

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

(WDC-2.0)4/2021-22: Nandurbar, Dist - Nandurbar



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



**Vasundhara Watershed Development Agency
Pune, Maharashtra**

About the ICAR-NBSS&LUP

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

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

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PREFACE

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

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

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



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

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EXECUTIVE SUMMARY

The Pradhan Mantri Krishi Sinchayee Yojana - Watershed Development Component (PMKSY-WDC 2.0) requires a scientific and collaborative approach to watershed development through systematic evaluation of land and water resources. For effective planning, the Land Resource Inventory (LRI) provides a critical technical input for informed planning, prioritization of interventions, and sustainable management of natural resources. In accordance with the programme guidelines, the ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP) was tasked with conducting the LRI and offering technical assistance for preparing watershed development plans.

Accordingly, the Bureau conducted a Land Resource Inventory and watershed assessment for the Nandurbar (WDC-2.0) Village Cluster-watershed. It is situated within the Tapi River basin, specifically located in Nandurbar Taluka, Nandurbar District, Maharashtra. Agriculture is the primary land use in this watershed, heavily relying on monsoon rainfall. The primary objectives of the study were to systematically characterize soil and land resources at watershed level, assess land capability and crop-site suitability, support watershed-based land use planning, and evaluate groundwater potential to aid sustainable watershed development under PMKSY-WDC 2.0.

The assessment was carried out following standard methodologies and procedures prescribed by ICAR-NBSS&LUP. Pre-field analysis, detailed soil survey, laboratory analysis, and GIS-based interpretation were undertaken to generate spatial and thematic datasets. Base maps were prepared using authenticated sources. Soils were characterized through field observations and laboratory analysis and classified using established soil classification systems.

The watershed exhibits variability in landforms, slope, soils, and land use, which governs runoff generation, soil erosion, moisture availability, and groundwater occurrence. Soils show variations in depth, texture, drainage, and fertility status, reflecting differences in terrain position and land management practices. Hydrological assessment and groundwater potential evaluation were carried out using integrated thematic analysis to support identification of suitable areas for soil and water conservation and groundwater recharge interventions. The outcomes of the Land Resource Inventory provide a scientific basis for watershed-level planning, identification of resource constraints, and prioritization of soil and water conservation measures. The technical inputs generated by ICAR-NBSS&LUP are intended to support implementing agencies in designing location-specific interventions and promoting sustainable management of land and water resources under PMKSY-WDC 2.0.

In conclusion, the Land Resource Inventory and watershed assessment carried out by ICAR-NBSS&LUP for the Nandurbar sub-watershed constitutes an essential technical framework for watershed development planning and implementation, in accordance with the objectives and guidelines of PMKSY-WDC 2.0.

CHAPTER 1

INTRODUCTION

A region, block, district, or village's Land Resource Inventory (LRI) has proven to be an essential component of planned agricultural development. This inventory provides critical baseline data for effective watershed management and sustainable land use planning, particularly through the application of advanced geospatial technologies. Encouraged by the success of LRI-based watershed programs in Karnataka, many states have started using soil/land data for rural development.

Administrators at the national and state level(s) have recognized the significance of LRI and documented in the PMKSY 2.0 document that at least 10% area of the watersheds be covered under LRI in the plateau and upland region of the country. In addition to LRI, the agro-ecological zone approach is deemed to be most effective for regeneration of *in-situ* resources for sustaining the biological growth and, in turn, soil health. Agro-ecological regions and subregions delineated by the ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP) therefore form the ideal base for selection and planning of watershed development, as our understanding of soil-crop and weather interactions is greatly enhanced under this approach.

The Government of Maharashtra directed the Bureau to conduct a Land Resource Inventory (LRI) in 14 watersheds located in different agro-ecological zones of the state. The objective is to measure improvements and ensure the long-term health of farming and related activities in rainfed areas, which will benefit the local farmers.

The process for selecting these watersheds was designed to fairly represent where existing projects were located across Maharashtra's distinct regions. As a result, four watersheds were selected for both the Vidarbha and Konkan regions, as they had a high number of ongoing projects. Western Maharashtra, Marathwada, and Northern Maharashtra were each assigned two watersheds, reflecting a lower concentration of implemented projects.

The project, planned for 48626 ha was implemented with the following objectives:

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

This report presents the Land Resource Inventory (LRI) conducted in the Nandurbar (WDC-2.0/4/2021-22 sub-watershed of Nandurbar Taluka under the Pradhan Mantri Krishi Sinchayee Yojana - Watershed Development Component (PMKSY-WDC 2.0). The study involved detailed field visits, soil observations, mapping, and assessment of local hydrological conditions. The information collected was carefully analyzed to understand land capability, soil suitability, drainage patterns and groundwater potential. These

findings provide a practical foundation for planning watershed development and soil and water conservation measures suited to local conditions.

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

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

Note-MWS-Micro Watershed

CHAPTER 2

NANDURBAR WATERSHED AT A GLANCE

2.1 Location and Extent

The watershed under study is situated in Nandurbar Taluka, one of the administrative subdivisions of Nandurbar District, located in the northwestern part (Khandesh Region) of Maharashtra. The cluster area lies between 21°36' N to 21°47' N latitude and 74°11' E to 74°40' E longitude. It is characterized by undulating terrain, moderate annual rainfall, and rural settlements interspersed with agricultural land. Nandurbar Taluka is part of the Nandurbar revenue division and is predominantly rural, with a mix of pediments, pediplains, and other permanent features such as river, and built-up areas.

