distance	Adm	km	10.6	5.23	8.12	10.98
8	Valley Index	Vi	-	1.04	1.17	1.16	1.10
9	Basin perimeter	P	km	57.88	21.04	42.35	43.29

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 W1 (80.27 km²) and lowest in W2 (10.69 km²). Mean basin width is also greater in W1 (6.0 km). Form factor (Ff) and elongation ratio (Re) are highest in W4 (0.45 and 0.76), suggesting a comparatively more circular basin, whereas W2 and W4 show lower values, indicating elongated shapes. Circularity ratio (Rc) is maximum in W4 (0.47), while compactness coefficient (Cc) is highest in W2 (1.84), reflecting greater basin irregularity. Standard sinuosity index (Ssi) ranges from 1.16 (W2) to 1.08 (W3), indicating relatively higher channel sinuosity in W2. Drainage parameters show that stream frequency (Fs) is highest in W2 (5.52 per km²) and lowest in W3 (4.54 per km²). Drainage density (Dd) is nearly similar in W4 (2.7 km/km²) but lower in W2 (2.4 km/km²). Drainage intensity (Di) follows a similar trend, with the highest value in W2 (2.27). Length of overland flow (Lg) is greatest in W2 (0.21 km) and lowest in W1 (0.19 km), indicating shorter runoff travel distance in W2.

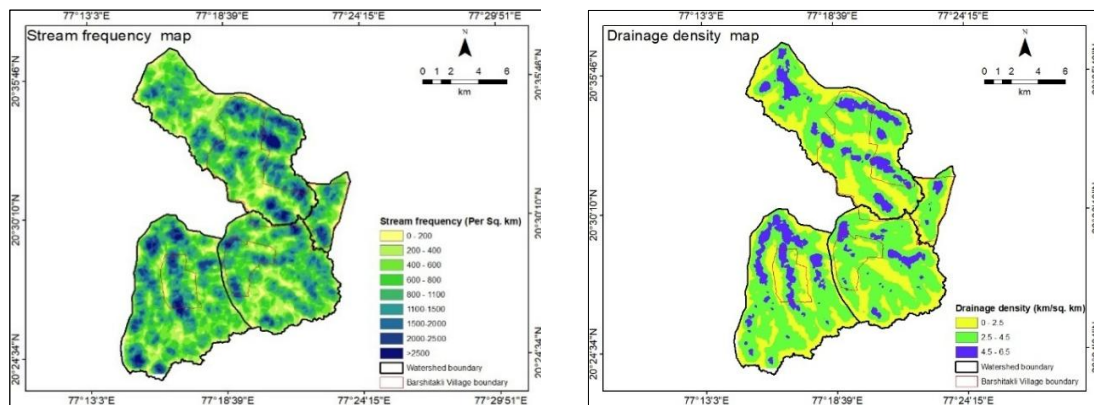


Fig. 3. Steam frequency and drainage density map of sub-watershed

Table 3. Areal morphometric parameters of sub-watersheds, Barshitakali cluster, Akola

Sr. No	Parameter	Symbol	Method/Formula	Unit	W1	W2	W3	W4
1.	Mean basin width	Wb	$Wb=A/Lb$	km	6.0	1.32	5.07	4.71
2.	Basin area	A	GIS Analysis	km ²	80.27	10.69	56.61	70.09
3.	Relative perimeter	Pr	$Pr= A/P$	km	1.39	0.51	1.34	1.62
4.	Length area relation	Lar	$Lar = 1.4*A^{0.6}$	km ²	19.45	5.80	15.77	17.93
5.	Lemniscate's	k	$K = Lb^2/A$	-	2.2	6.1	2.2	3.2
6.	Form factor	Ff	$Ff = A/Lb^2$	-	0.45	0.16	0.45	0.32
7.	Elongation ratio	Re	$Re = 2/Lb*(A/\pi)^{0.5}$	-	0.76	0.46	0.76	0.63
8.	Circularity ratio	Rc	$Rc = 12.57*(A/P^2)$	-	0.30	0.30	0.40	0.47
9.	Compactness coefficient	Cc	$Cc = 0.2841*P/A^{0.5}$	-	1.84	1.83	1.60	1.47
10.	Standard sinuosity index	Ssi	$Ssi = Ci/Vi$	-	1.12	1.16	1.08	1.15
11.	Stream frequency	Fs	$Fs = Nu/A$	Per km ²	4.65	5.52	4.54	4.81
12.	Drainage Density	Dd	$Dd = Lu/A$	km/km ²	2.6	2.4	2.5	2.7
13.	Drainage Intensity	Di	$Di = Fs/Dd$	-	1.80	2.27	1.81	1.80
14.	Length of Overland Flow	Lg	$Lg = A/2*Lu$	km	0.19	0.21	0.20	0.19

