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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: Lonar, Dist - Buldhana

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

Vasundhara Watershed Development Agency
Pune, Maharashtra

About the ICAR-NBSS&LUP

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

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

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PREFACE

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

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

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

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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)3/2021-22: Lonar, Dist – Buldhana" 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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CONTENTS

Figure	LIST OF FIGURES	Page No.

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 Buldhana Lonar Cluster-watershed, located in Lonar Taluka of Buldhana District, Maharashtra. The Cluster-watershed forms part of the Penganga and Purna River basins and represents the typical basaltic and black soil (Vertisol) terrain of the Deccan Plateau. Agriculture is the dominant land use in the watershed, largely dependent on monsoon rainfall, with groundwater and small irrigation tanks serving as supplementary water sources.

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.

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:

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

District	Project name	Block	No. of MWS*	No. of villages	Area (ha)
Akola	Akola (WDC-2.0)1/2021-22	Barshitakli	11	8	4898.00
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
Buldhana	Buldhana (WDC-2.0)3/2021-22	Lonar	7	7	2760.49
Osmanabad	Osmanabad (WDC-2.0)3/202 1-22	Tuljapur	25	10	3380.00
Palghar	Palghar (WDC-2.0) 6/2021-22	Dahanu	7	23	3926.27

Parbhani	Parbhani (WDC-2.0/3/2021-22	Gangakhed	8	9	3791.00
Raigad	Raigad (WDC-2.0)/2/2021-22	Roha	3	11	3825.00
Ratnagiri	Ratnagiri (WDC-2.0)/3/2021-22	Chiplun	13	9	2548.00
Sangli	Sangli (WDC-2.0)3/2021-22	Jath	23	4	3200.00
Sindhudurg a	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)/3/202 1-22	Seloo	12	7	2657.54
Washim	Washim (WDC-2.0)/5/202 1 -22	Lonar	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
d) To assess and characterize the groundwater potential of the watersheds.

This report documents the LRI of the Buldhana (WDC-2.0)3/2021-22 sub-watershed located in Lonar 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

LONAR WATERSHED AT A GLANCE/GEOGRAPHICAL SETTINGS

2.1 Location and Extent

The watershed (Fig. 2.1) is located in the Lonar area of Buldhana District in the state of Maharashtra, India. Lonar lies in the southeastern part of Buldhana District and experiences a semi-arid tropical climate, characterized by moderate and irregular rainfall, which is typical of the Vidarbha region of central India. Geographically, the watershed falls approximately between 76.45° to 76.60° East longitude and 19.95° to 20.10° North latitude. The geology of the area is predominantly composed of Deccan Traps basalt, representing the extensive hard rock terrain of the Deccan Plateau. A unique geological feature of the region is the Lonar Crater Lake, a meteorite impact crater formed in basaltic rock. Hydrologically, the watershed is part of the Purna River basin, which ultimately drains into the Godavari River system. The region surrounding Lonar is predominantly rural, consisting of scattered villages with an agrarian economy largely dependent on rainfed agriculture. The landscape varies from gently undulating plains to low basaltic plateaus, influencing drainage patterns and land use within the watershed.

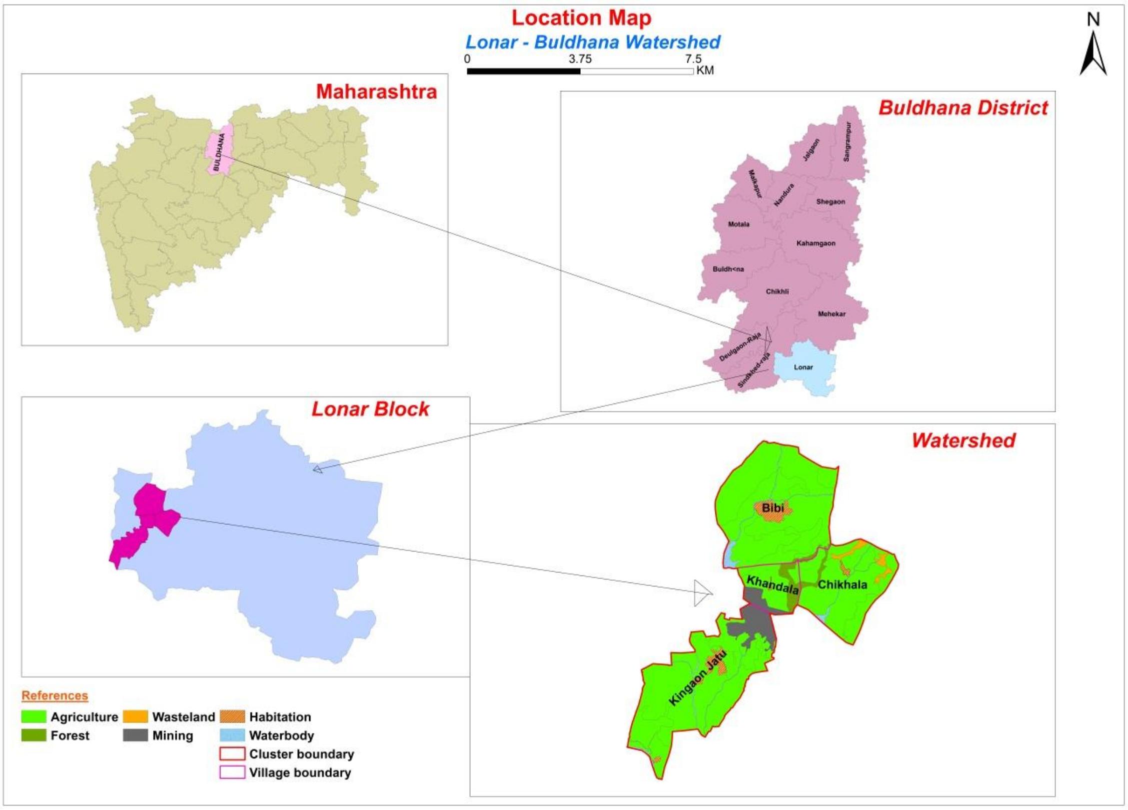


Fig. 2.1: Location map of the Buldhana-Lonar watershed

Table 2.1: Geographical and Administrative Profile

Sr. No.	Particulars	Details
1	District	Buldhana
2	Taluka	**Lonar**
3	Revenue Division	Amravati
4	Total sub-watershed Area	3589.79 ha
5	Micro-watershed (cluster/treated) area	2760 ha
6	Villages	04 (Bibi,Chikhla,Khandala,Kingaon Jattu)
7	Major River	Purna River
8	Climate	tropical semi-arid climate
9	Average annual Rainfall	780-800mm

2.2 Geology

The Lonar region, located in the southeastern part of Buldhana 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, which form the characteristic hard rock terrain of the Deccan Plateau in Maharashtra. These lava flows are generally massive and compact, with occasional vesicular and amygdaloidal structures. Thin intertrappean beds of sedimentary origin, such as clay, shale, or limestone, may occur between successive lava flows, representing quiescent phases during volcanic activity. The basaltic formations often exhibit columnar jointing and spheroidal weathering, which influence groundwater movement and soil development in the region.Weathering of basalt has led to the formation of shallow to moderately deep black cotton soils, while localized patches of red soils occur on elevated and well-drained areas. A distinctive geological feature of this region is the Lonar Crater Lake, a meteorite impact crater formed within the basaltic rocks of the Deccan Traps.

2.3 Geomorphology

Geomorphologically, the Lonar region lies within the eastern part of the Deccan Plateau, forming a transitional zone between the plateau uplands and the low-lying plains of the Purna River basin, which is part of the larger Godavari River drainage system. The terrain is predominantly undulating to gently rolling, with occasional low basaltic hills and mesas formed due to differential erosion of the Deccan Traps lava flows. The elevation of the region generally ranges from 350 to 500 meters above mean sea level. The surrounding plains consist of relatively deeper and more fertile black soils, which support agricultural activities, whereas the plateau and upland areas contain shallow soils, sparse vegetation, and are more prone to soil erosion. A remarkable geomorphic feature of this area is the Lonar Crater Lake, a circular meteorite impact crater formed in basaltic rock. The drainage network in the region generally exhibits a dendritic pattern, which is typical of basaltic terrains. The important geomorphic units observed in the watershed include basaltic hills and ridges, plateau tops, pediments, pediplains, escarpments, and valley plains, which collectively influence the drainage pattern, soil distribution, and land use of the region.

2.4 Physiography and Soil

The geomorphic units of the Lonar region significantly influence surface runoff patterns, soil distribution, and infiltration characteristics within the watershed. The underlying Deccan Traps basalt undergoes weathering processes that lead to the formation of soils with varying depth and texture, depending on the slope position and degree of landscape dissection. Slope values in the watershed range from nearly level areas to steep slopes exceeding 30–40%, although the majority of the region is characterized by gentle slopes below 6%. Steeper slopes are mainly confined to basaltic hills, ridges, escarpments, and plateau margins. Soils derived from basaltic parent material show considerable variation in texture, depth, and physical properties depending on the topographic position. Based on texture, the soils are predominantly loamy to clayey, with moderate fertility and good moisture-holding capacity, making them suitable for agriculture in plains and gently sloping areas. However, during short-duration, high-intensity rainfall events, soils on steeper slopes may experience surface sealing and rapid runoff, which can lead to localized soil erosion and sediment transport. These geomorphic and soil characteristics play an important role in determining watershed hydrology, land capability, and soil conservation needs in the region.

2.5 Climate

The watershed in the Lonar region experiences a semi-arid to sub-humid climate, which is typical of the eastern part of the Deccan Plateau in Maharashtra. The regional climate is mainly influenced by the southwest monsoon, which brings the majority of the annual rainfall between June and September. The average annual rainfall in the region ranges from 700 mm to 800 mm, with noticeable inter-annual and spatial variability. The monsoon season contributes approximately 80–90% of the total annual precipitation, making the watershed highly dependent on seasonal rainfall for agricultural activities and groundwater recharge. However, the rainfall pattern is often irregular and uneven, which sometimes results in periodic drought conditions and water scarcity. Temperature variations in the region are moderate to high throughout the year. The summer season (March–May) is generally hot and dry, with maximum temperatures often reaching 38–42°C. In contrast, the winter season (November–February) is relatively cooler, with minimum temperatures occasionally falling to around 10–12°C. Relative humidity remains high during the monsoon season (above 70%) but decreases significantly during the summer months. The region also experiences high evaporation rates, especially during the pre-monsoon period, which can intensify water stress in agricultural lands, particularly where irrigation facilities are limited.

2.6 Drainage

The Lonar watershed forms part of the Purna River basin, which ultimately drains into the Godavari River. The drainage network of the watershed exhibits a dendritic pattern, typical of basaltic terrains, reflecting the relatively uniform lithology and gentle slopes prevalent in the region. Several minor streams and rivulets traverse the watershed, eventually converging into the main Purna River channel. Drainage density varies with topography:

flatter plateau areas and alluvial plains generally have lower drainage density, whereas hilly areas, ridges, and escarpments exhibit denser stream networks due to higher runoff and steeper slopes. Surface runoff from rainfall events is primarily influenced by the combination of slope, soil permeability, and geomorphic units. Most streams in the watershed are seasonal, with peak flow during the monsoon months and minimal discharge during the dry season. The drainage system plays a critical role in irrigation, groundwater recharge, and soil conservation, and its characteristics are essential for planning watershed development interventions such as check dams, contour trenches, percolation tanks, and other water-harvesting structures.

2.7 Cropping Patterns, and Demography and Socioeconomics

2.7.1 Cropping Pattern

Agriculture in the Lonar 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 on well-drained soils of alluvial plains. Topography and soil depth strongly influence crop selection. Upland plateau and hilly areas with shallow, less fertile soils primarily support drought-resistant crops like sorghum and pigeon pea, whereas 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 efficiency. The construction of rainwater harvesting structures and minor irrigation facilities further enhances the sustainability of the cropping system in the watershed.

2.7.2 Demographic and Socioeconomic Status

The Lonar watershed lies in a predominantly rural landscape, with most of the population engaged in agriculture and allied activities, reflecting the semi-arid to sub-humid, rainfed conditions of the region. The population is primarily Hindu, with smaller communities of Muslims and other minorities. Small pockets of indigenous tribal communities contribute to the cultural diversity of the area. Education levels are moderate, with literacy improving steadily due to government initiatives and local schools. However, the gender ratio is slightly skewed toward males, particularly in rural settlements, mirroring broader demographic trends in the Vidarbha region. Economically, the watershed is largely agriculture-dependent, with limited industrial activity. Major sources of livelihood include crop cultivation, livestock rearing, and small-scale trade. Seasonal migration from upland and drought-prone areas occurs, with residents moving to nearby towns and cities in search of employment opportunities during periods of water scarcity or low agricultural productivity. Overall, the Lonar watershed represents a rural, agrarian economy characterized by moderate literacy, gender imbalances, dependence on seasonal rainfall, and reliance on small-scale livelihoods, reflecting the broader socio-economic profile of Buldhana District.

2.8 Water Resources

2.8.1 Surface Water

Surface water in the Lonar 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 significantly 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 store water for irrigation, livestock, and domestic uses during the dry season. The availability of surface water is highly seasonal, with most flows occurring between June and September, while smaller streams and ponds often dry up during the pre-monsoon and summer months. The spatial distribution of surface water is governed by topography, drainage density, and slope. Low-lying alluvial plains and natural depressions tend to accumulate larger water bodies, whereas hilly and plateau areas exhibit rapid runoff with limited water retention. Effective watershed management in the region emphasizes augmenting surface water storage, controlling runoff, and promoting infiltration to maintain water availability throughout the year.

2.8.2 Groundwater

Groundwater in the Lonar 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.

2.8.3 Irrigation and Water Management

Agriculture in the Lonar watershed is predominantly rainfed, reflecting the semi-arid to sub-humid climate and the seasonal variability of rainfall. Irrigation facilities are limited, with minor canal systems, farm ponds, check dams, and percolation tanks providing supplementary water to crops during dry periods. Farmers primarily cultivate crops suited to monsoon rainfall, while irrigation supports cash crops and high-value crops in areas where water availability permits. Water management in the watershed emphasizes the harvesting and conservation of both surface and groundwater. Structures such as contour bunds, farm ponds, percolation tanks, and check dams help regulate runoff, reduce soil erosion, and enhance groundwater recharge. These interventions are especially important in upland and plateau areas, where shallow soils and steeper slopes result in rapid runoff and limited water retention. Integrated water management practices aim to maximize water use efficiency, enhance agricultural productivity, and mitigate drought and water scarcity risks. Proper maintenance of minor irrigation structures, coupled with the adoption of soil moisture conservation techniques, is critical for sustaining crop yields and ensuring water security in the Lonar watershed.

2.9 Constraints

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

a) Seasonal water scarcity due to limited and erratic rainfall.

b) Inadequate structures for soil conservation.

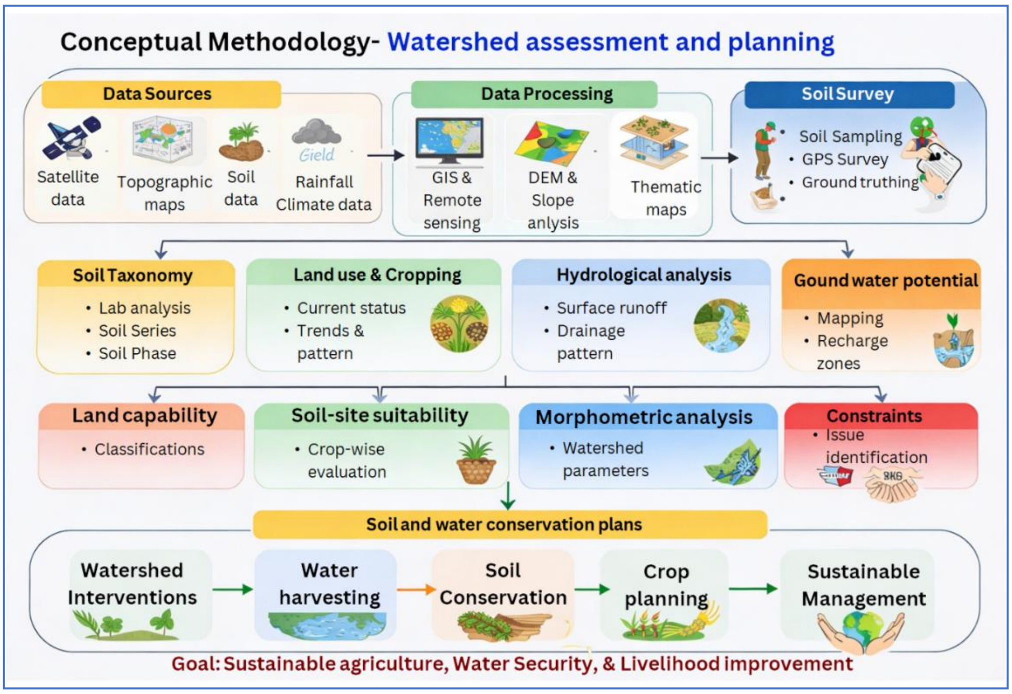
c) Depleting groundwater Levels.

CHAPTER 3

METHODOLOGY

3.1 Overview of activities

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



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

A. Pre-field

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

B. Soil Survey

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

C. Post-field phase

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

3.2 Preparation of Base Maps

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

3.3 Ground-truth Verification

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

3.4 Soil Sampling and Analysis

Soil samples from each horizon of all of the representative soil series were collected for laboratory studies. The soil samples collected during the fieldwork were initially air dried in the laboratory at room temperature, ground using a wooden pestle and mortar, screened through a 2 mm sieve, properly labelled, and stored in polythene bags for laboratory analysis. The soil samples were analysed in the laboratory for physical and chemical parameters using standard procedures. The particle size analysis was done by international pipette method. A combined glass-calomel electrode was used to determine the pH measured (1:2.5 soil/solution ratio). Soil organic carbon (SOC) was determined using the wet digestion method of Walkley and Black (1934). Available nitrogen (N) was measured by the alkaline permanganate method as described by Subbiah and Asija (1956). Available phosphorus (P) was determined by the Bray II method (Bray and Kurtz 1945). Cation exchange capacity (CEC) of soil was measured as per the procedure outlined by Jackson

(1976). Exchangeable cations [calcium (Ca), potassium (K), and magnesium (Mg)] were extracted with 1 M ammonium acetate (NH4Oac) (pH 7.0). Potassium content was determined by flame photometry (Rich 1965), while Ca and Mg were determined in ethylene diamine tetra acetic acid (EDTA) titration. Exchangeable Al was extracted with 1 N potassium chloride (KCl) solution and titrated with 0.1 N sodium hydroxide (NaOH) solution. Available micronutrient content [copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn)] were determined by diethylene triamine penta-acetic acid (DTPA) extraction (Lindsay and Norvell 1978), followed by atomic absorption spectrophotometry. Soils were classified according to Keys to Soil Taxonomy (Soil Survey Staff 2010).

3.5 Development of Soil Mapping Legend

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

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

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

3.6 Surface runoff estimation

Direct surface runoff occurring in the Lonar 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 Lonar 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 Lonar 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 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 Lonar cluster of District Buldhana reveals a strong dependence on wells, which account for 65.83% of irrigation sources across surveyed villages. Canal contributes only 8%, while irrigation systems such as borewell (4%). Notably, 22% of households have no irrigation source, indicating high exposure to rainfall variability. Villages such as Bibi and Kingaon Jattu rely almost entirely on wells, whereas Chikhla and Khandala show mixed sources. The overall pattern reflects restricted access to assured water infrastructure, which limits the capacity for stable year-round irrigation.