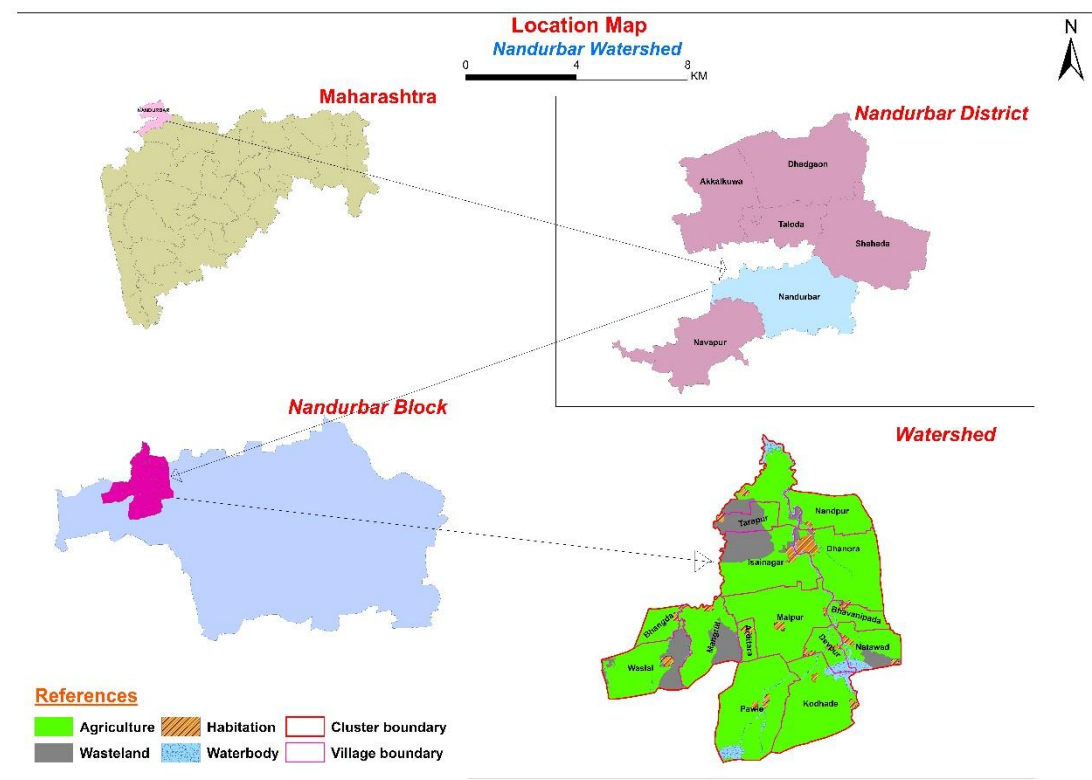


Fig. 2.1: Location map of the Nandurbar watershed

The Tapi River Basin is the major river system flowing through the taluka, serving as the primary water source for irrigation, domestic use, and small-scale industry. The study area includes a cluster of 14 villages. These villages are largely rural and rainfed, with agriculture being the primary livelihood. The region is prone to moderate surface runoff during monsoons, leading to soil erosion and water scarcity during the post-monsoon months. This situation, despite an annual rainfall of 943 mm, formed the rationale for selecting this area for watershed-based natural resource management interventions

Table 2.1: Geographical and Administrative Profile

Sr. No.	Particulars	Details
1	District	Nandurbar
2	Taluka	Nandurbar
3	Revenue Division	Nandurbar
4	Total sub-watershed Area	Approx. 6220 ha
5	Villages	14 villages (Arditara, Bhangda, Bhavanipada, Devpur, Dhanora, Isainagar, Kodhade, Malpur, Mangrul, Nandpur, Natawad, Pawle, Tarapur and Waslai)
6	Major River	Tapi River
7	Drainage Pattern	Sub-parallel to semi-dendritic, with seasonal tributaries
8	Average annual Rainfall	943 mm

2.2 Geology

The geology of the Nandurbar region is largely dominated by the Deccan Trap formations of Upper Cretaceous age, which consist mainly of basaltic lava flows. These basalt formations are frequently intersected by doleritic and basaltic dykes and are associated with weathered, fractured, and vesicular basalt layers that serve as important groundwater-bearing formations. In addition to the basaltic terrain, portions of the district, particularly along river valleys, are covered by recent alluvial deposits composed of sand, silt, and gravel. These geological formations strongly influence groundwater occurrence, infiltration characteristics, and soil formation processes in the watershed areas. The basaltic terrain generally supports groundwater under weathered and fractured conditions, whereas the alluvial formations provide relatively better storage and permeability.

2.3 Geomorphology

Geomorphologically, Nandurbar Taluka is mainly characterized by denudational landforms developed over basaltic rocks of the Deccan Trap. The dominant geomorphic units identified in the area include upper pediment, middle pediment, lower pediment, and pediplain. Pediment surfaces occur along the foothill and transitional zones with gentle slopes and comparatively shallow to moderately deep soils. The lower pediment gradually merges with the pediplain areas, which represent relatively level to gently sloping surfaces formed by long-term erosion and deposition processes. These landforms influence drainage conditions, soil depth, and land capability within the watershed area.

2.4 Physiography and Soil

The terrain of the Nandurbar watershed is undulating to moderately hilly, influenced by the Satpura hill ranges, with slopes ranging from nearly level areas in valley floors to steep slopes in upland hill sections. However, the majority of the agricultural landscape occurs under gentle to moderately sloping terrain. The geology of the watershed is predominantly composed of Deccan Trap basalt, which forms the major parent material for soil development. Alluvial deposits occur in limited patches along valley bottoms and drainage channels, particularly in areas associated with the Tapi river system and its tributaries. Geomorphologically, the watershed is largely characterized by pediment and pediplain landscapes, which together occupy a major portion of the area. Pediments account for approximately 60% of the watershed, representing gently sloping erosional surfaces developed over basaltic bedrock, while pediplains constitute around 32%, representing relatively level depositional surfaces. The remaining area consists of other geomorphic units such as valley fills, drainage channels, and minor hill slopes. The soils of the watershed are predominantly silty clay loam and silt loam in texture, with localized occurrences of clay loam, loam, silty clay, and clay. These soils are generally well drained and possess moderate moisture retention capacity, although variations in soil depth, texture, and gravel content occur across the landscape due to differences in landform position and parent material.

2.5 Climate

The climate of Nandurbar Taluka is generally dry except during the south-west monsoon season. The cold season extends from December to February and is followed by the hot season from March to May. The south-west monsoon season usually begins in June and continues up to September, while October and early November constitute the post-monsoon period. The area experiences a semi-arid to sub-humid climate typical of the Deccan Plateau region. The climate is largely governed by the southwest monsoon, which contributes the major share of the annual rainfall. The average annual rainfall of the region is around 943 mm, though higher rainfall is observed in the hilly areas associated with the Satpura Range and the western part of the district. Nearly 85 to 90 percent of the total rainfall occurs during the monsoon months from June to September, making agriculture and groundwater recharge largely dependent on seasonal precipitation. The summer months are hot and dry, with maximum temperatures often rising above 40 °C, while winters are relatively mild with cooler night temperatures. Relative humidity remains high during the monsoon season but decreases considerably during the summer months. Overall, the climatic conditions of the area show considerable variability in rainfall and temperature, which significantly influences agricultural activities and water resource availability in the watershed.

2.6 Drainage

The drainage system of Nandurbar Taluka is primarily governed by the basin of the Tapi River, which forms the main river system of the region and flows from east to west across the district. A network of small seasonal streams and nalas originates from the foothill

zones of the Satpura Range and drains towards the Tapi River, carrying surface runoff particularly during the monsoon season. The drainage pattern observed in the area is predominantly semi-dendritic, which is characteristic of regions underlain by the basaltic formations of the Deccan Trap. Most of the streams in the taluka are seasonal in nature and remain dry during the non-monsoon period, flowing mainly in response to rainfall events. These drainage features play an important role in controlling surface runoff, soil erosion processes, and groundwater recharge within the watershed area.

2.7 Cropping Patterns, and Demography and Socioeconomics

2.7.1 Cropping Pattern

The cropping pattern of the Nandurbar cluster is diverse and is heavily influenced by monsoon availability. In areas with light and alkaline soils, crops like bajra (pearl millet), kharif jowar, and groundnuts are predominantly grown, while the highly fertile deep black soils along the Tapi river are extensively utilized for cultivating groundnut, rabi jowar, and wheat. During the Kharif season, the primary crops sown include cotton (especially Bt cotton), paddy, soybean, maize, pearl millet, and sorghum. As the season transitions to rabi, farmers focus on wheat, chickpea, groundnut, and rabi sorghum.

2.7.2 Demographic and Socioeconomic Status

According to the 2011 Census, Nandurbar district is predominantly rural and features a massive tribal majority, with Scheduled Tribes (such as the Pawara and Bhil communities) and Scheduled Castes. Economically, the population is highly dependent on farming; the overall work participation rate is 40.30%, with the vast majority of these workers engaged either directly as cultivators or as agricultural laborers according to the 2011 Census.