Relief Aspects

The maximum basin height (Z) is highest in W4 (392 m) and lowest in W1 (346 m), while total basin relief (H) is also maximum in W4 (123 m) and minimum in W2 (56 m) (Table 4). Relief ratio (Rhl) is highest in W3 (8.8), indicating steeper terrain conditions, whereas W2 shows the lowest value (6.9).

Relative relief ratio (Rhp) is greatest in W4 (284.1), followed by W2 and W3, suggesting higher relief intensity in W4. The ruggedness number (Rn) is maximum in W4 (0.22), reflecting more dissected and erosion-prone terrain, while W2 has the lowest value (0.13). Similarly, the Melton ruggedness number (MRn) is highest in W2 (17.1), indicating comparatively higher susceptibility to runoff and erosion processes.

Table 4: Relief morphometric parameters of sub-watersheds, Barshitakali cluster, Akola

Sr. No	Parameters	Symbo l	Methods /Formula	W1	W2	W3	W4
1.	Height of at basin mouth (m)	z	DEM	231	298	283	269
2.	Maximum height of the basin (m)	Z	DEM	346	354	381	392
3.	Total basin relief (m)	H	$H = Z - z$	115	56	98	123
4.	Relief ratio	Rhl	$Rhl = H / Lb$	8.6	6.9	8.8	8.3
5.	Relative relief ratio	Rhp	$Rhp = H * 100 / P$	198.7	266.2	231.4	284.1
6.	Ruggedness number	Rn	$Rn = Dd*(H/1000)$	0.21	0.13	0.18	0.22
7.	Melton Ruggedness number	MRn	$MRn = H / A^{0.5}$	12.8	17.1	13.0	14.7

Slope plays an important role in controlling runoff, soil erosion, and watershed hydrological response. The slope analysis of the four sub-watersheds (W1, W2, W3 and W4) indicates that most of the area is dominated by very gently sloping (1–3%) and gently sloping (3–5%) terrain, which together occupy the largest proportion of land in all sub-watersheds. In W1, about 41.95% of the area falls under very gently sloping class, followed by 27.81% gently sloping and 19.64% nearly level land. Similarly, W2 is dominated by very gently sloping terrain (48.92%), indicating relatively smooth topography with moderate runoff potential. In W3 and W4, very gently sloping areas account for 43.56% and 41.78%, respectively, while gently sloping terrain contributes 28.11% in W3 and 27.38% in W4.

The soil conservation plan for the watershed is formulated by integrating morphometric characteristics with slope distribution, which together control runoff generation, erosion intensity, and water retention capacity. The analysis indicates that most of the watershed area falls under nearly level to gently sloping terrain (0–5%), which is suitable for agriculture but requires measures to reduce runoff and enhance infiltration; therefore, practices such as field bunding, strip cropping, and farm ponds are recommended to improve soil moisture and groundwater recharge. Sub-watersheds like W1, with a large basin area and well-developed drainage network, require check dams, percolation tanks, and water harvesting structures to manage higher runoff volumes. In W2, where stream frequency and drainage intensity are relatively high, vegetative barriers and contour cultivation are necessary to control rapid runoff. Areas with moderate slopes (5–10%), particularly in W3 and W4, should adopt contour trenching, and small gully control structures to reduce soil loss and stabilize slopes. Since W4 shows higher basin relief and ruggedness number, indicating greater erosion susceptibility, afforestation, grass cover development, and slope stabilization measures are essential to protect the terrain. Overall, a combination of agronomic measures, structural interventions, and vegetative conservation practices is required to reduce erosion, regulate runoff, and promote sustainable soil and water management across the watershed.