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

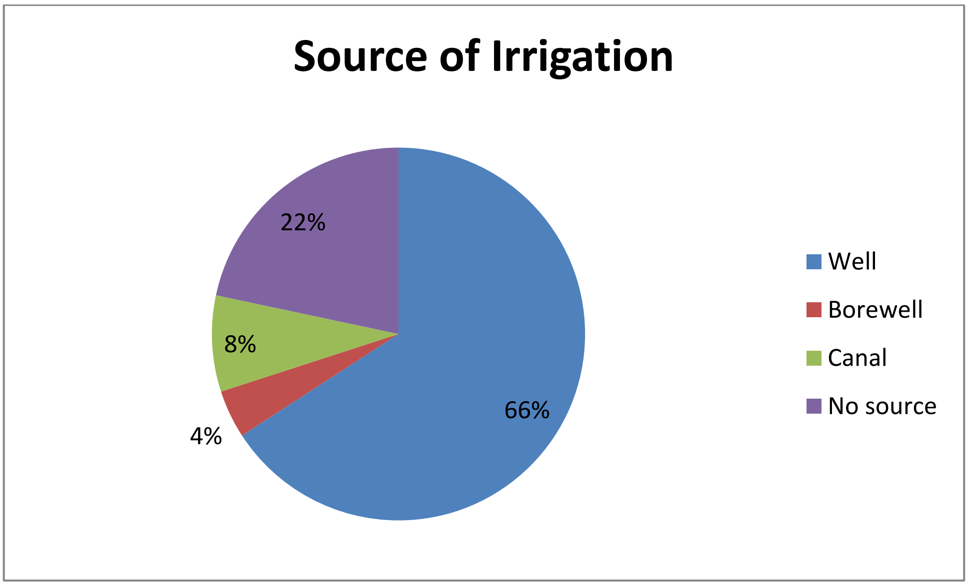


Fig. 4.1: Break-up of irrigation Sources in the Lonar watershed

4.1.2 Cropping Pattern

The cropping pattern in the Lonar watershed is largely influenced by monsoon rainfall, with kharif crops such as soybean, red gram, and cotton dominating the summer season, while rabi crops like gram and wheat are cultivated during the winter. Soybean is the most widely grown kharif crop, occupying 148.07 ha with a productivity of 1669.48 kg/ha, followed by red gram on 20.88 ha at 1295.01 kg/ha. Cotton is cultivated on a very limited area of 2.2 ha with relatively low yields. In the rabi season, gram and wheat are prominent, covering 73.95 ha and 30.46 ha, with average yields of 1611.89 kg/ha and 2429.41 kg/ha, respectively. The watershed shows a trend toward crop diversification, combining traditional cereals and pulses with high-value crops like soybean, which contributes to both household nutrition and income. However, the system remains highly dependent on rainfall, and limited irrigation access constrains stable production. The assessment highlights the need for targeted interventions such as improved water management, adoption of high-yielding varieties, and soil fertility enhancement to optimize productivity and ensure sustainable agriculture in the watershed.

Table 4.1: Crop Cultivation Pattern across the Lonar Cluster

Sr. No.	Crop	Farmers interviewed (n)	Season	Area (ha)	Productivity (kg ha^{-1})
1	Soybean	120	Kharif	148.07	1669.48
2	Cotton	4	Kharif	2.2	600
3	Redgram	77	Kharif	20.88	1295.01
4	Gram	76	Rabi	73.95	1611.89
5	Wheat	35	Rabi	30.46	2429.41

4.1.3 Socioeconomic Status

4.1.3.1 Land holding pattern

The farm size distribution in the watershed indicates that agriculture is predominantly smallholder-based. Marginal farmers, with less than 1 ha of land, constitute 37.5% of the respondents, holding an average of 0.81 ha. Small farmers, owning 1–2 ha, form the largest group at 52.5%, with an average landholding of 1.5 ha. Semi-medium farmers, cultivating 2–4 ha, account for 9.16% with an average of 3.0 ha. Only a very small proportion (0.83%) falls under the medium category (4–10 ha), averaging 4.8 ha, while there are no large farmers (>10 ha) in the surveyed area. This distribution highlights the predominance of small and marginal holdings, underscoring the need for targeted support in resource management, input access, and capacity building to enhance productivity and livelihoods in the watershed.

Table 4.2 Land holding pattern in Lonar-watershed

Farmer land holding category	Criteria Land (ha)	No. of Farmers Interviewed (n)	Farmers (%)	Average Land holding (ha)
Marginal Farmers	<1	45	37.5%	0.81
Small Farmers	1-2	63	52.5%	1.5
Semi-Medium Farmers	2-4	11	9.16%	3.0
Medium Farmers	4-10	1	0.83%	4.8
Large Farmers	>10	0	0	0

4.1.3.2 Income distribution

The income distribution in the Lonar 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 Lonar watershed.

Name of crops	No. of Farmers interviewed (n)	Crop area (%)	Average Income (Rs.)
Soybean	120	87.03%	103000
Cotton	4	1.2%	52000
Redgram	77	12.27%	24581.81
Gram	76	43.46%	81557.8
Wheat	35	17.90%	52857

Table 4.3 presents information on the major crops grown, number of farmers interviewed, percentage of crop area, and average income generated from each crop in the watershed region around Lonar. It reflects the cropping pattern and economic contribution of different crops cultivated by farmers in the study area. The data show that soybean is the dominant crop in the region. A total of 120 farmers reported cultivating soybean, covering 87.03% of the crop area. It also provides the highest average income of Rs. 103,000, indicating that soybean is the most economically important crop for farmers in the watershed. Cotton is cultivated by only 4 farmers, occupying 1.2% of the crop area, which is the lowest among all crops listed. The average income from cotton is Rs. 52,000, suggesting that cotton cultivation is limited and less widely adopted in the study area. Redgram (pigeon pea) is grown by 77 farmers and accounts for 12.27% of the crop area. However, it generates a relatively low average income of Rs. 24,581.81, indicating that although it is moderately cultivated, its economic return is comparatively lower than other crops. Gram (chickpea) is another important crop, cultivated by 76 farmers, covering 43.46% of the crop area. It provides a substantial average income of Rs. 81,557.8, making it one of the major rabi crops contributing significantly to farmers' income. Wheat is grown by 35 farmers with 17.90% of the crop area and generates an average income of Rs. 52,857. This suggests that wheat is a moderately cultivated crop, mainly during the rabi season. Overall, the table

indicates that soybean dominates the cropping pattern both in terms of cultivated area and income generation, followed by gram as an important rabi crop.

4.1.3.3 Education

The education profile of farmers in the watershed villages shows a diverse distribution across educational levels. In Bibi, a majority of farmers have attained higher secondary education (43.33%), while 30% completed primary education, 23.33% secondary, and only 3.33% have no formal education**.** Chikhla has a relatively higher proportion of farmers with primary education (43.33%) and secondary education (30%), while 13.33% completed higher secondary and 6.67% pursued higher studies; 6.67% have no education. In Khandala**,** 43.33% of farmers have higher secondary education, 26.67% secondary, 20% primary, and 10% have no formal education, with a small share (3.33%) undertaking higher studies. Kingaon Jattu stands out with 30% of farmers holding higher education degrees, 23.33% secondary, 20% higher secondary, 13.33% no education, and 6.67% primary. Overall, the data indicate that while most farmers possess at least secondary education, there is considerable variation among villages, with a growing share attaining higher education, particularly in Kingaon Jattu.

Table 4.4 Education profile of villages in Lonar watershed by population

Villages	No Education (%)	Primary (%)	Secondary (%)	Higher Secondary (%)	Higher Studies (%)
Bibi	3.33	30.00	23.33	43.33	0.00
Chikhla	6.67	43.33	30.00	13.33	6.67
Khandala	10.00	20.00	26.67	43.33	3.33
Kingaon Jattu	13.33	6.67	23.33	20.00	30.00

4.2 Land-use/Land-cover

The Land Use/Land Cover (LULC) analysis of the study area indicates that agriculture is the dominant land use, covering 3083.25 ha (85.89%) of the total geographical area. This reflects the agrarian nature of the region, where a large proportion of land is utilized for crop cultivation. Forest areas occupy 92.80 ha (2.59%), representing a relatively small portion of the landscape and contributing to ecological balance, biodiversity conservation, and environmental sustainability. Wastelands account for 36.44 ha (1.02%), indicating limited areas that are currently unproductive or degraded and may require reclamation measures for future utilization. A notable portion of the area, 187.29 ha (5.22%), is under mining activities, which may have implications for soil quality, land degradation, and environmental management in the region. Habitation areas cover 118.56 ha (3.30%), representing settlements and built-up areas, while water bodies occupy 71.45 ha (1.99%), providing important water resources for irrigation and domestic use.

Table 4.5 Land-use/land-cover statistics of Lonar watershed

Sr.No.	LULC Class	Area (ha)	Percent (%)
1	Agriculture	3083.25	85.89
2	Forest	92.80	2.59
3	Wasteland	36.44	1.02
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	3589.79	100.00

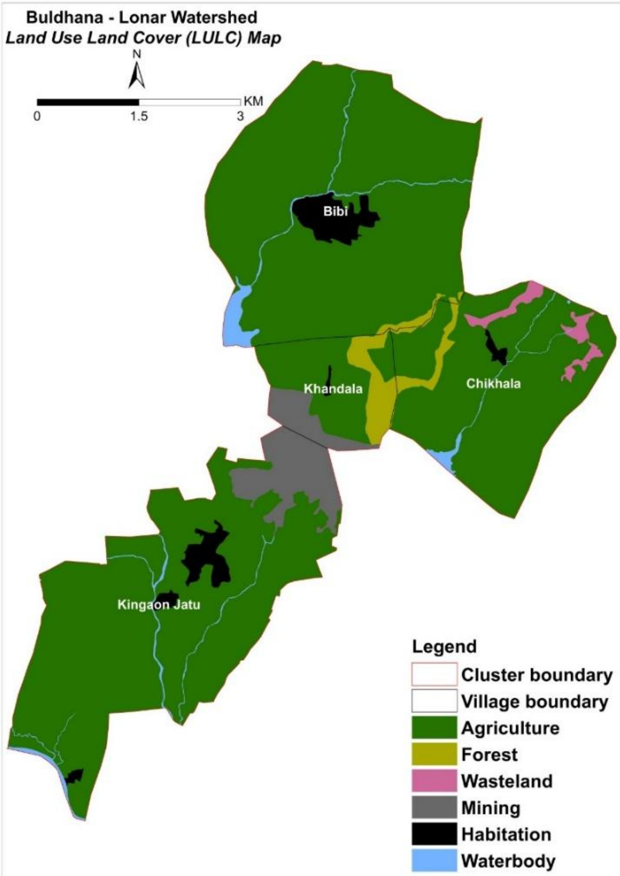


Fig. 4.2: Land-use/land-cover map Buldhana-Lonar

4.3 Landform Delineation

The landform analysis of the study area indicates a diverse geomorphological setting comprising plateau, pediment, upland, pediplain, and plain features (Table 4.6). Among these, pediment is the most dominant landform, covering 1183.86 ha (32.98%) of the total geographical area. Pediments generally represent gently sloping rock surfaces formed by erosion and are often associated with shallow to moderately deep soils that support agricultural activities. The plain landform occupies 718.47 ha (20.01%), representing relatively level terrain that is generally favorable for cultivation due to better soil accumulation and easier agricultural operations. Upland areas account for 581.10 ha (16.19%), indicating moderately elevated terrain that may experience varying degrees of soil erosion depending on slope and vegetation cover. Pediplain landforms cover 367.79 ha (10.25%), while plateau regions occupy 361.27 ha (10.06%) of the total area. Pediplains are typically formed by prolonged erosion processes resulting in gently sloping surfaces, whereas plateaus represent relatively flat elevated surfaces. Apart from natural landforms, mining activities occupy 187.29 ha (5.22%), indicating anthropogenic landscape modification in certain parts of the study area. Habitation areas account for 118.56 ha (3.30%), while water bodies cover 71.45 ha (1.99%). Overall, the study area is predominantly characterized by pediment and plain landscapes, along with moderate extents of uplands, pediplains, and plateau regions. These geomorphological features significantly influence soil formation, drainage characteristics, land use patterns, and agricultural potential within the watershed. The landform map of the study area is presented in Fig. 4.3.

Table 4.6: Landform features existing in Lonar watershed

Sr.No.	Landform	Area (ha)	Percent (%)
1	Plateau	361.27	10.06
2	Pediment	1183.86	32.98
3	Upland	581.10	16.19
4	Pediplain	367.79	10.25
5	Plain	718.47	20.01
6	Mining	187.29	5.22
7	Habitation	118.56	3.30
8	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

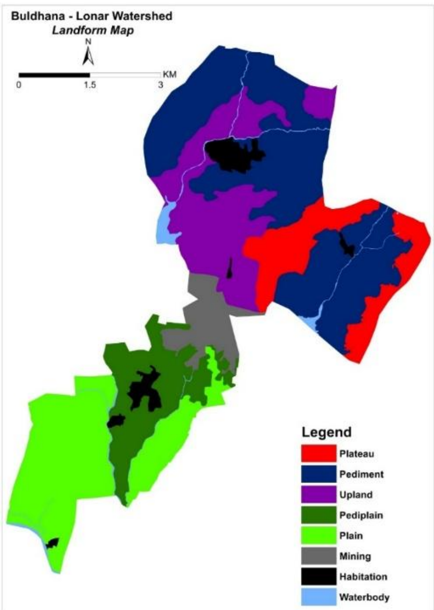


Fig. 4.3: Landform map of Buldhana Lonar

4.4 Soil series and phases

Fourteen soil series have been identified and mapped with fourteen soil mapping units (phases of series) (Fig 4.4). The detailed descriptions of the each series are given in Table 4.7. The soil series distribution in the study area indicates considerable spatial variability in soil characteristics, reflecting differences in parent material, topography, drainage, and pedogenic processes. Among the identified soil series, Chikhala_2 occupies the largest area of 433.92 ha (12.09%), followed by Bibi_3 covering 407.51 ha (11.35%), Bibi_2 with 391.45 ha (10.90%), and Kingaon_Jattu_3 accounting for 387.51 ha (10.79%) of the total geographical area. These soil series collectively form a significant portion of the watershed and are important for agricultural activities. Moderately distributed soil series include Bibi_1 (7.63%), Chikhala_3 (6.14%), Khandala_1 (5.28%), and Khandala_2 (5.07%), which contribute to the diversity of soil resources in the area. Other soil series such as Kingaon_Jattu_1 (4.59%), Kingaon_Jattu_2 (4.63%), and Chikhala_1 (3.93%) occupy comparatively smaller areas.

The least extensive soil series include Kingaon_Jattu_5 (2.86%), Kingaon_Jattu_4 (2.31%), and Bibi_4 (1.91%). Apart from these soil series, mining areas cover 187.29 ha (5.22%), habitation accounts for 118.56 ha (3.30%), and water bodies occupy 71.45 ha (1.99%) of the total area. Overall, the presence of multiple soil series indicates considerable heterogeneity in soil properties across the watershed, which plays a crucial role in determining land capability, crop suitability, and soil management practices for sustainable agricultural production.

Table 4.7 Dominant soil series identified in the Lonar watershed

Sr. No.	Soil Series	Area (ha)	Percent (%)
1	Bibi_1	273.86	7.63
2	Bibi_2	391.45	10.90
3	Bibi_3	407.51	11.35
4	Bibi_4	68.57	1.91
5	Chikhala_1	141.02	3.93
6	Chikhala_2	433.92	12.09
7	Chikhala_3	220.25	6.14
8	Khandala_1	189.65	5.28
9	Khandala_2	182.09	5.07
10	Kingaon_Jattu_1	164.79	4.59
11	Kingaon_Jattu_2	166.16	4.63
12	Kingaon_Jattu_3	387.51	10.79
13	Kingaon_Jattu_4	82.90	2.31
14	Kingaon_Jattu_5	102.79	2.86
15	Mining	187.29	5.22
16	Habitation	118.56	3.30
17	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

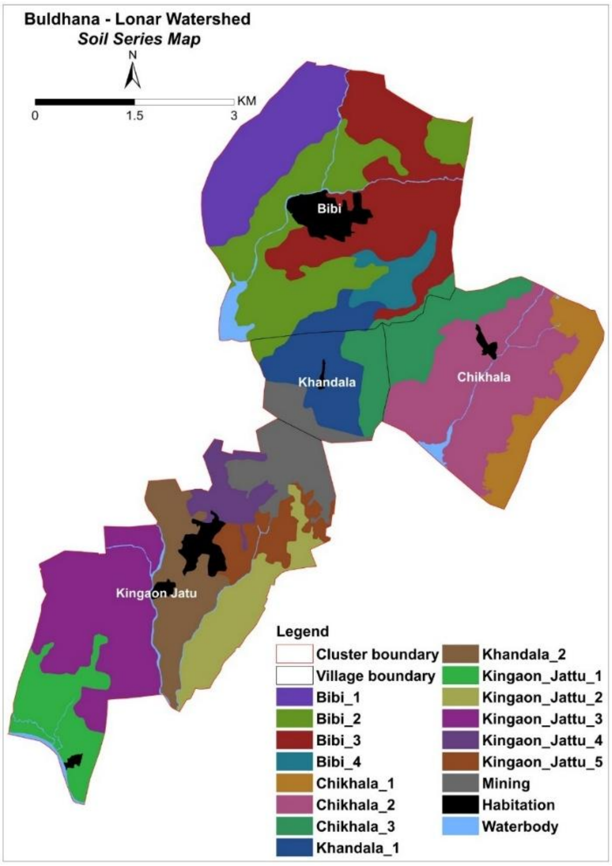


Fig. 4.4: Soil series map of Buldhana Lonar

Table 4.8 Soil phases existing identified in Buldhana Lonar

Sr. No.	Phase Class	Area (ha)	Percent (%)
1	Bbi2fB1	391.45	10.90
2	Bib5mA1	273.86	7.63
3	Bii5mA1	407.51	11.35
4	Chi2fC3	141.02	3.93
5	Chk5mB1	433.92	12.09
6	Chl1hD3	220.25	6.14
7	Ibb1eB3	68.57	1.91
8	Kha2mB2	189.65	5.28
9	Khn2fB1	182.09	5.07
10	Kia6mA1	387.51	10.79
11	Kig5mB1	166.16	4.63
12	Kij1hD4	82.90	2.31
13	Kin1iB2	164.79	4.59
14	Kit1fB3	102.79	2.86
15	Mining	187.29	5.22
16	Habitation	118.56	3.30
17	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

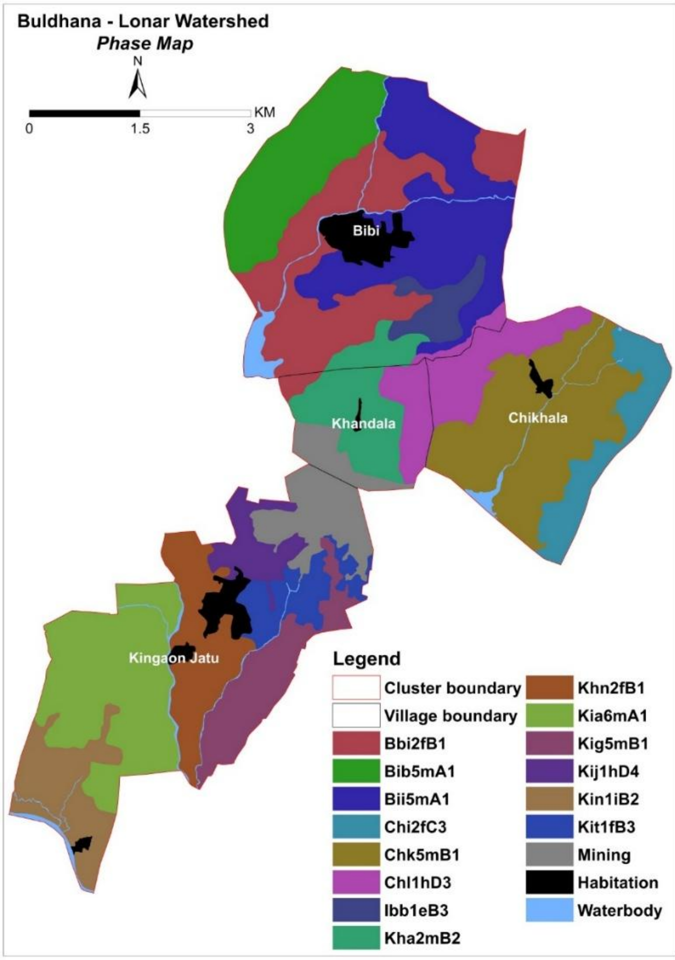


Fig.4.5 Soil Phase map of Buldhana Lonar

4.5 Soil Survey Interpretation

4.5.1 Slope

The slope analysis of the study area reveals that the terrain is predominantly characterized by very gentle slopes, which are generally favorable for agricultural activities (Table 4.9). The very gently sloping class (1–3%) occupies the largest portion of the area, covering 1699.43 ha (47.34%) of the total geographical area. These areas provide suitable conditions for cultivation due to moderate drainage and relatively low risk of soil erosion. The level to nearly level slopes (0–1%) account for 1068.89 ha (29.78%), representing flat terrain that is highly favorable for agricultural operations, irrigation management, and mechanized farming practices. Gently sloping areas (3–8%) cover 444.18 ha (12.37%), where moderate slopes may increase the potential risk of soil erosion, requiring appropriate soil and water conservation measures such as contour farming and bunding. In addition to these natural slope classes, mining areas occupy 187.29 ha (5.22%), while habitation covers 118.56 ha (3.30%) and water bodies occupy 71.45 ha (1.99%) of the total area.