2.8 Water Resources

2.8.1 Surface Water

The Nandurbar Taluka cluster is part of the Tapi River basin, which governs the drainage and hydrology of the area. Surface water resources in the cluster include seasonal streams, Dam, small rivers, and minor irrigation canals, totalling approximately 10.1 hectares of canal area as per LULC classification. These canals, along with other small-scale water harvesting structures, help capture and utilize monsoon runoff. However, most of the runoff from rainfall is not fully stored, as these structures have limited capacity and many are in need of maintenance or silt removal. The seasonal streams and minor canals rapidly convey water to the main river channels during the monsoon, with minimal storage for post-monsoon use, highlighting the need for enhanced water conservation measures in the cluster.

2.8.2 Groundwater

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

extractable ground water resources place the region under the “safe” category, with the groundwater extraction level under 52.9%

2.8.3 Irrigation and Water Management

Agriculture in the cluster is predominantly rainfed, with only a small portion of the total cultivable area possessing assured irrigation facilities. Because the local topography is highly undulated, there are no major irrigation projects; instead, groundwater extracted via tens of thousands of private open wells and borewells serves as the primary irrigation source. Modern climate-resilient interventions being adopted include precision micro-irrigation (drip and sprinkler systems), community lift irrigation powered by solar water pumps, and the use of reinforced geo-membrane linings in farm ponds to convert temporary rainwater recharge structures into long-term storage tanks for protective irrigation.

2.9 Constraints

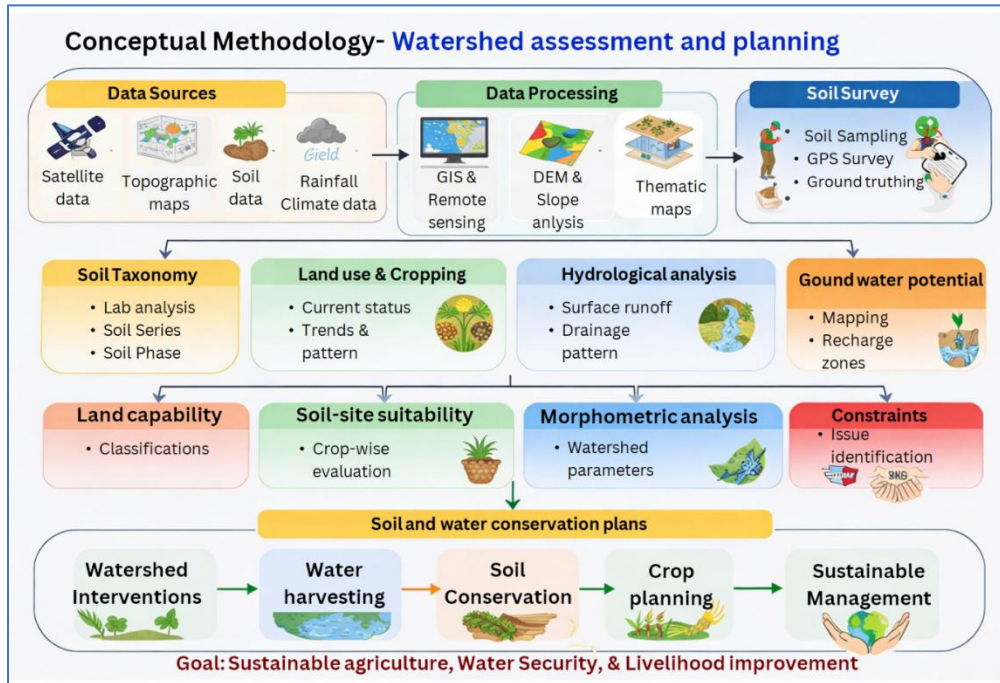
The following key issues were observed in the cluster villages, both through field surveys (2024-2025) and community consultations:

- a. Fast Runoff and Soil Loss: soils lead to erosion, particularly in pediment zones.
- b. Low Irrigation Coverage: Only canal fragments (10.1 ha) exist, offering minimal support to agriculture.

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)] was determined by diethylene triamine penta-acetic acid (DTPA) extraction (Lindsay and Norvell 1978), followed by atomic absorption spectrophotometry. Soils were classified according to Keys to Soil Taxonomy (Soil Survey Staff 2010).

3.5 Development of Soil Mapping Legend

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

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

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

3.6 Surface runoff

Direct surface runoff occurring in the Nandurbar 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 Zones

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 favourable 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 Nandurbar 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 Morphometric Analysis

Morphometric analysis was carried out to understand the drainage characteristics, hydrological behaviour, and terrain dynamics of the Nandurbar watershed, which lies within the northern part of Maharashtra and is influenced by the Satpura hill ranges and associated undulating terrain. These physiographic conditions strongly influence runoff generation, soil erosion processes, and groundwater recharge potential within the watershed. A Digital Elevation Model (DEM) was used as the primary dataset for terrain and drainage analysis. The DEM was processed in a Geographic Information System (GIS) environment to remove spurious depressions (sink filling) and to generate flow direction and flow accumulation grids, which represent the natural movement and concentration of surface runoff across the landscape. Based on a suitable 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, the watershed and sub-watershed boundaries were delineated by identifying outlet points along the major drainage channels. The resulting hydrologically closed units formed the basis for morphometric analysis at different spatial scales. Morphometric parameters were computed using standard equations widely adopted in geomorphological studies (Horton, 1945; Strahler, 1964; Schumm, 1956). These parameters were grouped into linear, areal, and relief aspects to comprehensively evaluate the drainage characteristics and watershed morphology.

Linear parameters such as number of streams, stream length, stream order, bifurcation ratio, channel length, and basin perimeter were calculated from the extracted stream network. These parameters help understand the degree of drainage branching and structural control on drainage development, which are particularly important in the structurally influenced terrain of the Satpura region. 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, infiltration capacity, and runoff potential. These parameters provide insights into how rainfall is converted into runoff and the potential response of the watershed to rainfall events.

Relief parameters such as basin relief, relief ratio, ruggedness number, and Melton ruggedness number were estimated using elevation data derived from the DEM. These indices help assess terrain steepness, landscape dissection, and susceptibility to soil erosion, which are particularly significant in the undulating and hilly landscapes of Nandurbar

district. The morphometric analysis was conducted at both the watershed and sub-watershed scales, as these parameters are governed by natural drainage boundaries rather than administrative limits. The derived morphometric indices were subsequently interpreted to understand runoff generation patterns, erosion susceptibility, and groundwater recharge potential within the watershed system. The results were further used to support soil and water conservation planning, prioritization of treatment areas, and sustainable watershed management strategies for the Nandurbar region.

3.10 Identification of Soil and Water Conservation Measures

The identification and spatial allocation of Soil and Water Conservation (SWC) measures in the Nandurbar watershed were carried out through an integrated land resource and geospatial assessment approach, incorporating terrain characteristics, soil resource information, land use patterns, and hydrological considerations. A comprehensive spatial database was developed using multiple datasets, including high-resolution satellite imagery, Digital Elevation Models (DEM), soil resource maps generated through Land Resource Inventory (LRI), land use/land cover data, and drainage network information. The DEM was used to derive important terrain attributes such as slope classes, flow direction, flow accumulation, and drainage patterns, which are essential for understanding runoff movement, erosion risk, and water harvesting potential within the watershed.