Table: 4.9. Land slope classes in Lonar watershed

Sr.No.	Slope Class	Area (ha)	Percent (%)
1	Level to nearly level (0 - 1)	1068.89	29.78
2	Very gently sloping (1 - 3)	1699.43	47.34
3	Gently sloping (3 - 8)	444.18	12.37
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

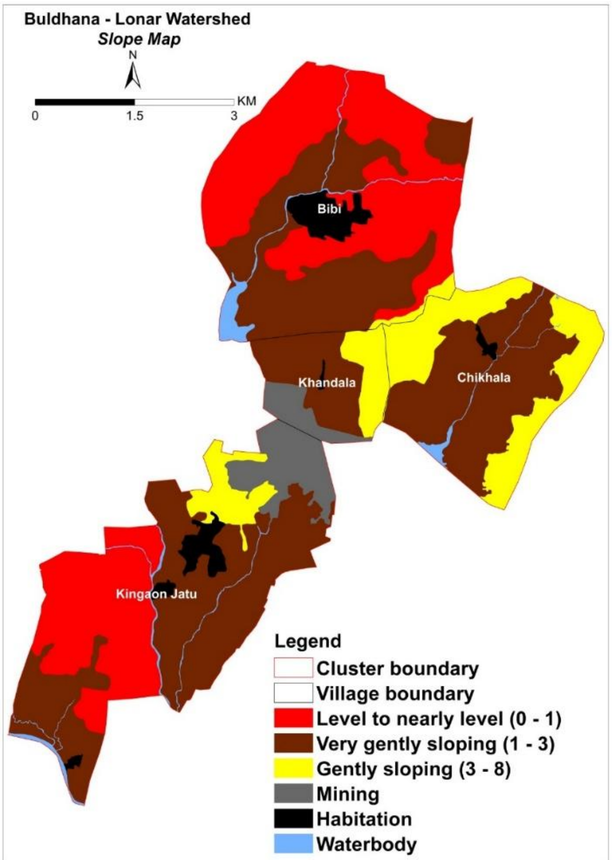


Fig. 4.6: Soil Slope map of Buldhana Lonar watershed

4.5.2 Soil Erosion

Soil erosion, caused by water, wind, or human activities, removes the nutrient-rich top layer of soil, thereby reducing its capacity to retain moisture and support plant growth. The degradation of soil quality ultimately leads to reduced agricultural productivity, making crops more susceptible to drought, nutrient deficiencies, and pest attacks. Furthermore, soil erosion contributes to the sedimentation of nearby water bodies, adversely affecting water quality and aquatic ecosystems. Implementing soil conservation measures such as crop cover, mulching and residue management, crop rotation, bunding, and terracing can effectively control erosion and maintain soil structure. In the Lonar watershed, the majority of the area experiences none to very slow erosion (57.40 %), followed by very slow erosion

(5.07 %), indicating relatively stable land conditions. However, moderate erosion affects 9.87 % of the area, while 14.84 % falls under moderate to severe erosion, and 2.31 % under very severe erosion, requiring priority attention. Areas under mining (5.22 %), habitation (3.3 0%), and water bodies (1.99 %) represent non-agricultural land uses. Overall, the watershed largely exhibits low erosion hazard, though certain pockets, particularly in vulnerable terrain, demand appropriate soil and water conservation interventions.

Table 4.10 Soil erosion status in the Lonar watershed

Sr.No.	Erosion Class	Area (ha)	Percent (%)
1	None - Very Slow	2060.42	57.40
2	Very Slow	182.09	5.07
3	Moderate	354.44	9.87
4	Moderate - Severe	532.63	14.84
5	Very Severe	82.90	2.31
6	Mining	187.29	5.22
7	Habitation	118.56	3.30
8	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

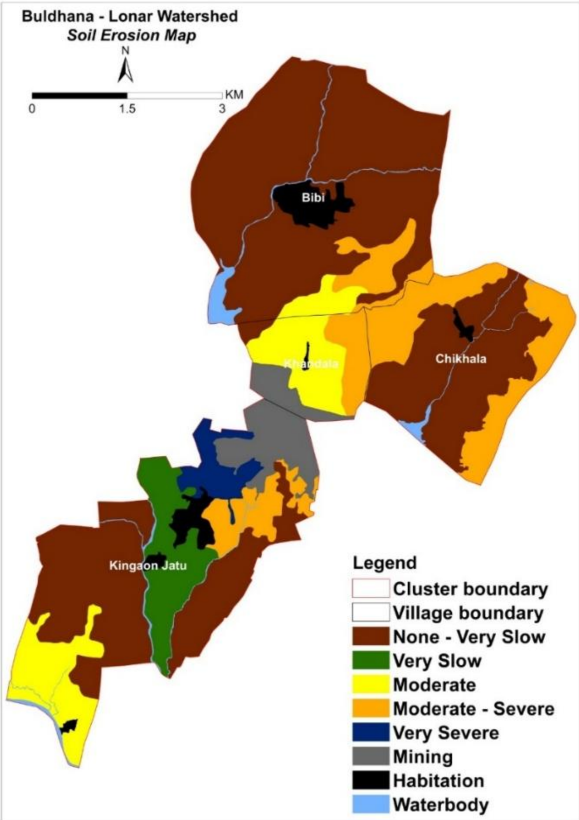


Fig. 4.7: Erosion map of Buldhana Lonar watershed

4.5.3 Soil Depth

Soil depth is a critical factor in agriculture as it acts as an integrative proxy for several other soil properties and functions, including soil moisture retention, organic carbon storage, effective rooting depth, nutrient availability, and overall profile development. These properties are intrinsically linked to pedogenic processes such as weathering, translocation, erosion-deposition dynamics, and biological activity, all of which are strongly modulated by landscape position and hydrological regime. As a result, spatial variability in soil depth reflects not only physical soil thickness but also broader gradients in soil fertility, water holding capacity, and ecosystem functioning across the terrain. Deeper soils generally provide more space for roots to penetrate, access water, and take up essential nutrients, which supports healthier plant growth and higher crop yields. Shallow soils, on the other hand, can restrict root development and limit the availability of nutrients and moisture, especially during dry periods. This can result in stunted plant growth, lower productivity, and increased vulnerability to drought stress. In regions with shallow soils, farmers may need to implement practices such as deep ploughing, irrigation, or the addition of organic matter to improve soil depth and enhance crop performance. Understanding soil depth helps farmers make better decisions on crop selection, irrigation, and soil management, promoting more efficient and sustainable agricultural practices. The soil depth in the watershed (Fig. 4.8) varies from shallow (<25 cm) to very deep (>100 cm). The area-wise distribution of soil depth classes (Table 4.11) indicates that the maximum area is occupied by very deep soils covering 46.49% of the watershed, followed by moderately deep soils (25–50 cm) occupying 25.19%. Shallow soils (<25 cm) account for 17.81% of the total area, which may restrict root penetration and moisture storage capacity. In addition, mining areas (5.22%), habitation (3.30%), and water bodies (1.99%) represent non-soil land use categories within the watershed. The predominance of very deep soils suggests favorable conditions for crop growth and higher soil moisture retention, while shallow soil areas require suitable soil and water conservation measures for sustainable land use.

Table 4.11 Soil depth classes in Lonar watershed

Sr.No.	Depth Class	Area (ha)	Percent (%)
1	Shallow (< 25)	639.31	17.81
2	Moderate (25 - 50)	904.21	25.19
3	Very Deep (> 100)	1668.97	46.49
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

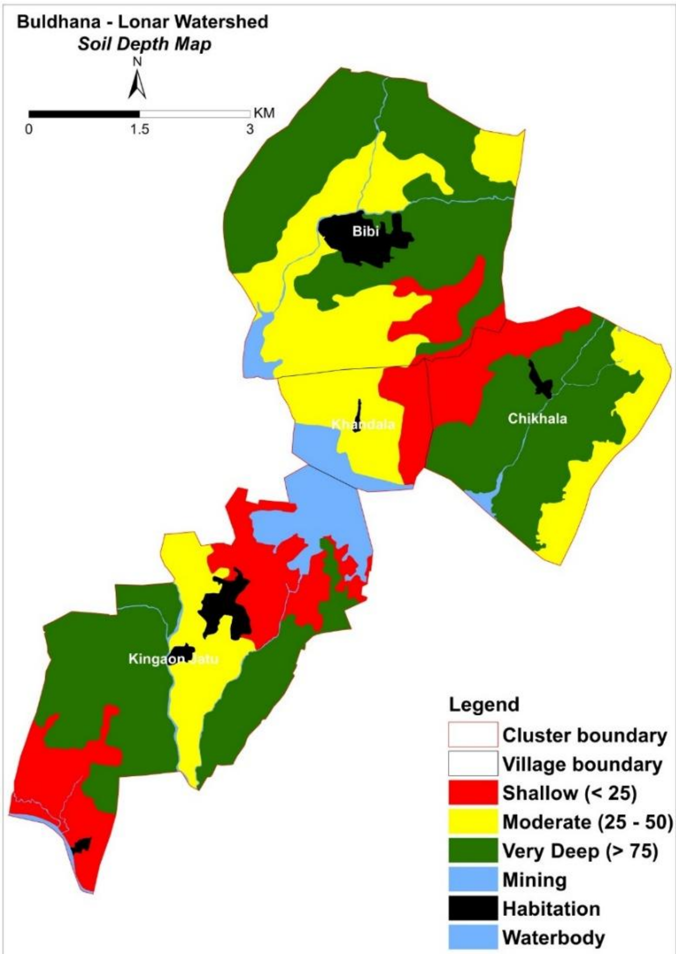


Fig. 4.8: Depth map of Buldhana-Lonar watershed

4.5.4 Surface texture

Soil texture plays a vital role in agriculture as it directly influences water retention, aeration, root penetration, and nutrient availability to plants. Balanced soil textures generally provide favorable conditions for crop growth by maintaining adequate moisture while allowing proper drainage. Clayey soils are usually rich in nutrients and have high water-holding capacity, though they may suffer from poor drainage and compaction, whereas sandy soils allow rapid drainage and often contain lower nutrient reserves. Understanding soil texture is therefore important for planning irrigation, crop selection, and soil management practices. The soils of the watershed were classified into five major texture classes (Table 4.12 and Fig. 4.9). Among these, clay was the dominant texture covering 1858.62 ha (51.78%) of the total area, followed by clay loam occupying 817.36 ha (22.77%). Sandy clay loam accounted for 303.16 ha (8.45%), while sandy clay covered 164.79 ha (4.59%) of the watershed. Silt loam occupied only 68.57 ha (1.91%), representing a very small portion of the study area. In addition, mining (5.22%), habitation (3.30%), and water bodies (1.99%) constitute non-agricultural land uses within the watershed. The predominance of clay and clay loam soils suggests relatively high moisture retention and nutrient-holding capacity, which can support good crop productivity when managed with proper drainage and soil conservation practices.

Table 4.12 Soil texture distribution in Buldhana-Lonar watershed

Sr.No.	Texture Class	Area (ha)	Percent (%)
1	Clay	1858.62	51.78
2	Clay Loam	817.36	22.77
3	Sandy Clay	164.79	4.59
4	Sandy Clay Loam	303.16	8.45
5	Silt Loam	68.57	1.91
6	Mining	187.29	5.22
7	Habitation	118.56	3.30
8	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

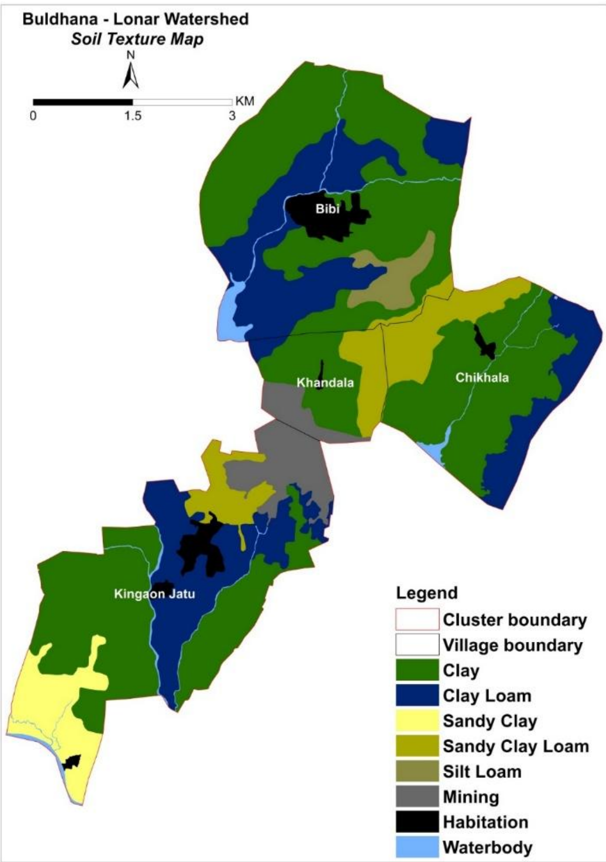


Fig. 4.9: Soil texture map of Buldhana-Lonar watershed

4.5.5 Soil reaction

Soil reaction (pH), which indicates the degree of soil acidity or alkalinity, plays an important role in plant growth as it directly affects nutrient availability, microbial activity, and overall soil fertility. Knowledge of soil pH is also essential for determining the type and quantity of soil amendments required to correct soil acidity or alkalinity for optimum crop production. The soils of the watershed were classified into different soil reaction classes (Table 4.13 and Fig. 4.10). The results revealed that the soils are predominantly moderately alkaline (pH 8.0–9.0), covering 1596.37 ha (44.47%) **of** the total area. This is followed by slightly alkaline soils (pH 7.5–8.0) occupying 1056.04 ha (29.42%). Neutral soils (pH 6.5–7.5) account for 457.28 ha (12.74%), while slightly acidic soils (pH 6.0–6.5) cover only 102.79 ha (2.86%) of the watershed area. In addition, mining (5.22%), habitation (3.30%), and water bodies (1.99%) represent non-agricultural land uses within the watershed. The predominance of slightly to moderately alkaline soils indicates the influence of basic cations and calcareous parent material, which may affect nutrient availability, particularly micronutrients, and therefore requires appropriate soil management practices for sustainable crop production.

Table 4.13 Soil pH distribution in Lonar watershed

Sr.No.	pH Class	Area (ha)	Percent (%)
1	Slightly Acidic (6.0 - 6.5)	102.79	2.86
2	Neutral (6.5 - 7.5)	457.28	12.74
3	Slightly Alkaline (7.5 - 8.0)	1056.04	29.42
4	Moderately Alkaline (8.0 - 9.0)	1596.37	44.47
5	Mining	187.29	5.22
6	Habitation	118.56	3.30
7	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

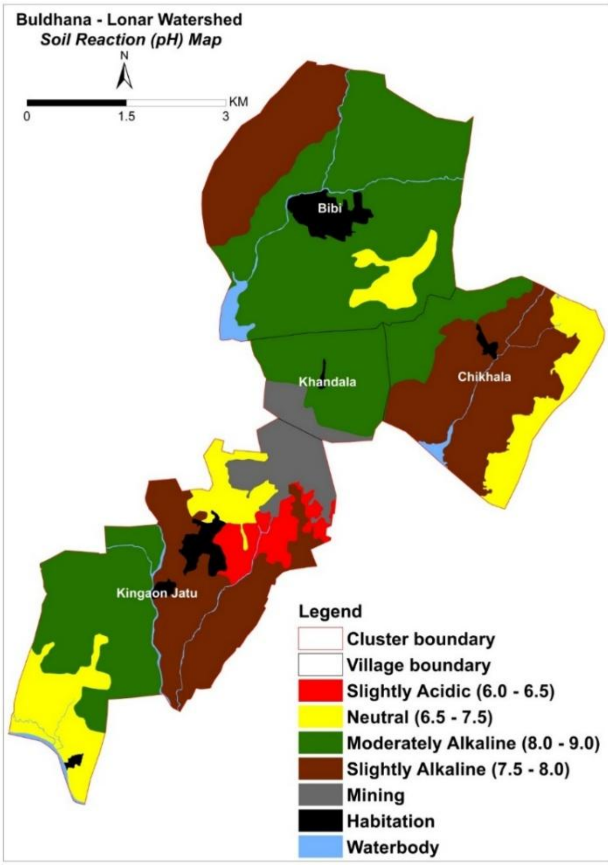


Fig. 4.10: Soil pH map of Buldhana-Lonar watershed

4.5.6 Soil salinity

Soil salinity refers to the concentration of soluble salts present in the soil and is commonly measured through electrical conductivity (EC) of the soil solution. Electrical conductivity is an important indicator of water-soluble salts in the soil and reflects the availability of mineral nutrients that can be readily utilized by plants. However, excessive salt accumulation may adversely affect plant growth by reducing water uptake and causing ionic imbalance. The electrical conductivity values of soils in the watershed were classified into salinity classes (Table 4.14). The results revealed that 3212.49 ha (89.49%) of the watershed area falls under the normal salinity class (0–1 dS m^{-1}), indicating that the soils are non-saline and suitable for crop cultivation without any salinity-related constraints. The remaining area consists of mining land (5.22%), habitation (3.30%), and water bodies (1.99%), which are non-agricultural land use categories. Overall, the EC values indicate that soil salinity is not a limiting factor for crop production in the watershed, and therefore no separate salinity map has been presented.