Soil resource information obtained through LRI surveys, including soil depth, texture, drainage characteristics, gravelliness, and soil limitations, was integrated with land use/land cover data to assess land capability and agricultural constraints. This integration enabled identification of areas vulnerable to soil erosion, runoff losses, and moisture stress, which are common challenges in the rainfed farming systems of Nandurbar district. Based on these datasets, terrain analysis and land capability assessment were performed to delineate management units within the watershed. Each management 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 adopted in watershed planning were applied to assign appropriate SWC measures. For instance, field bunding and strengthening of existing bunds were recommended in cultivated lands with gentle slopes and medium to deep soils to reduce runoff and enhance in situ soil moisture conservation. In areas with moderate slopes, contour bunding and graded bunds were proposed to intercept runoff and minimize soil erosion. In steeper slopes and degraded lands, continuous contour trenches, staggered trenches, and vegetative barriers were recommended to stabilize slopes and improve infiltration. The Broad Bed and Furrow (BBF) system was identified as a suitable in-situ moisture conservation practice for medium to deep black soils, where it helps improve surface drainage, reduce waterlogging, and enhance soil moisture distribution under rainfed conditions.

Water harvesting structures were identified based on runoff contributing areas, drainage density, channel characteristics, and storage potential. Farm ponds were proposed

in agricultural fields with adequate catchment areas to store runoff water for supplemental irrigation and livestock use. In locations where seepage losses could be significant, lined farm ponds were recommended. Structural interventions along drainage lines were identified after evaluating channel slope, contributing catchment area, and hydrological suitability. These included cement nala bunds (CNB), earthen nala bunds (ENB), loose boulder structures, and gully plugs, which help reduce flow velocity, control gully erosion, and enhance groundwater recharge. Existing water harvesting structures were also identified through field verification, and renovation and desilting of existing tanks and farm ponds were proposed where required to restore storage capacity.

Vegetative interventions were planned in degraded lands, hill slopes, and drainage margins, where afforestation, agroforestry, pasture development, and stream bank plantations could help stabilize soil and reduce erosion. In suitable upland areas, horticultural plantations supported with soil moisture conservation measures were proposed to improve land productivity and provide livelihood opportunities for local communities. Additional runoff management measures such as rooftop rainwater harvesting in rural habitations, roadside drainage protection works, and vegetative stabilization of embankments were also identified to manage runoff from non-agricultural surfaces.

Through the integration of terrain analysis, soil resource information derived from LRI, land use assessment, and hydrological analysis, site-specific soil and water conservation measures were systematically identified and spatially allocated within the watershed. This scientifically guided approach ensures that the proposed interventions are technically appropriate, hydrologically effective, and aligned with the natural resource conditions of the Nandurbar watershed, thereby supporting sustainable land and water management in the region.

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 seasonal distribution of irrigation sources in the Nandurbar watershed is presented in Table 4.1. During the Kharif season, well irrigation was the most important source, contributing 94.5% of the irrigation. Borewell irrigation contributed 24.00%, while pond irrigation had a contribution of 18.1%. A large cultivated area was under rainfed conditions, where no irrigation was available.

In the Rabi season, wells play an important role in irrigation, contributing 54.5%. Borewell irrigation also showed a significant contribution during this season, with 71.6%. Pond irrigation had a contribution of 22.2% of the total seasonal irrigation.

During the summer season, irrigation was mainly dependent on ponds, which contributed 77.1% irrigation. The results indicate that well and borewell irrigation dominate during the Kharif and Rabi seasons, while pond irrigation serves as an important source of irrigation during the summer season in the Nandurbar watershed.

Table 4.1 Seasonal Distribution of Irrigation Sources in the Nandurbar Watershed

Sr. No.	Number of Farmers Interviewed (n)	Irrigation Source	Seasonal Water Availability	Contribution to Season's Total Irrigation (%)
1	200	Rainfed	Kharif	0.0
2	120	Well	Kharif	94.5
3	66	Well	Rabi	54.5
4	4	Pond	Kharif	18.1
5	11	Pond	Rabi	22.2
6	28	Pond	Summer	77.1
7	25	Borewell	Kharif	24.0
8	56	Borewell	Rabi	71.6

4.1.2 Cropping Pattern

The cropping pattern of the Nandurbar watershed is rainfed, with crops cultivated in kharif and rabi seasons is presented in Table 4.2. The Gross Cropped Area of the Nandurbar watershed was recorded as 632.4 ha, while the Net Sown Area was 475.3 ha. Cropping intensity was calculated using the following formula.

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

$$\text{Cropping intensity}(\%) = \frac{632.4}{475.3} \times 100 = 133.0\%$$

The cropping intensity of the area was calculated as 133.0%, indicating that a portion of the agricultural land is cultivated more than once during the year despite the dominance of rainfed farming.

During the Kharif season, cotton is the dominant crop, occupying 44.2% of the total cropped area with a productivity of 1146 kg/ha, indicating its importance in the agricultural economy. Sorghum has 10.6% of the total cropped area with a productivity of 1209 kg/ha. Maize has 5.8% of the total cropped area with a productivity of 2834 kg/ha, and rice has a total cropped area of 3.4% with a productivity of 1420 kg/ha. Tur (1.8%), soybean (1.2%), and seasonal sugarcane (1.9%) are cultivated on smaller areas.

In the Rabi season, wheat occupies 11.7% of the total cropped area with a productivity of 1932 kg/ha, making it the most important crop in the season. Rabi maize covers 4.43% of the cropped area with a productivity of 2441 kg/ha. Sesamum (2.2%), gram (1.1%), sorghum (0.9%), and moong (0.5%), with productivity of 711 kg/ha, 960 kg/ha, 1065 kg/ha, and 690 kg/ha, respectively.

Sugarcane covers 2.8% of the total cropped area, with a productivity of 31,392 kg/ha. The cropping pattern of the cluster is dominated by Kharif crops under rainfed conditions, while rabi crops contribute to improved land utilization in the Nandurbar watershed.

Table 4.2 Crop-wise Distribution in the Nandurbar watershed

Sr. No.	Season	Crop	No. of Farmers Interviewed (n)	Irrigation Type	Total Cropped Area (%)	Productivity (kg/ha)
1	Kharif	Cotton	275	Rainfed	44.2	1146.0
2	Rabi	Wheat	107	Rainfed	11.7	1932.0
3	Kharif	Sorghum	118	Rainfed	10.6	1209.0
4	Kharif	Maize	49	Rainfed	5.8	2834.0
5	Rabi	Maize	34	Rainfed	4.4	2441.0
6	Kharif	Rice	55	Rainfed	3.4	1420.0
7	Perennial	Sugarcane	13	Rainfed	2.8	31392.0
8	Rabi	Sesamum	25	Rainfed	2.2	711.0
9	Kharif	Tur	40	Rainfed	1.8	628.0
10	Kharif	Soybean	6	Rainfed	1.2	1413.0
11	Rabi	Gram	11	Rainfed	1.1	960.0
12	Rabi	Sorghum	12	Rainfed	0.9	1065.0
13	Rabi	Moong	7	Rainfed	0.5	690.0

4.1.3 Socioeconomic Status

4.1.3.1 Land holding pattern

The landholding pattern of farmers in the Nandurbar watershed is presented in Table 4.3. It was observed that the highest number of farmers were semi-medium farmers (2-4 ha), with 134 respondents (43.9%) having an average landholding of 3.1 ha, which is followed by medium farmers (4-10 ha) with 91 respondents (29.8%) having an average landholding of 6.0 ha.

Small farmer category (1–2 ha) includes 70 respondents (22.9%) with an average landholding of 1.7 ha. A small number of farmers belong to the large farmer category (>10 ha), having 9 respondents (2.9%) with an average landholding of 14.8 ha.