Table 4.14 Soil salinity classes in the Lonar watershed

Sr.No.	Electrical conductivity (dSm^{-1})	Area (ha)	Percent (%)
1	Normal (0 - 1)	3212.49	89.49
2	Mining	187.29	5.22
3	Habitation	118.56	3.30
4	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

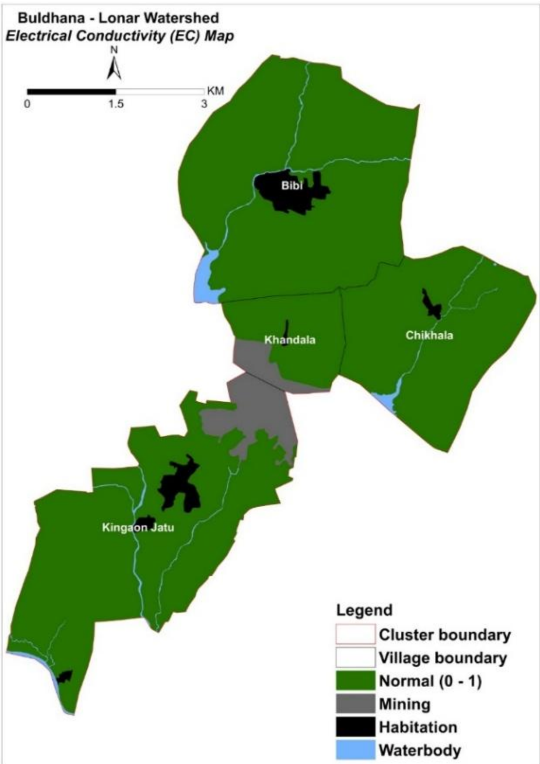


Fig 4.11 EC map of Buldhana-Lonar watershed

4.7.7 Calcium carbonate ($CaCO_3$) content

The soils of the watershed are predominantly calcareous, with $CaCO_3$ content varying from very low to very high (Table 4.15 and Fig. 4.12). Analysis of the data indicates that 26.78% of the watershed area contains very high $CaCO_3$ levels (>10%), followed by high (5–10%) and moderately high (2–5%) $CaCO_3$ content, which occupy 25.00% and 20.97% of the area, respectively. Soils with medium (1–2%), low (0.5–1%), and very low (<0.5%) $CaCO_3$ together cover 17.74% of the area. In addition, mining (5.22%), habitation (3.30%), and water bodies (1.99%) represent non-agricultural land uses. The predominance of high to very high calcareous soils (over 50% of the area) may affect nutrient availability, particularly phosphorus and certain micronutrients, potentially limiting normal crop growth. Therefore, appropriate soil management interventions, such as gypsum application or organic amendments, may be necessary to enhance soil fertility and support sustainable agricultural productivity.

Table 4.15 Extent of calcareousness in soils of Buldhana-Lonar watershed

Sr.No.	$CaCO_3$ Class	Area (ha)	TGA (%)
1	Very Low (< 0.5)	267.58	7.45
2	Low (0.50 - 1.0)	82.90	2.31
3	Medium (1.0 - 2.0)	250.66	6.98
4	Moderately High (2.0 - 5.0)	752.73	20.97
5	High (5.0 - 10.0)	897.43	25.00
6	Very High (> 10.0)	961.18	26.78
7	Mining	187.29	5.22
8	Habitation	118.56	3.30
9	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

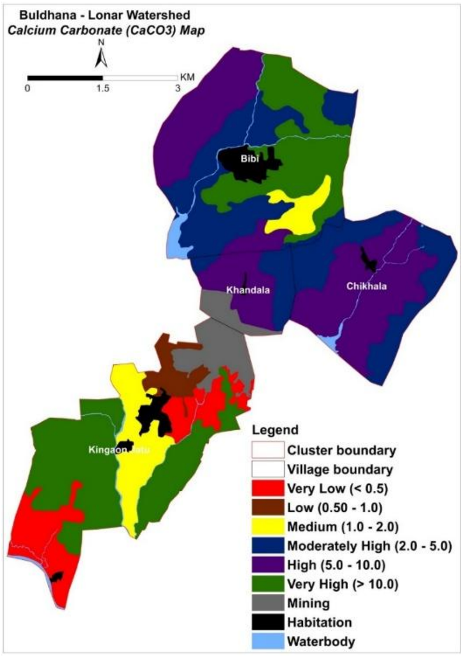


Fig. 4.12: Status of soil calcareousness in Buldhana-Lonar watershed

4.5.8 Soil organic carbon

The soil organic carbon (SOC) is a critical component to several ecological processes, and is primarily derived from plant decomposition and animal residues, like leaves, roots, and dead organisms. It serves as a significant indicator of soil health and fertility. The SOC influences the soil's ability to retain and release essential nutrients, regulate water-holding capacity and support microbial activity. It also acts as a reservoir for carbon sequestration, helping mitigate climate change by removing carbon dioxide from the atmosphere. Monitoring SOC levels is crucial for sustainable land use and management. The loss of SOC through practices like deforestation and intensive agriculture can result in degraded soils leading to reduced agricultural productivity and enhanced greenhouse gas emissions. Promotion of climate-smart practices that increase SOC can ensure healthier and productive soils. Soils of Lonar watershed supported very low to high SOC content, which can be inferred from Table 4.16 and Fig. 4.13. This is also indicated by the moderate-deep soils and loamy texture prevalent in the watershed. However, there is an immense need for application of organic manures by the farmers in the watershed area in general, and in about 10.06% of the area exhibiting low SOC. High SOC content was found to occur in approximately 433.92 ha of the watershed.

Table 4.16 Soil organic carbon status of Lonar watershed

Sr.No.	OC Class	Area (ha)	TGA (%)
1	Very Low (< 0.20)	361.27	10.06
2	Low (0.21 - 0.40)	572.30	15.94
3	Medium (0.41 - 0.60)	1662.90	46.32
4	Moderately High (0.61 - 0.80)	182.09	5.07
5	High (0.81 - 1.00)	433.92	12.09
6	Mining	187.29	5.22
7	Habitation	118.56	3.30
8	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

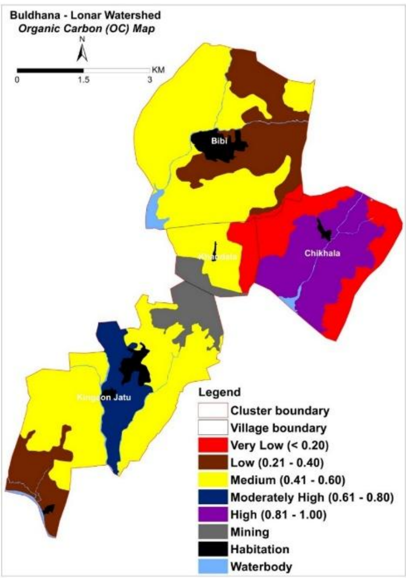


Fig. 4.13: Soil organic carbon map of Buldhana-Lonar watershed

4.5.9 Available nitrogen (N)

Available nitrogen content in soils is crucial as it forms the primary building block for plant growth, is essential for producing proteins, amino acids, and chlorophyll to support photosynthesis, plant health and yield. The agricultural soils of watershed are inherently deficient in available N content. The nitrogen status of the watershed soils, as presented in Table 4.17 and Fig. 4.14**,** indicates that a vast majority of the area **(**3212.49 ha; 89.49%**)** falls under the low nitrogen category (141–280 kg ha^{-1})**.** The remaining portion consists of mining land (5.22%)**,** habitation (3.30%)**,** and water bodies (1.99%)**,** which are non-agricultural areas. The predominance of low nitrogen levels suggests a potential limitation for crop growth**,** emphasizing the importance of applying nitrogenous fertilizers according to crop-specific requirements to improve soil fertility and maximize agricultural productivity in the watershed

Table 4.17 Available N content in soils of Buldhana-Lonar watershed

Sr.No.	N Class	Area (ha)	TGA(%)
1	Low (141 - 280)	3212.49	89.49
2	Mining	187.29	5.22
3	Habitation	118.56	3.30
4	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

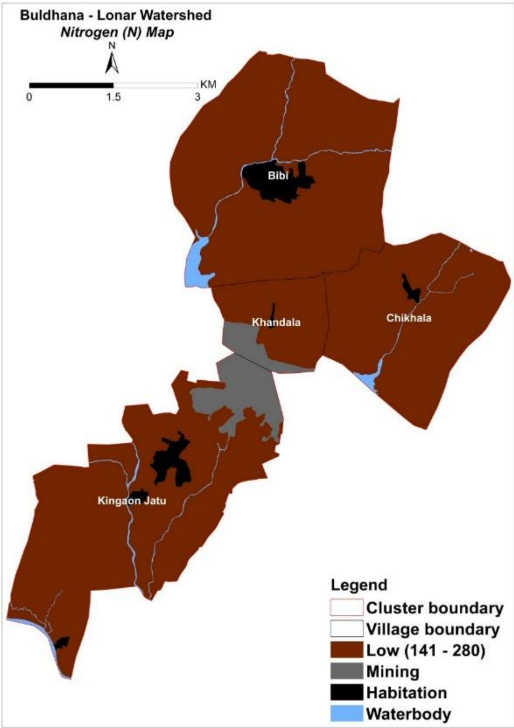


Fig. 4.14: Available soil nitrogen map of Buldhana -Lonar watershed

4.5.10 Available Phosphorous (P)

Among the three major nutrients, phosphorus (P) plays an important role to complete the life cycle of a plant; its functions start right from the stimulation of root growth to proper seed filling and seed setting. It also plays a vital role in photosynthesis, carbohydrate breakdown and transfer of energy in the form of ATP and ADP compounds in various metabolic processes. The phosphorus status of the agricultural soils in the watershed, as presented in Table 4.18 and Fig. 4.15**,** shows that the majority of the area **(**2548.33 ha; 70.99%**)** falls under the very low P category (<15 kg ha^{-1})**.** Low P soils (16–30 kg ha^{-1}) cover 595.59 ha (16.59%)**,** while a very small portion (68.57 ha; 1.91%**)** exhibits very high P levels (>80 kg ha^{-1})**.** The remaining area is comprised of mining (5.22%)**,** habitation (3.30%)**,** and water bodies (1.99%)**,** which are non-agricultural land uses. The predominance of soils with very low to low phosphorus content (over 87% of the area) suggests that either phosphatic fertilizers are not being applied adequately or a substantial portion of applied phosphorus becomes fixed in the calcareous soils, limiting its availability to crops. Therefore, site-specific phosphorus management strategies, including balanced fertilizer application and the use of phosphate-solubilizing amendments, are necessary to enhance soil fertility and improve crop productivity in the watershed.

Table 4.18 Available P content of soils of Buldhana-Lonar watershed

Sr.No.	P Class	Area (ha)	TGA(%)
1	Very Low (< 15)	2548.33	70.99
2	Low (16 - 30)	595.59	16.59
3	Very High (> 80)	68.57	1.91
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

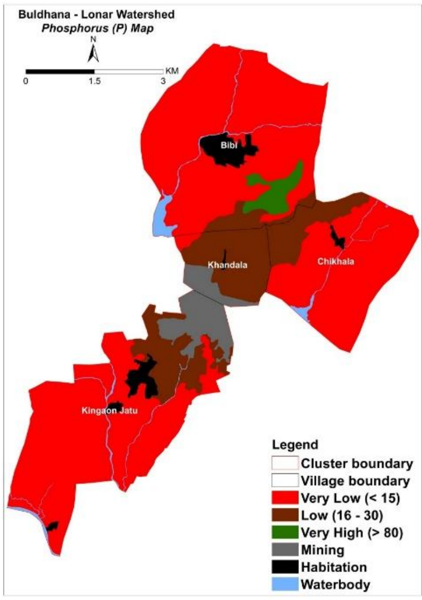


Fig. 4.15: Available soil phosphorus map of Buldhana-Lonar watershed

4.5.11 Available Potassium (K)

The importance of potassium (K) is well recognized in agriculture. Exchangeable K or available K is widely used to evaluate the soil K status and to predict the crop K requirements. The potassium status of the watershed soils, as shown in Table 4.19 and Fig. 4.16, was classified into five categories. A significant portion of the watershed (11.31% in very low and 8.52% in low K classes) falls under deficient potassium levels, indicating potential constraints for crop growth. Additionally, moderately high to medium K soils (5.28%–11.35%) also require monitoring. Overall, a combined area of approximately 45% exhibits low to medium potassium content (121–240 kg ha^{-1}), highlighting the need for site-specific application of potassic fertilizers to maintain soil fertility and ensure optimum crop productivity in the watershed.

Table 4.19 Available K content of soils of Lonar watershed

Sr.No.	K Class	Area (ha)	TGA (%)
1	Very Low (< 120)	405.95	11.31
2	Low (120 - 180)	305.81	8.52
3	Moderately High (241 - 300)	189.65	5.28
4	High (301 - 360)	407.51	11.35
5	Very High (> 360)	1903.58	53.03
6	Mining	187.29	5.22
7	Habitation	118.56	3.30
8	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

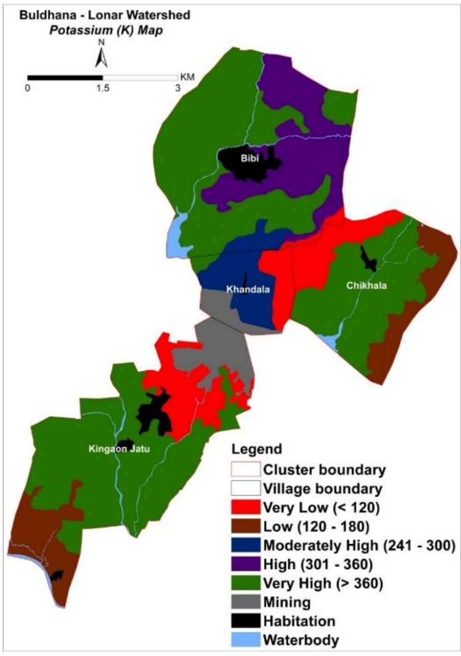


Fig. 4.16: Available soil potassium map of Buldhana-Lonar watershed

4.5.12 Micronutrient status of soils

Although required in small quantities, soil micronutrients—namely iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn), measured as DTPA-extractable micronutrients, are involved in vital plant processes like photosynthesis, enzyme activation, and nitrogen fixation. Deficiencies in any of these micronutrients can lead to poor plant development, reduced yields, and lower quality crops. Proper micronutrient management is particularly important in maintaining soil fertility by optimizing the efficiency of fertilizers. Three classes of available Fe were found in the watershed (Table 4.20 and Fig. 4.17). The Very High Fe class (>10.5) occupies the largest portion of the watershed with 2584.73 ha (72.00%). This indicates that the majority of the area contains very high iron concentration, which is mainly related to the basaltic rocks of the Deccan plateau and the meteoritic origin of the Lonar crater. Such high iron levels strongly influence the soil composition, color, and geochemical characteristics of the watershed.

The Medium Fe class (4.5–6.5) covers 407.51 ha (11.35%), representing areas with moderate iron concentration. These zones are comparatively smaller and may have more balanced soil conditions than the very high Fe areas. The High Fe class (8.5–10.5) accounts for 220.25 ha (6.14%), indicating zones where iron concentration is significantly elevated but not as extreme as the very high category. The majority of the area is adequately supplied with Mn (Table 4.21, Fig. 4.18). Soils of the entire watershed are sufficient with respect to DTPA-extractable Cu (Table 4.22, Fig. 4.19), whereas more than 35.95% of the soils exhibit deficiency in bioavailable Zn (Table 4.23, Fig. 4.20) and 49.56% area under medium category necessitating external Zn fertilization by the farmers.

Table 4.20: Available Fe content in the soils of Buldhana-Lonar watershed

Sr.No.	Fe Class	Area (ha)	TGA(%)
1	Medium (4.5 - 6.5)	407.51	11.35
2	High (8.5 - 10.5)	220.25	6.14
3	Very High (> 10.5)	2584.73	72.00
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

Table 4.21: Available Mn content in the soils of Buldhana-Lonar watershed

Sr.No.	Mn Class	Area (ha)	TGA (%)
1	Very High (> 9.0)	3212.49	89.49
2	Mining	187.29	5.22
3	Habitation	118.56	3.30
4	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

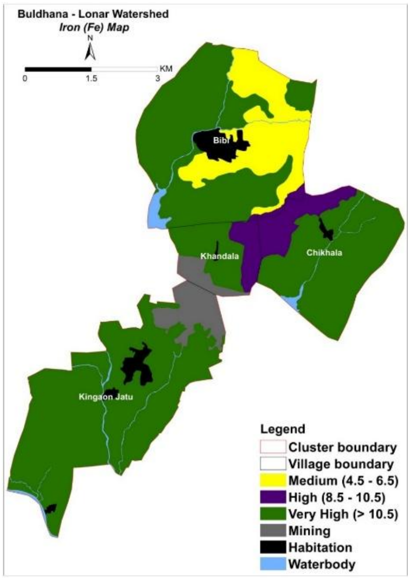


Fig. 4.17: DTPA-extractable soil Fe map of Buldhana-Lonar watershed

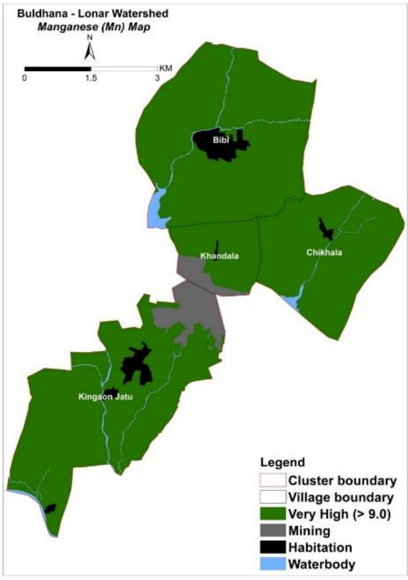


Fig. 4.18: DTPA-extractable soil Mn map of Lonar watershed

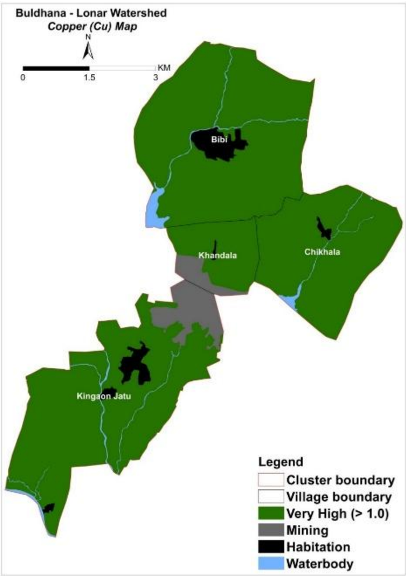


Fig. 4.19: DTPA-extractable soil Cu map of of Buldhana-Lonar watershed

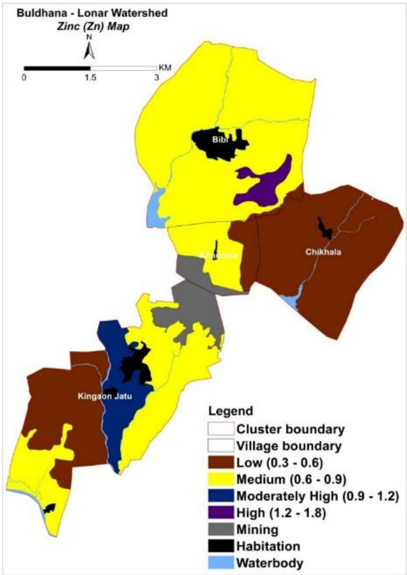


Fig. 4.20: DTPA-extractable soil Zn map of Buldhana-Lonar watershed

Table 4.22: Available Cu content in the soils of Buldhana-Lonar watershed

Sr.No.	Cu Class	Area (ha)	Percent (%)
1	Very High (> 1.0)	3212.49	89.49
2	Mining	187.29	5.22
3	Habitation	118.56	3.30
4	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

Table 4.23: Available Zn content in the soils of Buldhana-Lonar watershed

Sr.No.	Zn Class	Area (ha)	TGA (%)
1	Low (0.3 - 0.6)	1182.71	32.95
2	Medium (0.6 - 0.9)	1779.12	49.56
3	Moderately High (0.9 - 1.2)	182.09	5.07
4	High (1.2 - 1.8)	68.57	1.91
5	Mining	187.29	5.22
6	Habitation	118.56	3.30
7	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

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 Lonar Taluka, where average annual rainfall is about 770 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.