Average landholding in the Nandurbar watershed was found to be 4.0 ha, indicating that agriculture in the area is characterized by semi-medium and medium landholdings. This distribution suggests comparatively larger farm sizes, which facilitate better adoption of improved agricultural practices and investment in irrigation infrastructure.

Table 4.3 Land holding pattern in Nandurbar watershed

Category	Criteria Land (ha)	No. of Farmers Interviewed (n)	Farmers (%)	Average Land Holding (ha)
Marginal Farmers	<1	1	0.3	0.5
Small Farmers	1-2	70	22.9	1.7
Semi-Medium Farmers	2-4	134	43.9	3.1
Medium Farmers	4-10	91	29.8	6.0
Large Farmers	>10	9	2.9	14.8
Average land holding			4.0	

4.1.3.2 Income distribution

The income distribution from different crops in the Nandurbar watershed is presented in the Table 4.4, which indicates the dominance of field crops in the cropping pattern.

Cotton is the major crop cultivated in the Nandurbar watershed, covering 47.5% of the cropped area with an average income of 31,000 Rs, indicating its importance as the primary income-generating crop in the watershed.

Sorghum (Jowar) is the second important crop, with 12.4% of the cropped area. Wheat occupies 12.5% of the cropped area, while maize covers 11.0% of the total cropped area. Sugarcane covers 5.1% of the cropped area, indicating the presence of limited commercial crop cultivation. Rice covers 3.6% of the cropped area, while sesame occupies 2.4%. Arhar (Tur) covering 2.0% of the area.

The cropping pattern of the watershed is largely dominated by cotton and cereal crops, while pulses and oilseeds occupy comparatively smaller areas.

Table 4.4 Average annual income of farmers in Nandurbar watershed.

Name of Crops	No. of Farmers Interviewed (n)	Crop Area (%)	Average Income (Rs.)
Cotton	275	47.5	31000
Sorghum	130	12.4	Not disclosed
Wheat	109	12.5	Not disclosed
Maize	87	11.0	Not disclosed
Rice	56	3.6	Not disclosed
Tur	44	2.0	Not disclosed
Sesamum	28	2.4	Not disclosed
Sugarcane	22	5.1	Not disclosed
Gram	10	1.1	Not disclosed
Black Gram	9	0.5	Not disclosed

4.1.3.3 Education

The educational profile of the population in the villages of the nandurbar watershed is presented in Table 4.5. Kesarpada has the highest illiterate population (33%), followed by Arditara (30%) and Pawle (30%), Nandpur (29%), Mangrul (26%), Waslai (25%), Devpur (24%), and Dhanora (23%) and Isainagar (23%). Lower illiteracy was observed in Bhangda (18%), Kothade (14%), Malpur (10%) and Natawad (10%), while Bhawanipada recorded the lowest illiteracy (9%).

Nandpur has the highest population with primary education (48%), followed by Bhangda (41%), Arditara (25%), Devpur (24%), Isainagar (23%), and Malpur (25%). With respect to secondary education, Kothade has the highest population with secondary education (48%), followed by Bhawanipada (18%), Isainagar (18%), Mangrul (17%) and Malpur (15%), indicating moderate educational attainment.

Higher secondary education shows a higher population in Bhawanipada (55%), followed by Waslai (45%), Mangrul (43%), Natawad (40%) and Kesarpada (30%) and Malpur (30%), indicating better educational progression in these villages.

With respect to higher studies, Natawad village has the highest population (30%), followed by Malpur (20%), Devpur (19%), Bhawanipada (18%), Waslai (15%), and Bhangda (14%), while Nandpur recorded no respondents with higher studies (0%).

The results indicate moderate educational attainment. This educational pattern influences farmers' awareness levels, decision-making ability, and adoption of improved agricultural technologies and extension practices in the watershed area.

Table 4.5 Education profile of villages in Nandurbar watershed by population

Village	No Education (%)	Primary (%)	Secondary (%)	Higher Secondary (%)	Higher Studies (%)
Arditara	30	25	5	30	10
Bhangda	18	41	5	23	14
Bhawanipada	9	0	18	55	18
Devpur	24	24	10	24	19
Dhanora	23	27	7	30	13
Isainagar	23	23	18	27	9
Kesarpada	33	12	12	33	8
Kothade	14	14	48	19	5
Malpur	10	25	15	30	20
Mangrul	26	9	17	43	4
Nandpur	29	48	10	14	0
Natawad	10	15	5	40	30
Pawle	30	30	15	20	5
Waslai	25	5	10	45	15

4.2 Land-use/Land-cover

The Land Use Land Cover (LULC) classification of the area reveals that agriculture is the predominant land use type, occupying 5035.5 hectares, and constitutes approximately 81% of the total area (Table 4.6 and Fig. 4.1). Wastelands represent 11.4% of the area, which indicate land degradation or areas unsuitable for cultivation. Waterbodies are limited to 275 ha, making up 4.4% of the total area, reflecting the presence of limited surface water resources in the region. This LULC distribution highlights the dominance of agricultural activities in the area with secondary coverage by wasteland categories.

Table 4.6 Land-use/land-cover statistics of Nandurbar watershed

Land use	Area(ha)	Percent (%)
Agriculture	5035.5	81.0
Wasteland	711.4	11.4
Habitation	197.3	3.2
Waterbody	275.0	4.4
Total	6219.2	100.0

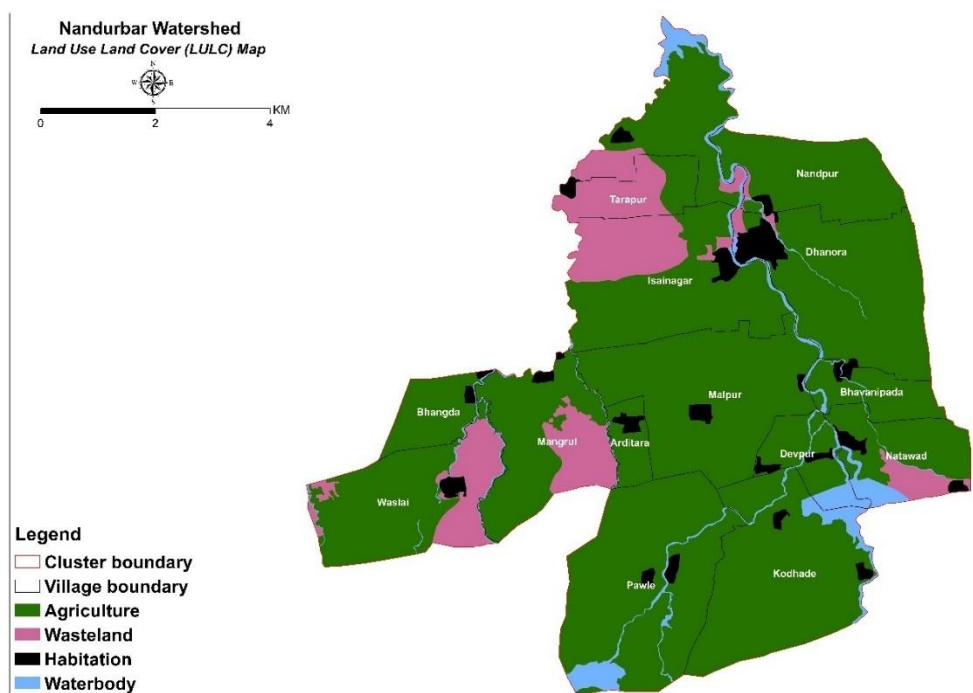


Fig. 4.1: Land-use/land-cover map

4.3 Landform Delineation

The landform analysis of the area indicates a diverse geomorphological setting. Middle Pediment is the most extensive landform (Table 4.7), covering 2343.3 ha, or 37.7% of the total area. The pediplain covers 1981.1 hectares (31.9%), while the Lower pediment, often representing gently sloping rock surfaces, spans 975.1 hectares. Upper Pediment are relatively less extensive (7.2% of the area), signifying steep slopes or breaks in the landscape. Overall, the area is characterized by a prevalence of pediment features, with a mixture of erosional and depositional landforms. The landform map of the watershed is presented in Fig. 4.2.