Daily rainfall data for the 11-year period (2014-24) were obtained from IMD and grouped into storm events for runoff estimation. Runoff was computed for each event and subsequently aggregated on monthly and annual bases to identify seasonal patterns and long-term trends. The results indicate a strongly seasonal runoff regime, with the majority of runoff occurring during July, August, and September. The highest runoff was consistently observed in July and August, mainly due to short, high-intensity rainfall events that exceeded soil infiltration capacity. September also contributed notable runoff in years with extended monsoon activity when soils remained saturated. In contrast, June and October produced minimal runoff despite receiving rainfall, primarily because of dry antecedent soil conditions at the onset of the monsoon and reduced rainfall intensity toward its end.

Table 4.24. Details of Monthly (June-Oct) runoff (mm) for the period 2014-24

Year/Month	June		July		Aug		Sept		Oct	
	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)
2014	38.1	0.0	154.6	2.9	251.7	70.5	170.0	70.0	20.9	0.0
2015	87.9	0.0	20.5	0.0	229.3	60.7	198.7	55.0	5.5	0.0
2016	181.3	32.5	337.4	91.4	118.3	17.2	153.4	6.5	36.6	0.0
2017	234.3	31.2	136.5	23.5	143.7	16.7	126.9	9.2	60.1	0.0
2018	114.4	0.0	181.2	29.8	207.5	54.4	29.8	0.0	0.0	0.0
2019	111.2	5.8	156.3	10.2	109.8	28.7	194.3	3.6	96.5	0.0
2020	186.7	17.9	148.6	1.4	176.4	13.9	151.1	1.6	52.0	0.0
2021	182.7	6.4	213.6	29.3	186.4	48.5	297.0	63.4	135.4	44.0
2022	127.5	0.7	244.1	27.3	114.4	19.4	157.4	2.3	141.9	7.9
2023	44.3	0.0	301.2	51.9	100.6	0.0	157.3	11.0	2.4	0.0
2024	181.3	7.8	204.2	0.2	174.9	7.7	167.0	7.3	86.8	2.9
Average	**135.4**	**9.3**	**190.7**	**24.4**	**164.8**	**30.7**	**163.9**	**20.9**	**58.0**	**5.0**

Over the study period, the proportion of rainfall converted to runoff averaged 12.3%, with considerable inter-annual variability. The highest runoff percentage was recorded in 2014 (21.4%), while the lowest occurred in 2024 (3.0%). Wet years such as 2021, with rainfall exceeding 1000 mm, produced nearly 192 mm of runoff, whereas moderate rainfall years like 2019 yielded only 50 mm. The number of runoff events averaged 15 per year, ranging from 9 to 22, indicating that storm frequency and distribution strongly influence annual totals. These results highlight that rainfall alone does not guarantee water availability; rather, its intensity, distribution, and antecedent conditions govern how much is retained and how much is lost as surface flow.

Table 4.25. Relationship between rainfall and runoff

Year	Rainfall mm	Runoff mm	No. of Runoff Events	Runoff (%)
2014	813.5	173.9	16	21.4
2015	625.5	115.7	9	18.5
2016	856.4	147.6	20	17.2
2017	701.5	80.6	19	11.5
2018	543.2	84.1	9	15.5
2019	722.7	50.4	12	7.0
2020	737.3	34.9	16	4.7
2021	1056.7	191.6	22	18.1
2022	786.1	57.4	16	7.3
2023	767.1	82.7	15	10.8
2024	852.9	25.9	16	3.0
Average	**769.4**	**95.0**	**15**	**12.3**

The rainfall-runoff analysis for the period 2014-24 shows clear seasonal and interannual variability within the watershed. Monsoon rainfall (June-October) ranged from about 540-600 mm in drier years such as 2015, 2018, and 2023 to more than 1000 mm in 2021, the wettest year of the study period. Runoff followed a similar trend but remained much lower in magnitude, with the highest runoff recorded in 2021 (about 180 mm) and the lowest in 2020 and 2024, indicating that rainfall distribution, storm intensity, and antecedent soil moisture strongly influence runoff generation. Monthly patterns reveal that runoff is highly seasonal, with July, August, and September producing the majority of runoff. July recorded the highest average runoff (around 30-35 mm) due to intense rainfall events exceeding infiltration capacity, followed by August and September, when soils remain saturated from continuous monsoon rainfall. In contrast, June and October produced relatively low runoff despite receiving rainfall, reflecting dry soil conditions at the onset of the monsoon and reduced rainfall intensity toward its end. Outside the monsoon period (November-May), both rainfall and runoff were negligible, indicating that runoff generation in the watershed is largely controlled by monsoon rainfall dynamics.

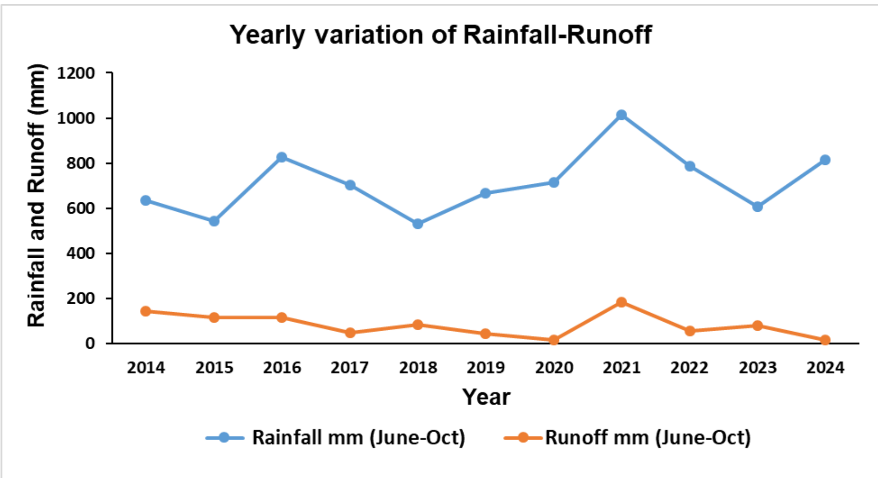


Fig.4.21 Yearly variation in rainfall and runoff during 2014-24

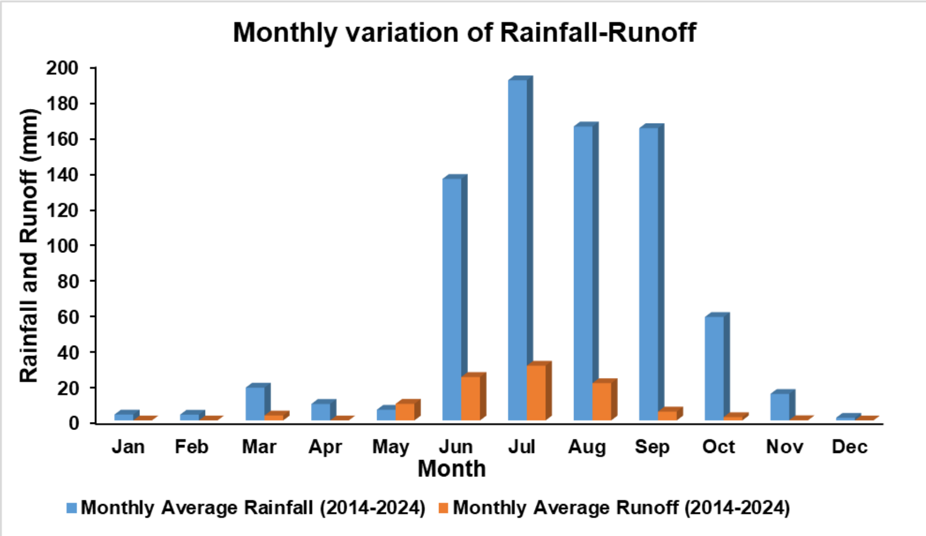


Fig.4.22 Monthly variation in average rainfall and runoff during 2014-24

4.7 Mapping of Groundwater Potential Zones

Groundwater plays a vital role in supporting agriculture and domestic water supply in Lonar taluka of Buldhana district, where rainfall variability and limited surface water resources constrain water availability. The taluka receives an average annual rainfall of about 770 mm, which is often inadequate for consistent aquifer recharge. In basaltic terrains of Maharashtra, hydrogeological studies have shown that groundwater occurrence is largely controlled by fractured rock systems, uneven permeability, and localized recharge zones. Similar conditions are observed in Lonar, where upland and non-command areas frequently experience water scarcity despite receiving seasonal monsoon rainfall.

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 classified the watershed into five groundwater potential categories: Very Good, Good, Moderate, Poor, and Very Poor. The spatial distribution shows that 8.5% of the area falls under Very Poor zones, 38% under Poor, 30.2% under Moderate, 20.9% under Good, and 2.5% under Very Good categories. These results are consistent with typical patterns observed in basaltic terrains, where poor potential zones dominate due to undulating topography and limited infiltration capacity. Overall, only about 23% of the watershed exhibits favorable conditions for groundwater recharge, highlighting the restricted extent of productive aquifers in the area.

The implications of this study are significant for watershed management under PMKSY-WDC 2.0. Research on watershed development programs in India has emphasized the importance of micro-watershed prioritization, recharge structure placement, and soil-water conservation measures to enhance groundwater sustainability. In conclusion, the integrated assessment of groundwater potential in Lonar Taluka provides a scientific basis for sustainable resource management. By combining hydrogeological insights with watershed development strategies, the study contributes to long-term water security for domestic, agricultural, and ecological needs. The findings reinforce the broader literature on groundwater in basaltic terrains, highlighting both the constraints and opportunities for effective management in semi-arid regions of Maharashtra.

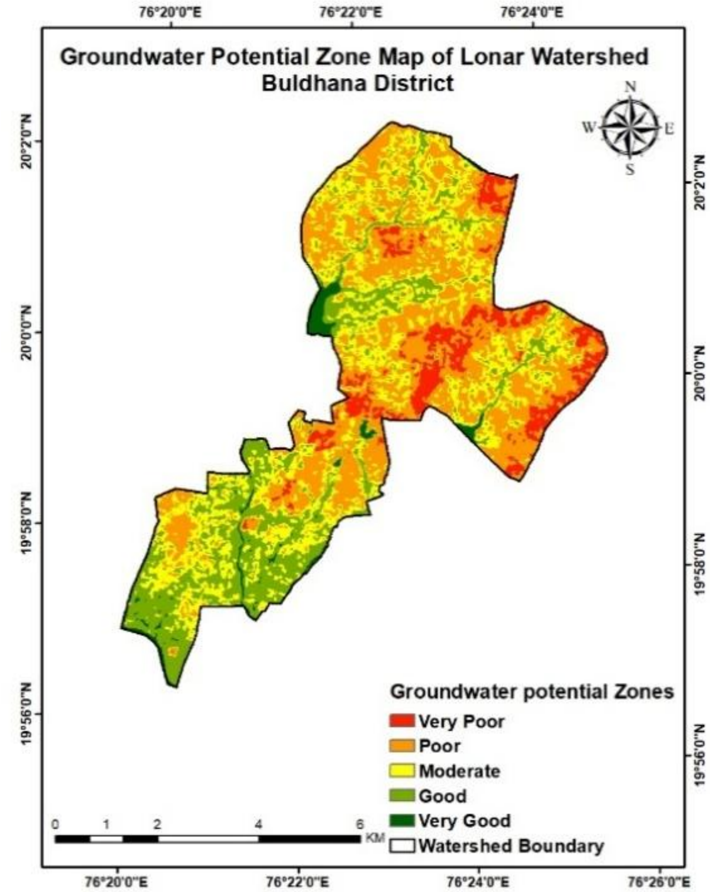


Fig.4.23 Ground water potential zone map of Lonar watershed, Buldhana

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 (*Sorghum bicolor*) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is summarized in Table 4.26. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as highly suitable (S1), providing favourable soil and environmental conditions for optimal crop growth. The moderately suitable (S2) category covers 440.31 ha (12.27% of TGA), where minor soil or site limitations may moderately influence crop productivity. A substantial portion of the watershed, 697.26 ha (19.42% of TGA), falls under the marginally suitable (S3) class, reflecting moderate to severe constraints related to soil fertility, soil physical properties, and terrain, which may limit yield potential unless appropriate agronomic interventions are implemented. Furthermore, 405.95 ha (11.31% of TGA) is classified as not suitable (N) for jowar cultivation due to severe soil and site limitations. The remaining area consists of mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the evaluation suggests that nearly 59% of the watershed is highly to moderately suitable, whereas a significant proportion is marginally suitable or unsuitable, emphasizing the importance of targeted land-use planning and soil and water management practices to enhance jowar productivity in the watershed.

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

Sr.No.	sorghum	Area (ha)	Percent (%)
1	Highly Suitable (S1)	1668.97	46.49
2	Moderately Suitable (S2)	440.31	12.27
3	Marginally Suitable (S3)	697.26	19.42
4	Not Suitable (N)	405.95	11.31
5	Mining	187.29	5.22
6	Habitation	118.56	3.30
7	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

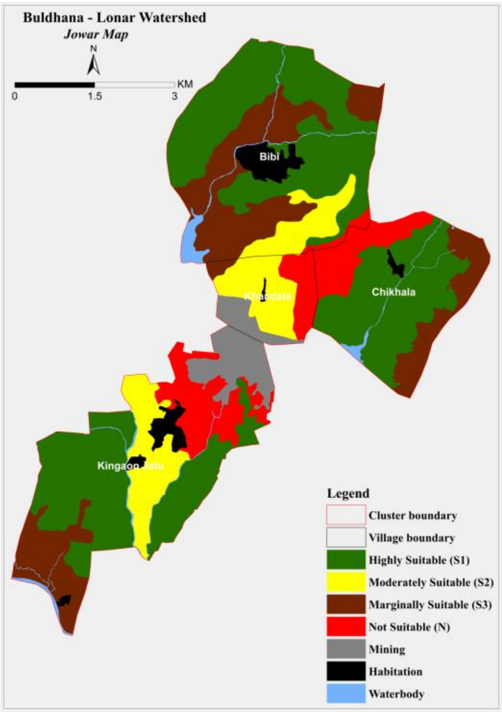


Fig. 4.24 Soil site suitability map for sorghum (jowar) Cultivation

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

The soils of the watershed were evaluated for pearl millet (bajra) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is summarized in Table 4.27. The results indicate that 1502.81 ha (41.86% of the total geographical area, TGA) are classified as highly suitable (S1), offering favourable conditions for optimum crop growth and productivity. A substantial portion of the study area, 997.92 ha (27.80% of TGA), falls under the moderately suitable (S2) category, where certain soil or site-related limitations may moderately influence crop performance. The marginally suitable (S3) class occupies 305.81 ha (8.52% of TGA), reflecting moderate to severe constraints associated with soil fertility, physical properties, and terrain, which may restrict yield potential unless appropriate agronomic management practices are adopted. Furthermore, 405.95 ha (11.31% of TGA) is categorized as not suitable (N) for bajra cultivation due to severe soil and site limitations. The remaining area consists of mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment highlights that nearly 70% of the watershed is highly to moderately suitable, while a smaller but significant portion is marginally suitable or unsuitable, emphasizing the importance of targeted land-use planning and soil and water conservation measures for sustainable bajra cultivation.

Table 4.27 Area under suitability sub-classes for Bajra Cultivation

Sr.No.	Bajra	Area (ha)	Percent (%)
1	Highly Suitable (S1)	1502.81	41.86
2	Moderately Suitable (S2)	997.92	27.80
3	Marginally Suitable (S3)	305.81	8.52
4	Not Suitable (N)	405.95	11.31
5	Mining	187.29	5.22
6	Habitation	118.56	3.30
7	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

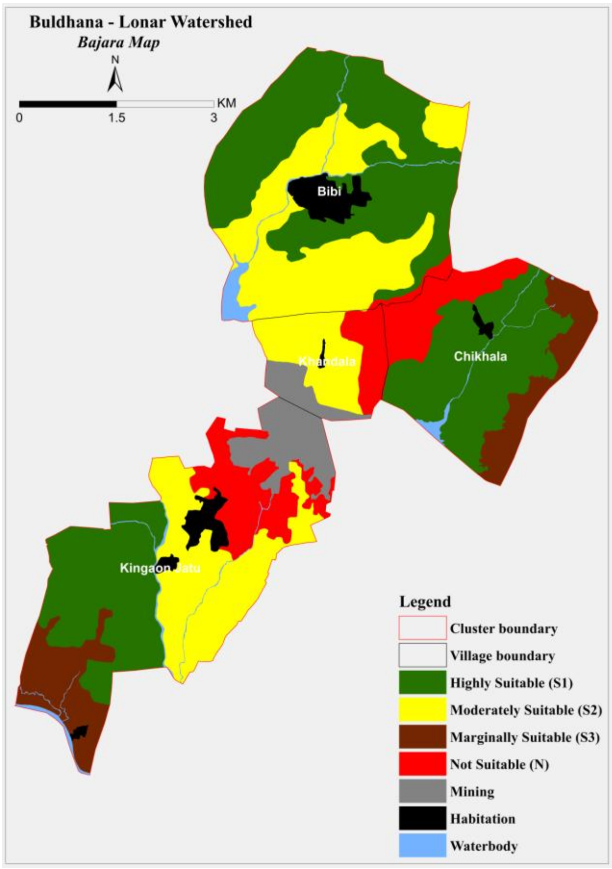


Fig. 4.25 Soil site suitability map for pearl millet (bajra) cultivation

4.8.4 Soil-Site Suitability for Pigeonpea Cultivation

The soils of the watershed were evaluated for pigeonpea (*Cajanus cajan*) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is summarized in Table 4.28. The results indicate that 553.67 ha (15.42% of the total geographical area, TGA) are classified as highly suitable (S1), reflecting favorable soil and environmental conditions for optimal crop growth. The moderately suitable (S2) category covers 1115.30 ha (31.07% of TGA), where certain soil or site-related limitations may moderately influence crop productivity. A major portion of the watershed, 1543.52 ha (43.00% of TGA), is classified as not suitable (N) for pigeonpea cultivation due to severe soil and site constraints. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural.

Table 4.28 Area under suitability sub-classes for pigeonpea cultivation

Sr.No.	Pigeonpea	Area (ha)	Percent (%)
1	Highly Suitable (S1)	553.67	15.42
2	Moderately Suitable (S2)	1115.30	31.07
3	Not Suitable (N)	1543.52	43.00
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

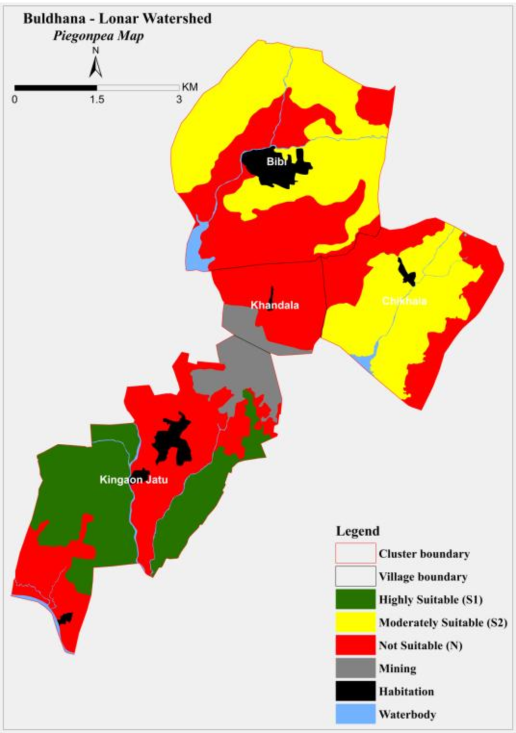


Fig. 4.26. Soil site suitability map for Pigeonpea (*tur*) Cultivation

4.8.5 Soil-Site Suitability for Soybean Cultivation

The soils of the watershed were evaluated for soybean (*Glycine max*) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.29. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as highly suitable (S1), reflecting favorable soil and environmental conditions for optimal crop growth. The marginally suitable (S3) category covers 1137.57 ha (31.69% of TGA), where noticeable soil or site limitations may restrict maximum yield potential. A smaller portion, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site constraints. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the evaluation shows that nearly 78% of the watershed is highly to marginally suitable for soybean cultivation, highlighting the potential for crop production under appropriate soil and water management practices, while the unsuitable areas require careful land-use planning or alternative cropping strategies.

Table 4.29 Area under suitability sub-classes for Soybean Cultivation

Sr. No.	Soybean	Area (ha)	Percent (%)
1	Highly Suitable (S1)	1668.97	46.49
2	Marginally Suitable (S3)	1137.57	31.69
3	Not Suitable (N)	405.95	11.31
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

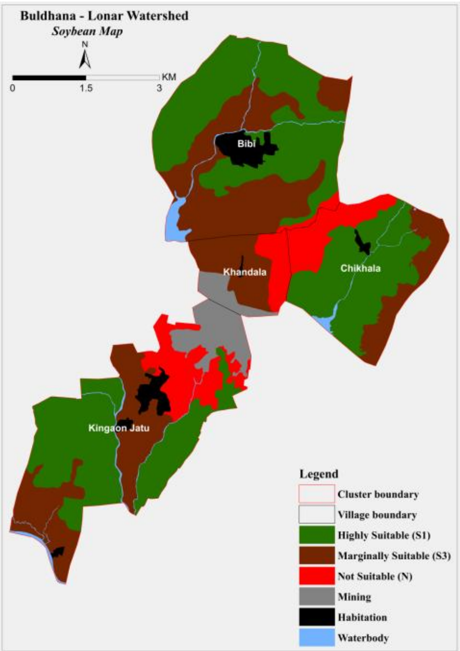


Fig. 4.27. Soil site suitability map for Soybean Cultivation

4.8.6 Soil-Site Suitability for Wheat Cultivation

The soils of the watershed were evaluated for wheat (Triticum aestivum) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.30. The results indicate that 987.60 ha (27.51% of the total geographical area, TGA) are classified as highly suitable (S1), reflecting favourable soil and environmental conditions for optimal wheat growth. The moderately suitable (S2) category covers 681.37 ha (18.98% of TGA), where moderate limitations related to soil properties or terrain may slightly restrict productivity. The marginally suitable (S3) class occupies 1137.57 ha (31.69% of TGA), indicating areas with noticeable constraints that may limit optimum crop performance without appropriate management practices. A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) for wheat cultivation due to severe soil and site limitations. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the evaluation suggests that less than half of the watershed is highly to moderately suitable, whereas a substantial portion exhibits marginal or poor suitability, emphasizing the importance of targeted land-use planning and soil and water management interventions to optimize wheat production.

Table 4.30 Area under suitability sub-classes for Wheat Cultivation

Sr.No.	Wheat	Area (ha)	Percent (%)
1	Highly Suitable (S1)	987.60	27.51
2	Moderately Suitable (S2)	681.37	18.98
3	Marginally Suitable (S3)	1137.57	31.69
4	Not Suitable (N)	405.95	11.31
5	Mining	187.29	5.22
6	Habitation	118.56	3.30
7	Waterbody	71.45	1.99
		3589.79	**100.00**

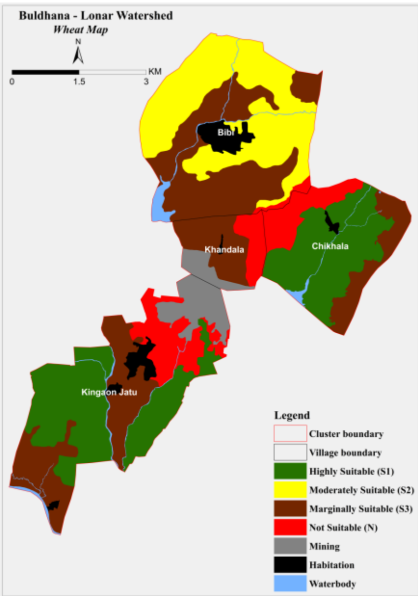


Fig. 4.28 Soil site suitability map for Wheat Cultivation

4.8.7 Soil-Site Suitability for Chickpea Cultivation

The soils of the watershed were evaluated for chickpea (*Cicer arietinum*) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.31. The results indicate that 1261.46 ha (35.14% of the total geographical area, TGA) are classified as highly suitable (S1), reflecting favorable soil and environmental conditions for optimal chickpea growth.The moderately suitable (S2) category covers 713.32 ha (19.87% of TGA), where certain soil or site limitations may slightly restrict productivity but chickpea cultivation is feasible with appropriate management. The marginally suitable (S3) class occupies 831.76 ha (23.17% of TGA), indicating areas with moderate constraints that may reduce yield potential.A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that while over half of the watershed is highly to moderately suitable for chickpea cultivation, a significant area is marginally suitable or unsuitable, emphasizing the importance of careful site selection and targeted soil and water management for sustainable chickpea production.

Table 4.31 Area under suitability sub-classes for Chickpea Cultivation

Sr.No.	Chickpea	Area (ha)	Percent (%)
1	Highly Suitable (S1)	1261.46	35.14
2	Moderately Suitable (S2)	713.32	19.87
3	Marginally Suitable (S3)	831.76	23.17
4	Not Suitable (N)	405.95	11.31
5	Mining	187.29	5.22
6	Habitation	118.56	3.30
7	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

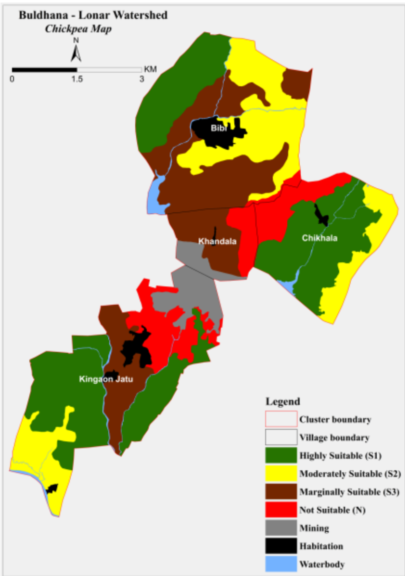


Fig. 4.29 Soil site suitability map for Chickpea Cultivation

4.8.8 Soil-Site Suitability for Cotton Cultivation

The soils of the watershed were evaluated for cotton (*Gossypium spp*.) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.32. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as highly suitable (S1), reflecting favorable soil and environmental conditions for optimal cotton growth. The marginally suitable (S3) category covers 722.12 ha (20.12% of TGA), where moderate soil or site limitations may restrict maximum yield potential. A portion of the watershed, 821.40 ha (22.88% of TGA), is classified as not suitable (N) due to severe soil and site constraints. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that while nearly two-thirds of the watershed is highly to marginally suitable for cotton cultivation, a significant area is unsuitable, emphasizing the importance of site-specific land-use planning and soil and water management interventions for sustainable cotton production.

Table 4.32 Area under suitability sub-classes for Cotton Cultivation

Sr.No.	Cotton	Area (ha)	Percent (%)
1	Highly Suitable (S1)	1668.97	46.49
2	Marginally Suitable (S3)	722.12	20.12
3	Not Suitable (N)	821.40	22.88
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

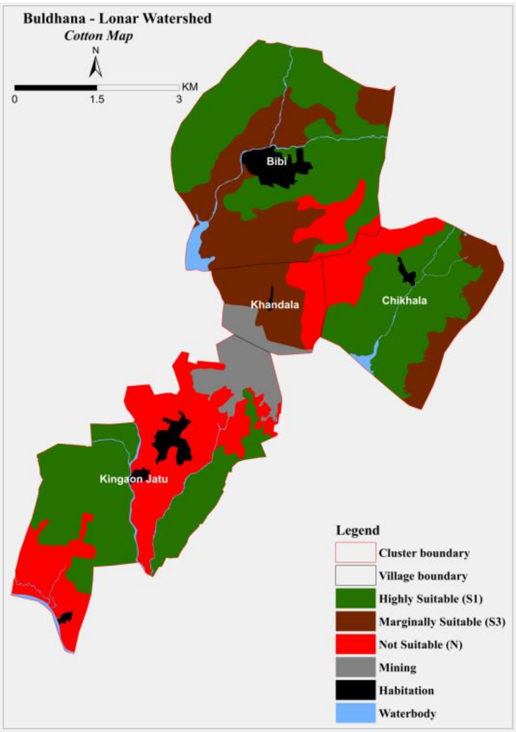


Fig. 4.30 Soil site suitability map for Cotton Cultivation

4.8.13 Soil-Site Suitability for Turmeric Cultivation

The soils of the watershed were evaluated for turmeric (*Curcuma longa*) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.33. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for turmeric growth, though minor limitations may slightly affect productivity. The marginally suitable (S3) category covers 1137.57 ha (31.69% of TGA), where noticeable soil or site constraints may reduce yield potential without appropriate management interventions. A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly three-quarters of the watershed is moderately to marginally suitable for turmeric cultivation, while a smaller portion is unsuitable, emphasizing the need for targeted site selection and appropriate soil and water management practices for sustainable turmeric production.

Table 4.33 Area under suitability sub-classes for turmeric Cultivation

Sr.No.	Turmeric	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1668.97	46.49
2	Marginally Suitable (S3)	1137.57	31.69
3	Not Suitable (N)	405.95	11.31
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100**

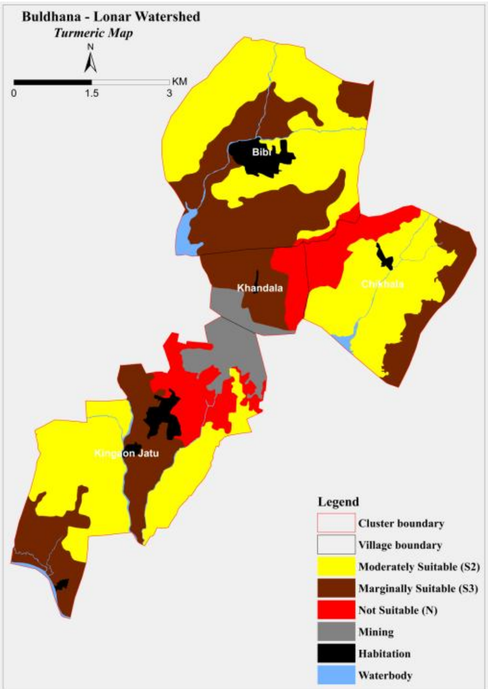


Fig. 4.31 Soil site suitability map for Turmeric Cultivation

4.8.14 Soil-Site Suitability for Maize Cultivation

The soils of the watershed were evaluated for maize (*Zea mays*) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.34. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for maize growth, though minor limitations may slightly affect productivity. The marginally suitable (S3) category covers 1137.57 ha (31.69% of TGA), where noticeable soil or site constraints may reduce yield potential without appropriate management interventions. A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly three-quarters of the watershed is moderately to marginally suitable for maize cultivation, while a smaller portion is unsuitable, emphasizing the importance of targeted site selection and appropriate soil and water management practices for sustainable maize production.

Table 4.34 Area under suitability sub-classes for Maize Cultivation

Sr.No.	Maize	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1668.97	46.49
2	Marginally Suitable (S3)	1137.57	31.69
3	Not Suitable (N)	405.95	11.31
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

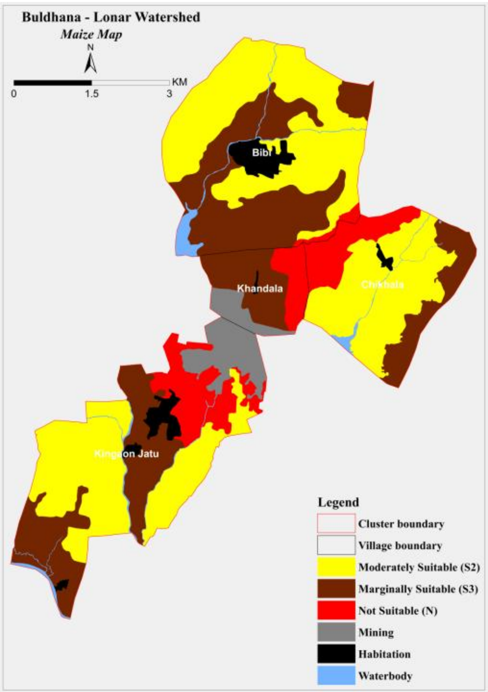


Fig. 4.32 Soil site suitability map for Maize Cultivation

4.8.15 Soil-Site Suitability for Tomato Cultivation

The soils of the watershed were evaluated for tomato (*Solanum lycopersicum*) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.35. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for tomato growth, though minor limitations may slightly affect productivity. The marginally suitable (S3) category covers 1137.57 ha (31.69% of TGA), where noticeable soil or site constraints may reduce yield potential without appropriate management interventions. A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly three-quarters of the watershed is moderately to marginally suitable for tomato cultivation, while a smaller portion is unsuitable, emphasizing the need for targeted site selection and appropriate soil and water management practices for sustainable tomato production.

Table 4.35 Area under suitability sub-classes for Tomato Cultivation

Sr.No.	Tomato	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1668.97	46.49
2	Marginally Suitable (S3)	1137.57	31.69
3	Not Suitable (N)	405.95	11.31
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

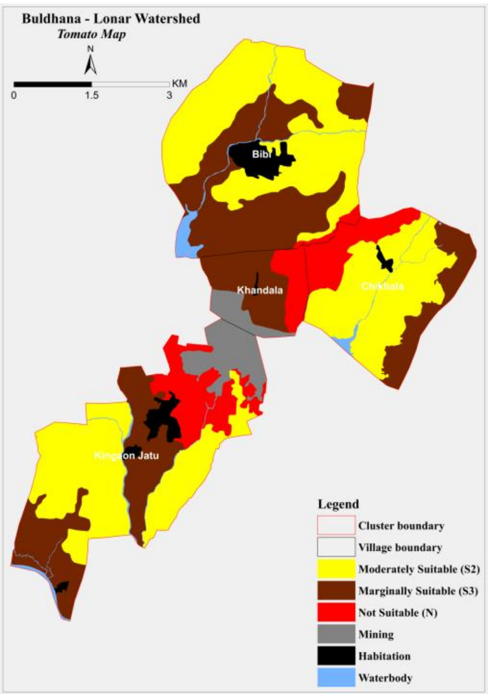


Fig. 4.33. Soil site suitability map for Tomato Cultivation

4.8.16 Soil-Site Suitability for Chilli Cultivation

The soils of the watershed were evaluated for chilli (Capsicum spp.) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.36. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for chilli growth, though minor limitations may slightly affect productivity. The marginally suitable (S3) category covers 1137.57 ha (31.69% of TGA), where noticeable soil or site constraints may reduce yield potential without appropriate management interventions. A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly three-quarters of the watershed is moderately to marginally suitable for chilli cultivation, while a smaller portion is unsuitable, emphasizing the importance of targeted site selection and appropriate soil and water management practices for sustainable chilli production.

Table 4.36 Area under suitability sub-classes for Chilli Cultivation

Sr.No.	Chilli	Area (ha)	Percent (%)
1	Marginally Suitable (S3)	1137.57	31.69
2	Moderately Suitable (S2)	1668.97	46.49
3	Not Suitable (N)	405.95	11.31
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

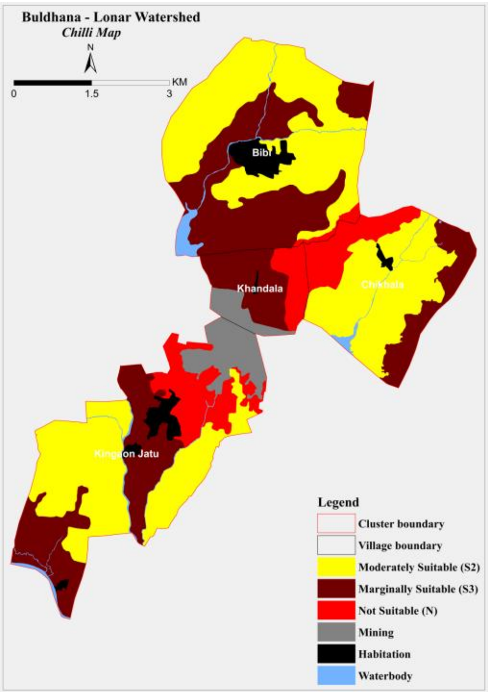


Fig. 4.34. Soil site suitability map for Chilli Cultivation

4.8.17 Soil-Site Suitability for Groundnut Cultivation

The soils of the watershed were evaluated for groundnut (Arachis hypogaea) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.37. The results indicate that 1281.46 ha (35.70% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for groundnut growth, though minor limitations may slightly affect productivity. The marginally suitable (S3) category covers 1137.57 ha (31.69% of TGA), where noticeable soil or site constraints may reduce yield potential without appropriate management interventions. A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The highly suitable (S1) areas account for 387.51 ha (10.79% of TGA), offering favourable conditions for optimum crop growth. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly three-quarters of the watershed is highly to moderately suitable for groundnut cultivation, while a smaller portion is marginally suitable or unsuitable, emphasizing the importance of targeted site selection and appropriate soil and water management practices for sustainable groundnut production.