Table 4.7: Landform features existing in Nandurbar watershed

Landform	Area(ha)	Percent (%)
Upper Pediment	447.3	7.2
Middle Pediment	2343.3	37.7
Lower Pediment	975.1	15.7
Pediplain	1981.1	31.9
Habitation	197.3	3.2
Waterbody	275.0	4.4
Total	6219.2	100.0

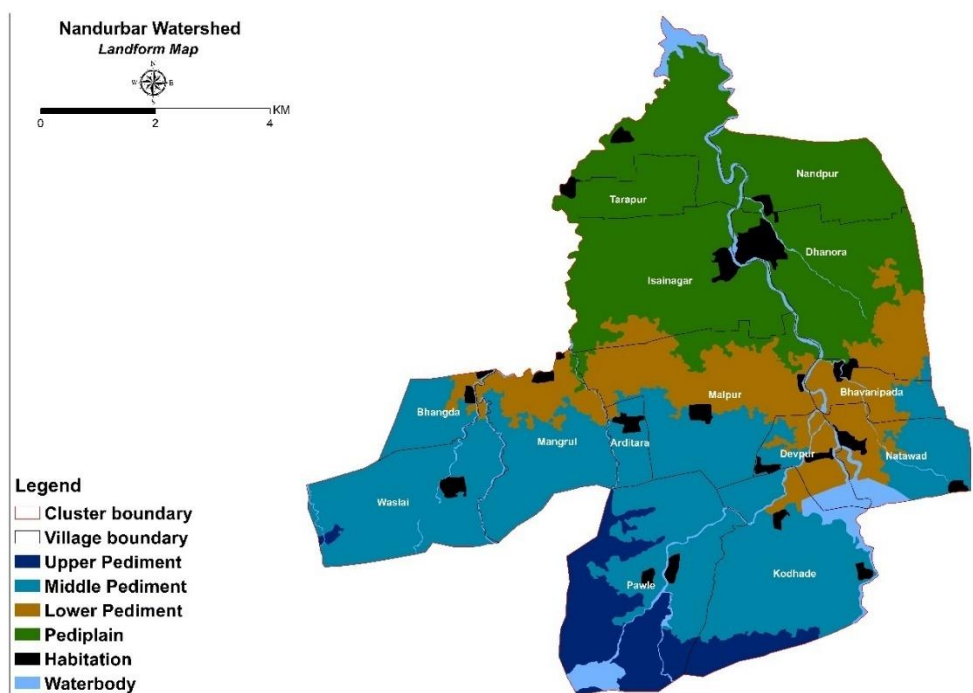


Fig. 4.2: Landform map of Nandurbar watershed

4.4 Soil series and phases

Eight soil series have been identified and mapped with soil mapping units (phases of series) (Fig 4.3). The taxonomic classification and mapping legend of the soil series along with its landform. The detailed descriptions of phase are given in Table 4.8 and Fig. 4.4.

Table 4.8. Dominant soil series identified in the watershed

Sr. No.	Series	Area(ha)	Percent (%)
1	Tarapur	1473.9	23.7
2	Waslai	1150.3	18.5
3	Natwad	1073.1	17.3
4	Pawle	838.1	13.5
5	Kodhade	447.3	7.2
6	Dhanora	397.6	6.4
7	Malpur	321.3	5.2
8	Waterbody	275	4.4
9	Habitation	197.3	3.2
10	Bhangde	45.3	0.7
	Total	6219.2	100

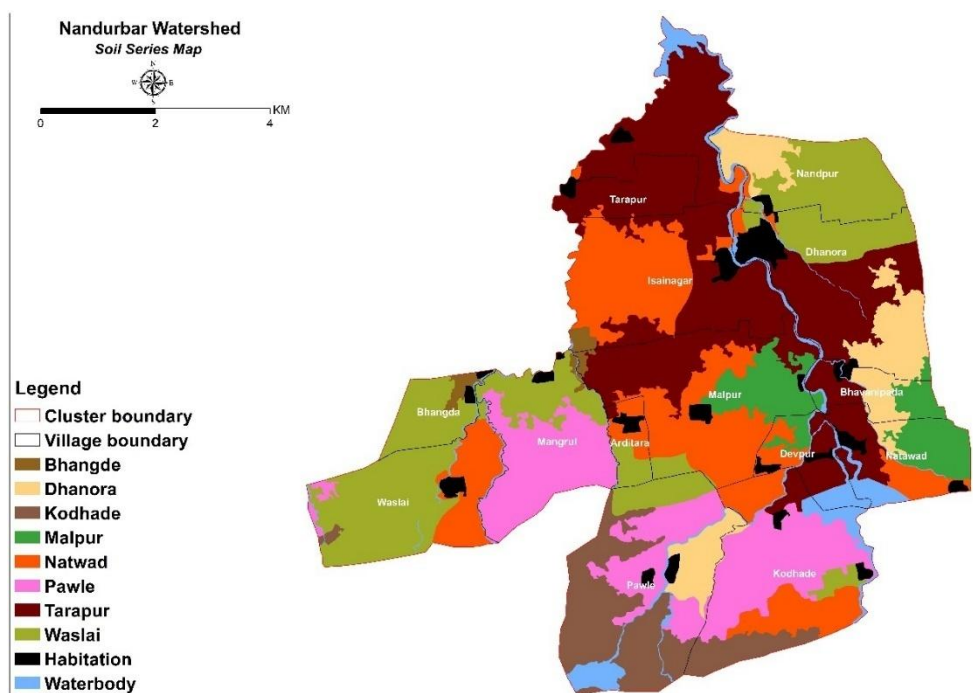


Fig. 4.3: Soil series map of Nandurbar watershed

Table 4.9. Soil phases existing in Nandurbar watershed

Sr. No.	Phase	Area(ha)	Percent (%)
1	Bha1fC2	17.2	0.3
2	BhamB1	28.1	0.5
3	Dha5gB1	213.8	3.4
4	Dha5mB1	86.7	1.4
5	Dha5mC2	97.0	1.6
6	Kod1eD2	327.5	5.3
7	Kod1eD3	119.8	1.9
8	Mal4kB1	152.2	2.4
9	Mal5gC2	169.1	2.7
10	Nat1fB1	51.7	0.8
11	Nat2dB1	107.5	1.7
12	Nat2dB2	229.0	3.7
13	Nat2eB1	136.2	2.2
14	Nat2fB1	61.1	1.0
15	Nat2gB1	368.6	5.9
16	Nat2kD2	119.0	1.9
17	Paw1eB1	316.2	5.1
18	Paw1eD2	184.5	3.0
19	Paw1gC2	137.3	2.2
20	Paw1gD2	200.0	3.2
21	Tar2dC2	91.6	1.5
22	Tar2gB1	575.1	9.2

23	Tar2kB2	182.9	2.9
24	Tar3gB1	274.5	4.4
25	Tar3mA1	349.7	5.6
26	Was3gC1	135.2	2.2
27	Was3kB1	483.4	7.8
28	Was4eB2	129.3	2.1
29	Was5gA1	402.5	6.5
30	Habitation	197.3	3.2
31	Waterbody	275.0	4.4
	Total	6219.2	100.0

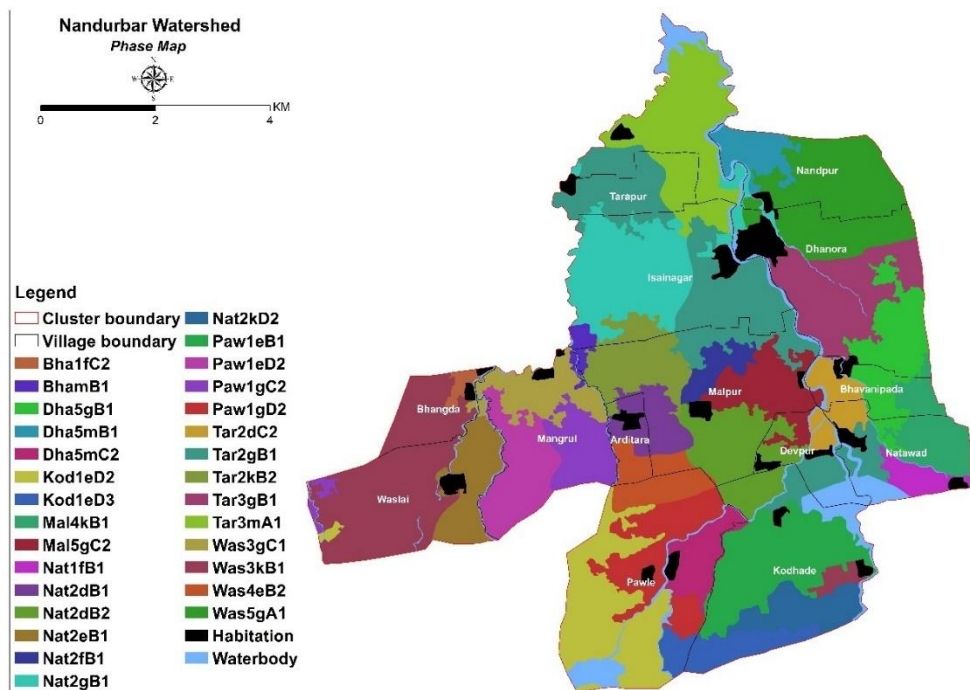


Fig. 4.4: Soil Phase map of Nandurbar watershed

4.5 Soil Survey Interpretation

4.5.1 Slope

Land slope plays a crucial role in agriculture, as it affects water drainage, soil erosion, and the ease with which crops can be cultivated. Gentle slope tends to have higher rates of surface runoff, which can lead to soil erosion and loss of valuable topsoil, reduce soil fertility and compromise crop yields. On the other hand, very gently sloping lands allow for better water retention, easier mechanization, and more efficient irrigation practices, leading to higher productivity. The slope also influences the microclimate of the area, with sloped terrains potentially being more prone to temperature extremes or frost in certain regions. By considering the slope of land, farmers can implement soil conservation techniques, such as terracing, bunding or contour farming, to reduce erosion and optimize land use, ensuring more sustainable agricultural practices. Among the different slope classes (Table 4.10, Fig. 4.5) the maximum area of watershed is under very gently sloping

(1-3%) i.e. 61.1% followed by gently sloping (3-8%) i.e. 61.1%, level to nearly level (0-1%) i.e. 5.6%. The analysis indicates that no steep slope categories are present in the watershed, suggesting that the area is prevalence characterized by gentle terrain, which is favourable for agricultural activities and reduces the risk of severe soil erosion.

Table: 4.10. Land slope classes in Nandurbar watershed

Sr. No.	Slope Class (%)	Area (ha)	TGA (%)
1	Level to nearly level (0 - 1)	349.7	5.6
2	Very gently sloping (1 - 3)	3798.9	61.1
3	Gently sloping (3 - 8)	1598.3	25.7
4	Habitation	197.3	3.2
5	Waterbody	275	4.4

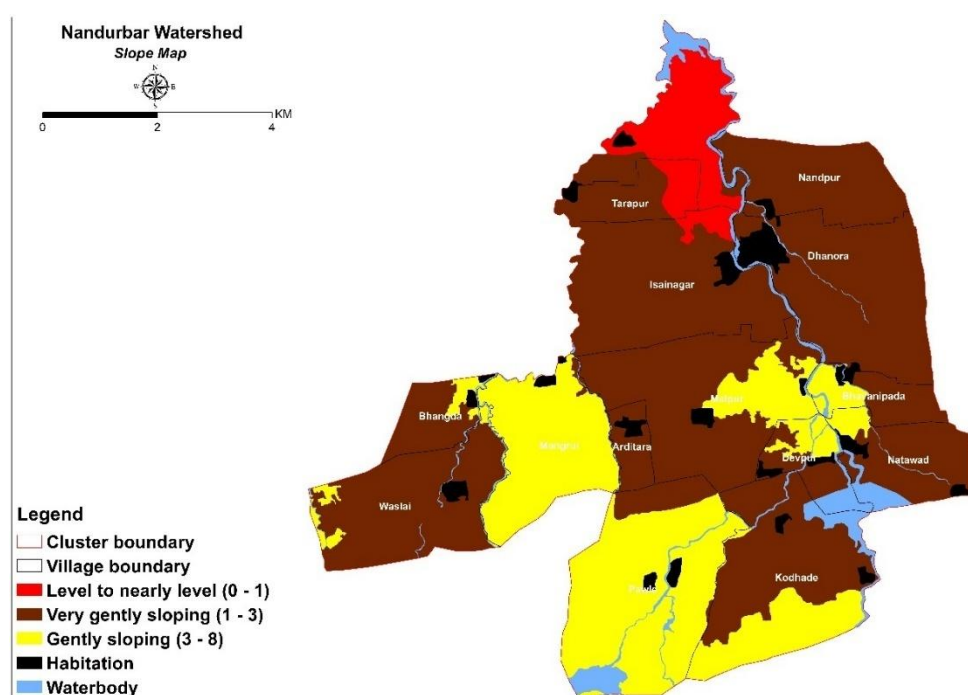


Fig. 4.5: Slope map of Nandurbar watershed

4.5.2 Soil Erosion

Soil erosion, caused by water, wind, or human activity, strips away the nutrient-rich layers of soil, reducing its ability to retain water and support plant roots. This depletion of soil quality can result in decreased agricultural productivity, making crops more vulnerable to drought, nutrient deficiencies, and pests. Additionally, soil erosion can lead to the sedimentation of nearby water bodies, affecting water quality and ecosystems. Reducing soil erosion through crop cover, mulching and residue management, crop rotation, bunding, terracing, etc. helps maintain soil structure and prevent further degradation. As per the watershed area erosion classification levels prevalence varied from non-very low to moderate-severe (Table 4.11), followed by moderate-severe is 119.8 ha (1.9%) indicating high erosion hazard in Nandurbar watershed, moderate 21.7% of the area, which suffers

from moderate erosion (Fig. 4.6), particularly parts of the 68.4% of the watershed is very slow and 0.40% is non-very slow soil erosion.