Table 4.37 Area under suitability sub-classes for Groundnut Cultivation

Sr.No.	Groundnut	Area (Ha)	Percent (%)
1	Highly Suitable (S1)	387.51	10.79
2	Moderately Suitable (S2)	1281.46	35.70
3	Marginally Suitable (S3)	1137.57	31.69
4	Not Suitable (N)	405.95	11.31
5	Mining	187.29	5.22
6	Habitation	118.56	3.30
7	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

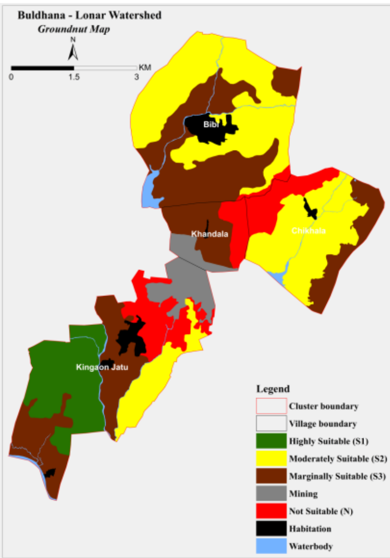


Fig. 4.35. Soil site suitability map for Groundnut Cultivation

4.8.18 Soil-Site Suitability for Green gram Cultivation

The soils of the watershed were evaluated for green gram (Vigna radiata) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.38. The results indicate that 1235.05 ha (34.40% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for green gram growth, though minor limitations may slightly affect productivity. The marginally suitable (S3) category covers 1137.57 ha (31.69% of TGA), where noticeable soil or site constraints may reduce yield potential without appropriate management interventions. A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The highly suitable (S1) areas account for 433.92 ha (12.09% of TGA), providing favourable conditions for optimum crop growth. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly three-quarters of the watershed is highly to moderately suitable for green gram cultivation, while a smaller portion is marginally suitable or unsuitable, emphasizing the importance of targeted site selection and appropriate soil and water management practices for sustainable green gram production.

Table 4.38 Area under suitability sub-classes for Green gram Cultivation

Sr.No.	Green gram	Area (ha)	Percent (%)
1	Highly Suitable (S1)	433.92	12.09
2	Moderately Suitable (S2)	1235.05	34.40
3	Marginally Suitable (S3)	1137.57	31.69
4	Not Suitable (N)	405.95	11.31
5	Mining	187.29	5.22
6	Habitation	118.56	3.30
7	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

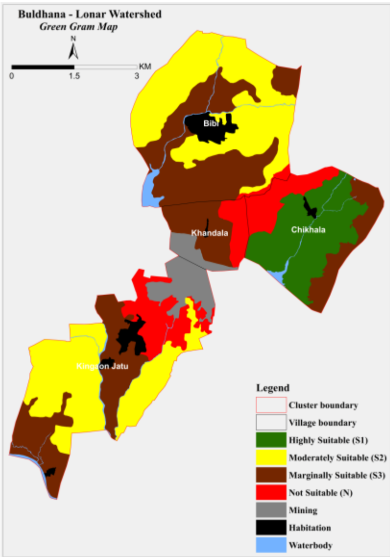


Fig. 4.36. Soil site suitability map for Green gram Cultivation

4.8.19 Soil-Site Suitability for Black gram Cultivation

The soils of the watershed were evaluated for black gram (Vigna mungo) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.39. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for black gram growth, though minor limitations may slightly affect productivity. The marginally suitable (S3) category covers 1137.57 ha (31.69% of TGA), where noticeable soil or site constraints may reduce yield potential without appropriate management interventions. A portion of the watershed, 405.95 ha (11.31% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly three-quarters of the watershed is moderately to marginally suitable for black gram cultivation, while a smaller portion is unsuitable, emphasizing the need for targeted site selection and appropriate soil and water management interventions for sustainable black gram production.

Table 4.39 Area under suitability sub-classes for Black gram Cultivation

Sr.No.	Black gram	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1668.97	46.49
2	Marginally Suitable (S3)	1137.57	31.69
3	Not Suitable (N)	405.95	11.31
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

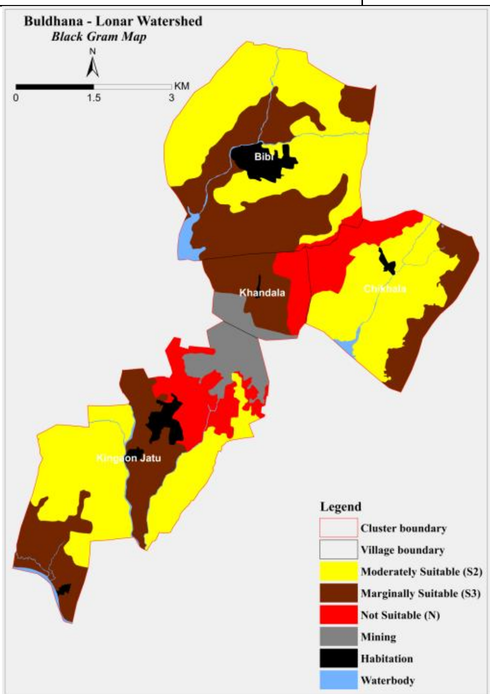


Fig. 4.37. Soil site suitability map for Black gram Cultivation

4.8.20 Soil-Site Suitability for Citrus Cultivation

The soils of the watershed were evaluated for citrus (orange) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.40. The results indicate that 166.16 ha (4.63% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for citrus growth, though minor limitations may slightly affect productivity. The marginally suitable (S3) category covers 1502.81 ha (41.86% of TGA), where noticeable soil or site constraints may reduce yield potential without appropriate management interventions. A significant portion of the watershed, 1543.52 ha (43.00% of TGA), is classified as not suitable (N) due to severe soil and site limitations. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly half of the watershed is marginally suitable or unsuitable for citrus cultivation, highlighting the need for careful site selection, soil amendments, and water management interventions to ensure successful orange production.

Table 4.40 Area under suitability sub-classes for Citrus Cultivation

Sr.No.	Citrus	Area (ha)	Percent (%)
1	Marginally Suitable (S3)	1502.81	41.86
2	Moderately Suitable (S2)	166.16	4.63
3	Not Suitable (N)	1543.52	43.00
4	Mining	187.29	5.22
5	Habitation	118.56	3.30
6	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

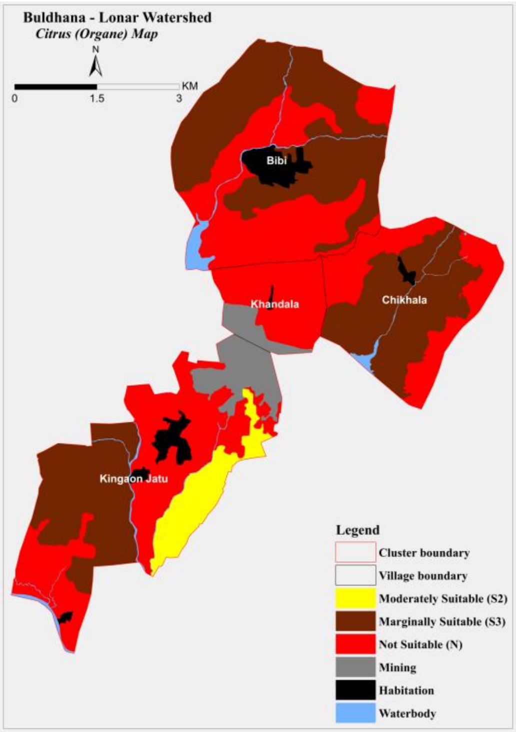


Fig. 4.38. Soil site suitability map for Citrus Cultivation

4.8.21 Soil-Site Suitability for Sweet Orange Cultivation

The soils of the watershed were evaluated for sweet orange (Mosambi) cultivation based on crop-specific soil and site requirements. The distribution of suitability classes is presented in Table 4.41. The results indicate that 1668.97 ha (46.49% of the total geographical area, TGA) are classified as moderately suitable (S2), reflecting areas with acceptable soil and environmental conditions for sweet orange growth, though minor limitations may slightly affect productivity. A significant portion of the watershed, 1543.52 ha (43.00% of TGA), is classified as not suitable (N) due to severe soil and site constraints. The remaining area includes mining land (187.29 ha; 5.22%), habitation (118.56 ha; 3.30%), and water bodies (71.45 ha; 1.99%), which are non-agricultural. Overall, the assessment shows that nearly half of the watershed is suitable for sweet orange cultivation under moderate conditions, while a similar share is unsuitable, emphasizing the need for careful site selection, soil management, and irrigation planning to ensure productive orchards.

Table 4.41 Area under suitability sub-classes for Sweet Orange Cultivation

Sr.No.	Sweet Orange	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1668.97	46.49
2	Not Suitable (N)	1543.52	43.00
3	Mining	187.29	5.22
4	Habitation	118.56	3.30
5	Waterbody	71.45	1.99
	Total	**3589.79**	**100.00**

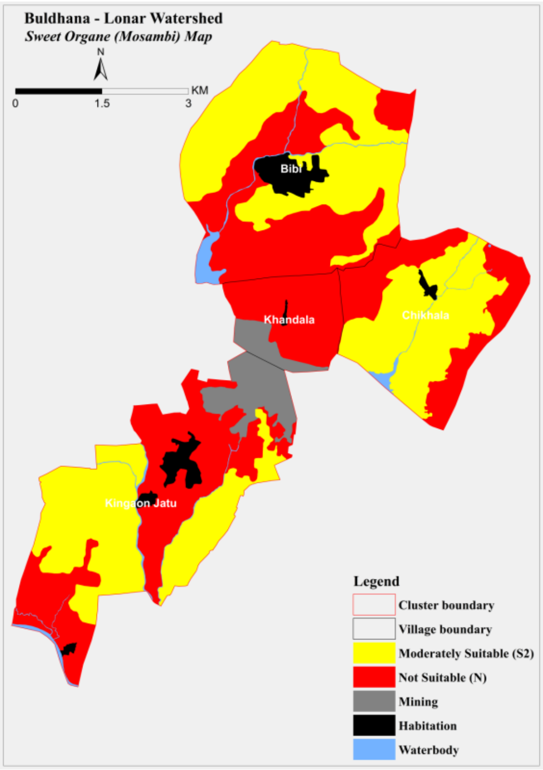


Fig. 4.39. Soil site suitability map for Sweet Orange Cultivation

4.9 Soil and Water Conservation measures

Soil and Water Conservation (SWC) forms the final and most crucial component of the watershed development strategy for Lonar Taluka. After assessing land use, cropping patterns, groundwater status, runoff estimation, and groundwater potential zonation, the SWC plan provides the operational framework for implementing interventions on the ground. The objective of this plan is to reduce soil erosion, manage runoff, enhance infiltration, and improve water availability through a combination of structural and vegetative measures. The interventions have been carefully matched with the landform and land use characteristics of the taluka, ensuring that each unit receives the most appropriate treatment.

The largest share of the plan is devoted to field bunding combined with farm pond construction. These measures are concentrated in cultivable lands where bunds help retain soil moisture and prevent erosion, while farm ponds provide localized storage for irrigation and groundwater recharge. In selected locations, farm ponds are lined to minimize seepage losses and ensure durability. The Broad Bed and Furrow (BBF) system is adopted in shallow soil areas, particularly in pediplains and plains, where it improves in-situ moisture conservation and enhances crop productivity. Conservation Bench terracing is introduced in unbunded upland fields to intercept runoff and reduce soil loss, especially in areas where slopes are moderate and bunding alone is insufficient.

Vegetative measures are equally important in the conservation framework. Afforestation and in-situ moisture conservation practices are prioritized in escarpments, uplands, and wastelands, which are highly erosion-prone due to shallow soils and steep gradients. These interventions stabilize slopes, reduce runoff velocity, and improve infiltration. In specific locations, afforestation is combined with percolation tanks, providing both vegetative cover and recharge structures. Horticultural plantations are promoted in scrublands, converting degraded lands into productive orchards. Stream bank plantation is undertaken along river courses to stabilize banks, prevent erosion, and enhance ecological resilience.

Water resource management is addressed through renovation of existing waterbodies and rooftop rainwater harvesting. Renovation includes desilting, strengthening embankments, and restoring storage capacity, while rooftop harvesting ensures that urban runoff is captured and reused. Miscellaneous conservation measures are applied to crusher and mining zones, focusing on land stabilization and safe runoff disposal. Roadside stabilization works are also included to manage drainage and reduce erosion along transport corridors.

The conservation plan brings a total of 3,590 hectares under treatment. The largest share is under field bunding and farm ponds, followed by BBF systems, afforestation, waterbody renovation, and other targeted interventions such as rooftop harvesting, stream bank plantation, bench terracing, horticultural plantations, and miscellaneous measures. This distribution reflects a balanced mix of structural and vegetative interventions, tailored to the specific land use and management needs of Lonar Taluka.

In conclusion, the Soil and Water Conservation plan represents a comprehensive approach to watershed management. By covering 3,590 hectares under treatment, the plan addresses both agricultural productivity and ecological stability. It ensures that cultivable lands are protected from erosion, uplands and escarpments are stabilized, waterbodies are rejuvenated, and urban runoff is harnessed. The integration of structural measures like bunds, farm ponds, percolation tank and terraces with vegetative measures like afforestation and horticultural plantations provides a robust framework for reducing runoff, enhancing groundwater recharge, and sustaining water resources. This plan not only supports immediate conservation needs but also lays the foundation for long-term water security and socio-economic development in Lonar Taluka.

Table 4.42 Soil and water conservation plan for Lonar watershed, Buldhana district

S.No.	Proposed SWC Plan
1	Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm pond
2	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm pond
3	Field bund/Strengthening of existing bund with safe disposal of runoff water
4	Afforestation, In-situ Moisture Conservation Measures
5	Field bund/Strengthening of existing bund with safe disposal of runoff water, Farm pond with Lining
6	Rooftop Rainwater Harvesting
7	Renovation of Waterbody as per the site condition
8	Conversation Bench Terrace in Unbunded Field/Field bund/Strengthening of existing bund with safe disposal of runoff water
9	Stream Bank Plantation
10	Miscellaneous
11	In-situ Moisture Conservation Measures
12	Road
13	Afforestation, In-situ Moisture Conservation Measures, Percolation Tank
14	Horticultural Plantation, In-situ Moisture Conservation Measures
15	Broad Bed and Furrow (BBF) system/Field bund/Strengthening of existing bund with safe disposal of runoff water

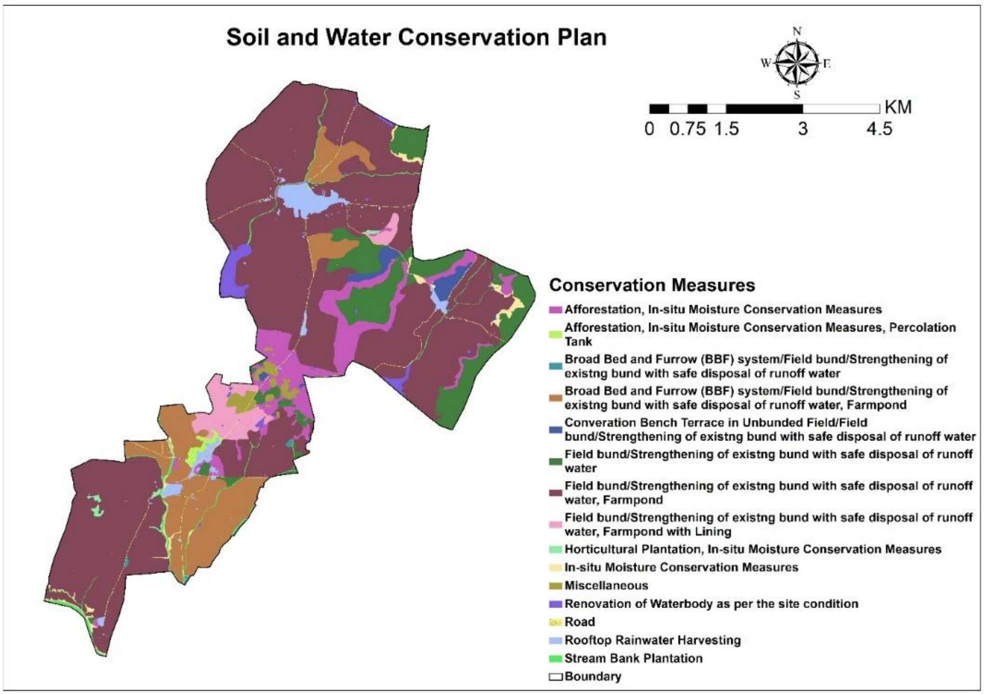


Fig. 4.40 Soil and water conservation measures for Lonar watershed, Buldhana

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

- The Lonar watershed's economy is largely agriculture-based on a soybean/tur and commercial cotton cropping pattern.
- The water management is hindered by critical issues, seasonal water scarcity, and depleting groundwater levels.
- The watershed is part of the Deccan Volcanic Province, exhibits significant heterogeneity in its landforms (e.g., mesas, pediplains), slope, and land use.
- The soils, which originated from basaltic parent material, show marked variations in their depth, texture, drainage, and overall fertility status.
- An extensive survey was conducted to classify and map the dominant soil series and phases.
- Soil health status was comprehensively mapped, providing critical data on distribution of land slope, different classes of soil erosion, and soil depth. Spatial distribution of soil pH, soil salinity, extent of calcareousness, and the status of soil organic carbon (SOC). Nutrient deficiencies were quantified and mapped for the availability of major nutrients (Nitrogen, Phosphorus and Potassium) and micronutrients (Iron, Manganese, Copper, and Zinc) to identify specific areas requiring soil amendments.
- The hydrological assessment quantified the relationship between rainfall and surface runoff, providing historical data for monthly runoff from 2014 to 2024.
- The groundwater potential zones were successfully mapped using integrated thematic analysis.
- A major outcome of the LRI is the Evaluation of Soil-Site Suitability for Crops. Suitability classes (S1, S2, S3, N) were determined and mapped for major crops, including rainfed agricultural crops and horticultural crops. Runoff analysis (2014-24) for Lonar watershed showed average runoff remained relatively low compared to rainfall, indicating that a large proportion of precipitation is lost through infiltration, soil moisture storage, and recharge.
- Groundwater potential mapping in revealed that poor and moderate zones dominate in the Lonar watershed due to basaltic geology, undulating topography, and limited infiltration capacity. Only a small portion of the watershed shows favorable recharge conditions, highlighting the limited extent of productive aquifers.
- Soil and water conservations proposed for Lonar watershed include field bunds, farm ponds, terraces, nala bunds, afforestation, and stream bank stabilization.

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 Buldhana Lonar 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 evaluation of soil fertility parameters revealed that the soils of the watershed suffer from multiple nutrient deficiencies, particularly in available nitrogen, phosphorus, and zinc. In addition, most of the area falls under the very low to medium category of organic carbon. This situation requires serious attention to optimize the productivity potential of the watershed soils. Farmers in the Buldhana Lonar watershed need to be made aware of the importance of balanced nutrient application to maintain long-term soil health. They should also adopt the regular use of organic manures on their farms to improve and sustain soil organic carbon levels. Furthermore, the assessment of crop suitability in the watershed indicates that the soils are capable of supporting crop diversification through a combination of agricultural and horticultural crops, which can help enhance soil health as well as improve the socio-economic conditions of the farmers.

The study demonstrates that integrated watershed management is essential for improving water availability in semi-arid basaltic regions. Runoff analysis revealed that surface flow is concentrated during peak monsoon months, increasing the risk of soil erosion and water loss. Groundwater potential mapping indicated that only a limited portion of the watershed has favourable recharge conditions, emphasizing the need for careful resource management. The proposed soil and water conservation measures provide practical solutions to capture runoff, enhance groundwater recharge, and protect soil resources. Implementing these interventions will strengthen agricultural productivity, improve water security, and support sustainable livelihoods in the watershed under climate variability.

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 resource.

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 Lonar cluster, Buldhana

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

Morphometric analysis involves the quantitative assessment of drainage network characteristics, basin geometry, slope, and relief, all of which directly influence runoff generation, soil erosion, and groundwater recharge. These parameters must be derived from a hydrologically closed unit defined by natural divides. A watershed represents such a unit, where streams develop in a hierarchical order and converge toward a common outlet, enabling accurate computation of indices such as drainage density, bifurcation ratio, stream frequency, form factor, and relief ratio.

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

The Lonar cluster, Buldhana, Maharashtra, comprises four villages. Together, these villages constitute the study cluster having one sub-watershed (Fig. 1).

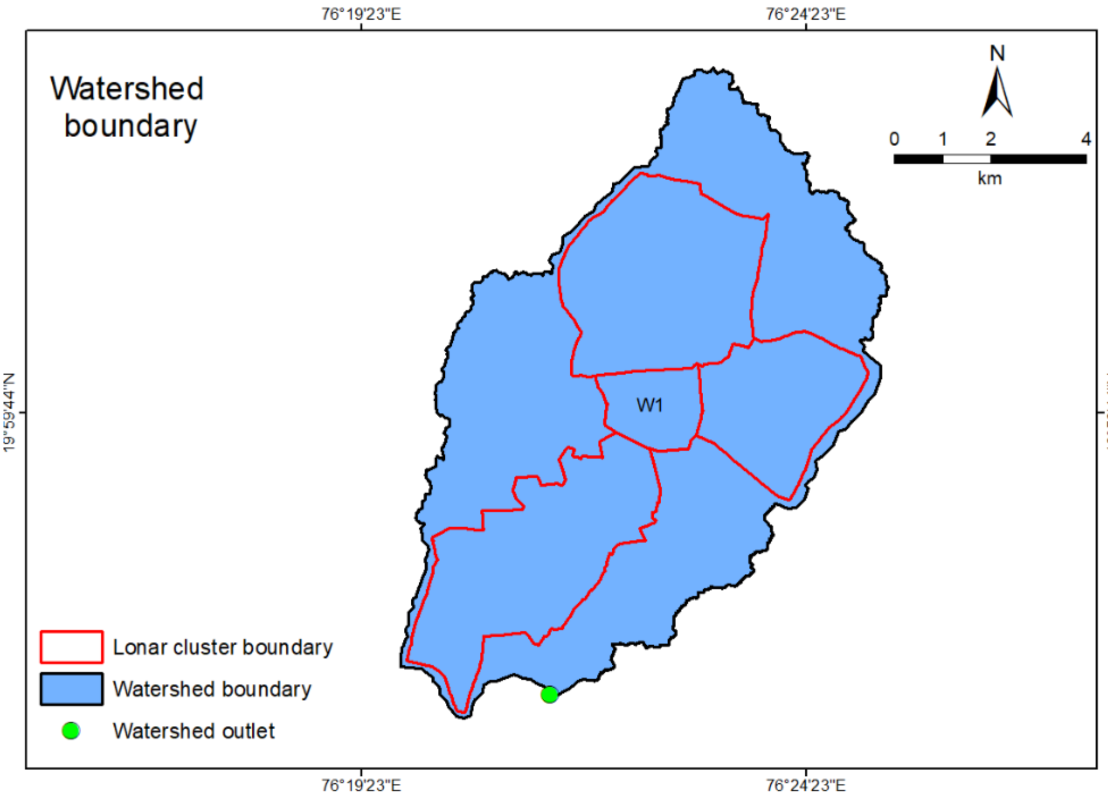


Fig. 1: Map of Lonar cluster, Buldhana depicted through sub-watershed

Table 1: Distribution of area under different sub-watershed, Lonar cluster, Buldhana

Sl. No.	Sub-watershed name	Sub-watershed order	Elevation (m)	Area (km^2)	Flow origination
1	W1	5^{th}	413-549	74.56	North-south

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

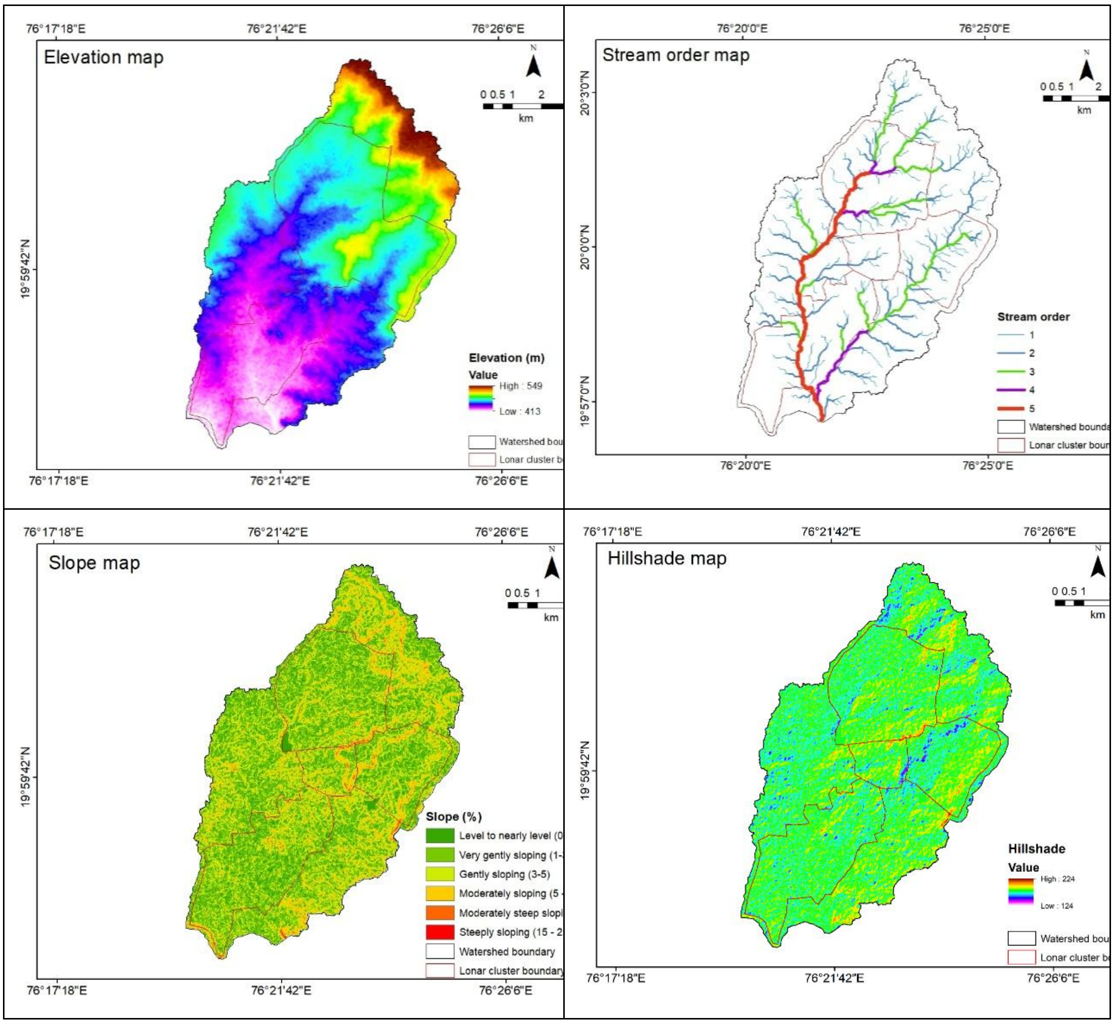


Fig. 2: Elevation, stream network, slope and hill shade map of sub-watershed

Linear aspect

Linear morphometric parameters focus on the stream network characteristics and its influence on runoff and watershed behavior. The morphometric analysis of the sub-watersheds shows clear variation in drainage characteristics.

W1 has the number of streams (372) and total stream length (188.2 km), indicating a well-developed drainage network (Table 2). The bifurcation ratio indicated as 4.2, suggesting relatively greater structural influence watershed. Mean channel length and valley length of watershed, reflecting more mature channel development. Channel index of watershed W1 (1.31), indicating greater sinuosity. Basin perimeter of W1 (52.06 km), confirming it as the most extensive sub-watershed.

Table 2: Linear morphometric parameters watersheds, Lonar cluster, Buldhana

Sr. no.	Morphometric parameter	Symbol	Unit	W1
1	No. of streams	Nu	No	372
2	Stream length	Lu	km	188.2
3	Bi-furcation ratio	Rb	-	4.2
4	Mean channel length	Cl	km	16.15
5	Valley Length	Vl	km	15.03
6	Channel Index	Ci	-	1.31
7	Minimum areal distance	Adm	km	12.30
8	Valley Index	Vi	-	1.22
9	Basin perimeter	P	km	52.06

Areal Aspects

Areal parameters describe the two-dimensional properties of the watershed, including shape, size, and drainage efficiency, which directly influence runoff and groundwater recharge. Basin area of watershed W1 (74.56 km²) and mean basin width is4.63 km. Form factor (Ff) and elongation ratio (Re) in W1 (0.29 and 0.61), suggesting a comparatively more circular basin. Circularity ratio (Rc) of W1 is 0.35, while compactness coefficient (Cc) as 1.71, reflecting greater basin irregularity. Standard sinuosity index (Ssi) as 1.07, indicating relatively higher channel sinuosity in W1.Drainage parameters show that stream frequency (Fs) is 5 per km² and Drainage density (Dd) as 2.78 km/km².Drainage intensity (Di) follows a similar trend, with the highest value as 1.80.Length of overland flow (Lg) as (0.18 km)indicating shorter runoff travel distance in W1.

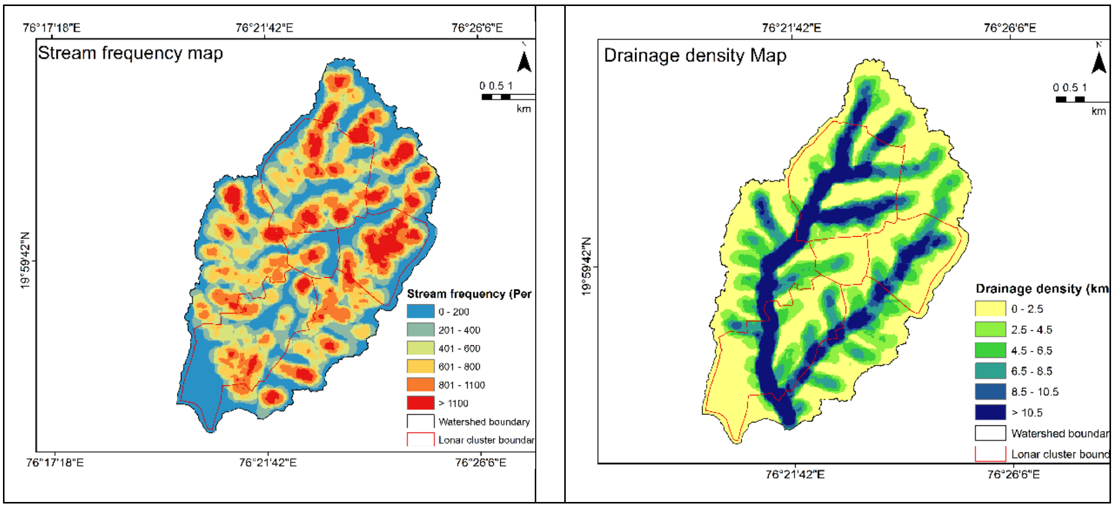


Fig. 3: Steam frequency and drainage density map of sub-watershed

Table 3: Areal morphometric parameters of sub-watersheds, Lonar cluster, Budhana

Sr. No.	Parameter	Symbol	Method/ Formula	Unit	W1
1.	Mean basin width	Wb	Wb=A/Lb	km	4.63
2.	Basin area	A	GIS Analysis	km2	74.56
3.	Relative perimeter	Pr	Pr= A/P	km	1.43
4.	Length area relation	Lar	Lar = 1.4*A0.6	km2	18.61
5.	Lemniscate's	k	K = Lb2/A	-	3.48
6.	Form factor	Ff	Ff = A/Lb2	-	0.29
7.	Elongation ratio	Re	Re = 2/Lb*(A/π)0.5	-	0.61
8.	Circularity ratio	Rc	Rc = 12.57*(A/P2)	-	0.35
9.	Compactness coefficient	Cc	Cc = 0.2841*P/A0.5	-	1.71
10.	Standard sinuosity index	Ssi	Ssi = Ci/Vi	-	1.07
11.	Stream frequency	Fs	Fs = Nu/A	Per km2	5.0
12.	Drainage Density	Dd	Dd = Lu/A	km/km2	2.78
13.	Drainage Intensity	Di	Di = Fs/Dd	-	1.80
14.	Length of Overland Flow	Lg	Lg = A/2*Lu	km	0.18

Relief Aspects

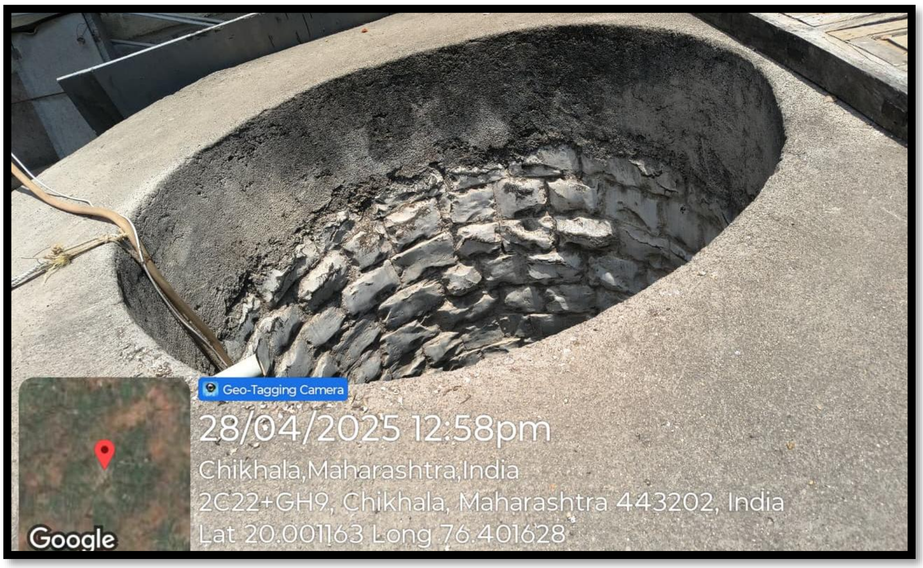
The maximum basin height (Z) of W1 (549 m) and total basin relief (H) is also maximum as (136 m) (Table 4). Relief ratio (Rhl) as W1 (8.4), indicating steeper terrain conditions, while Relative relief ratio (Rhp) of W1 (261.2) suggesting higher relief intensity in W1. The ruggedness number (Rn) of watershed W1 (0.24), reflecting more dissected and erosion-prone terrain.Similarly, the Melton ruggedness number (MRn) is shown in W1 (15.8), indicating comparatively higher susceptibility to runoff and erosion processes.

Table 4: Relief morphometric parameters of sub-watershed, Lonar cluster, Buldhana

Sr. No	Parameters	Symbol	Methods /Formula	W1
1.	Height of at basin mouth	z	DEM	413
2.	Maximum height of the basin	Z	DEM	549
3.	Total basin relief	H	H = Z - z	136
4.	Relief ratio	Rhl	Rhl = H / Lb	8.4
5.	Relative relief ratio	Rhp	Rhp = H * 100 / P	261.2
6.	Ruggedness number	Rn	Rn = Dd*(H/1000)	0.24
7.	Melton Ruggedness number	MRn	MRn = H / A^0.5	15.8

The slope distribution of sub-watershed W1 indicates that the terrain is predominantly gentle. The very gently sloping class (1-3%) occupies the largest portion of the watershed, covering 39.69% of the total area, followed by gently sloping land (3–5%) which accounts for 25.96%. The level to nearly level class (0-1%) covers 17.54% of the area, indicating the presence of relatively flat terrain in some parts of the watershed. Moderately sloping land (5-10%) occupies 13.04%, reflecting moderately undulating terrain conditions. The moderately steep slope class (10-15%) covers only 0.72% of the watershed, while steep slopes (15-25%) are absent in the study area. Overall, the slope distribution suggests that W1 is largely dominated by gentle slopes with limited areas of moderate relief.

The morphometric characteristics of sub-watershed W1 indicate a moderately developed drainage system with relatively high stream frequency and drainage density, suggesting efficient runoff generation and comparatively lower infiltration potential. The moderate bifurcation ratio indicates structural control over the drainage network, while the higher channel index and sinuosity reflect mature channel development and increased flow path complexity. The basin shape parameters, including moderate form factor, elongation ratio, and circularity ratio, suggest a semi-circular basin that may produce relatively quicker hydrological response compared to elongated basins. Furthermore, the relatively short length of overland flow indicates faster runoff concentration toward the drainage network. Relief parameters such as basin relief, relief ratio, and relative relief ratio indicate moderate terrain dissection, while the ruggedness number and Melton ruggedness number suggest susceptibility to erosion and runoff processes. Although the watershed is predominantly characterized by very gently sloping and gently sloping lands, the presence of moderately sloping areas can enhance surface runoff during intense rainfall events. Therefore, appropriate soil and water conservation measures should emphasize both runoff regulation and in-situ moisture conservation. Structural interventions such as small check dams, gully plugs, and percolation tanks along drainage lines are recommended to reduce runoff velocity and enhance groundwater recharge. In agricultural areas with gentle slopes, field bunds, and vegetative barriers can effectively reduce soil erosion and improve soil moisture retention, while practices such as strip cropping, mulching, and broad bed and furrow (BBF) systems may be adopted in moderately sloping zones to control runoff and maintain soil productivity within the watershed.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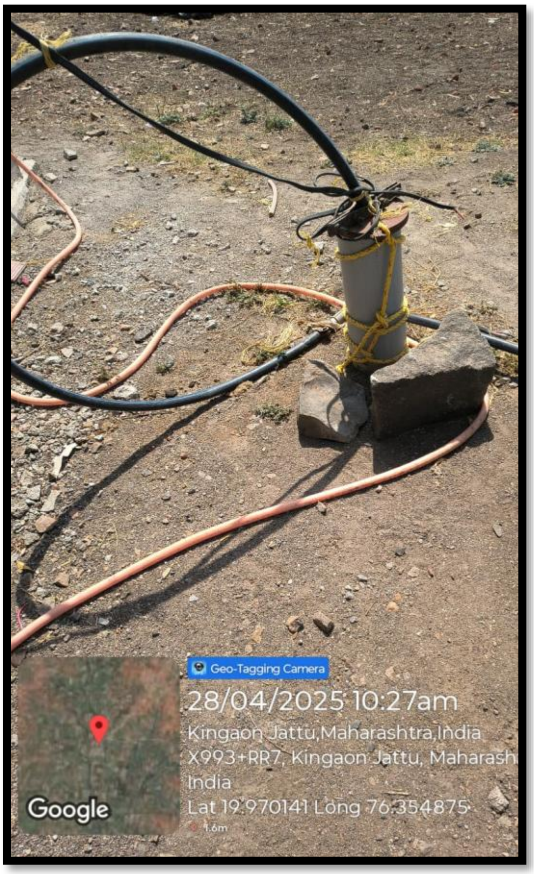
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