Table 4.11: Soil erosion status in Nandurbar watershed

Sr. No.	Erosion class	Area (ha)	Percent (%)
1	Very Slight	4277.11	68.77
2	Moderate	1349.95	21.71
3	Severe	119.82	1.93
4	Habitation	197.30	3.17
5	Waterbody	275.03	4.42
	Total	6219.21	100.00

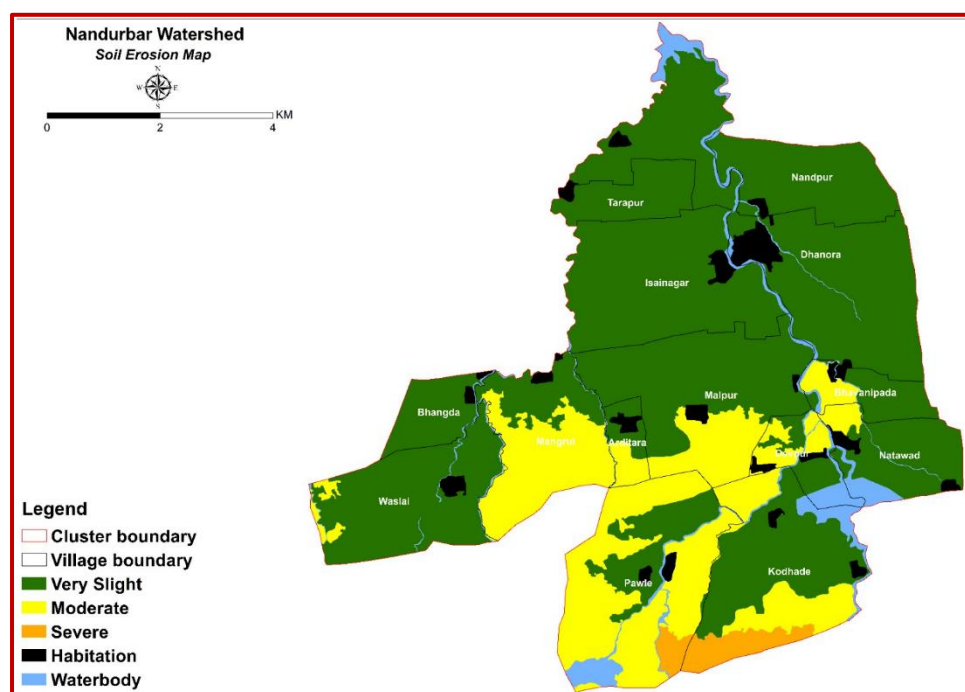


Fig. 4.6: Erosion map of Nandurbar watershed

4.5.3 Soil Depth

Soil depth is a crucial 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 paedogenic processes such as weathering, translocation, erosion-deposition dynamics, and biological activity, all of which are strongly modulated by landscape position and hydrological condition. 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. 4.7) varies from shallow (<25 cm) to very deep (>100 cm). Area wise distribution of the data showed that maximum area was under moderate (30.1%) followed by shallow (22.2%), moderately deep (20%), very deep 15.6% and deep soils (4.5%).

Table 4.12. Soil depth classes in Nandurbar watershed

Sr. No.	Depth Class (cm)	Area (ha)	TGA (%)
1	Shallow (< 25)	1382.4	22.2
2	Moderate (25 - 50)	1871.1	30.1
3	Moderately Deep (50 - 75)	1242.8	20.0
4	Deep (75 - 100)	281.4	4.5
5	Very Deep (> 100)	969.1	15.6
6	Habitation	197.3	3.2
7	Waterbody	275.0	4.4
	Total	6219.2	100.0

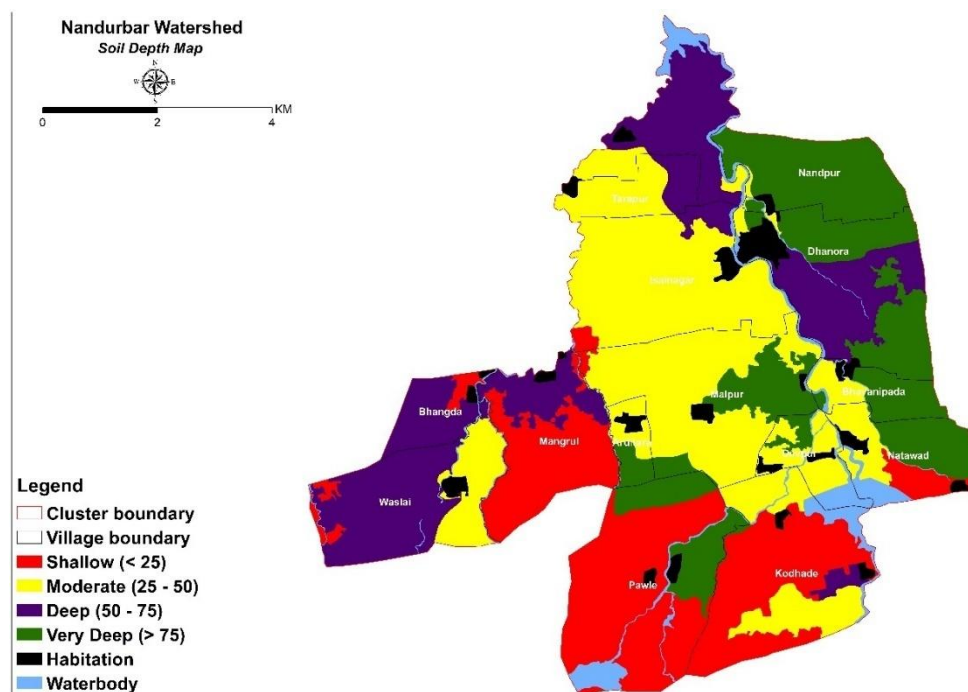


Fig. 4.7: Depth map of Nandurbar watershed

4.5.4 Surface texture

Soil texture plays a vital role in agriculture by directly influencing water retention, root development, and nutrient availability to plants. Soils with a balanced texture, such as loam, provide optimal conditions for plant growth by allowing good water drainage while retaining enough moisture for the roots. Clay soils, though rich in nutrients, can become compacted and poorly drained, while sandy soils may drain too quickly and lack essential

nutrients. Understanding soil texture helps farmers make informed decisions about irrigation practices, crop selection, and the appropriate use of soil amendments. The texture of the watershed area soils was grouped into six classes (Table 4.13, Fig. 4.8). Among the different classes silt clay loam texture was found in 39.8% area followed by silty loam (19.5%), silty clay (15.1%), clay (9%), loam (6.9%) and clay loam (2.1%). Based on the texture, the soils of the watershed particularly the moderately deep to deep soils are expected to be fertile and produce good crops.

Table 4.13. Soil texture distribution in Nandurbar watershed

Sr.No.	Texture	Area (ha)	TGA (%)
1	Clay	561.6	9.0
2	Clay Loam	130.0	2.1
3	Loam	428.1	6.9
4	Silt Loam	1213.5	19.5
5	Silty Clay	937.5	15.1
6	Silty Clay Loam	2476.2	39.8
7	Habitation	197.3	3.2
8	Waterbody	275.0	4.4
	Total	6219.2	100.0

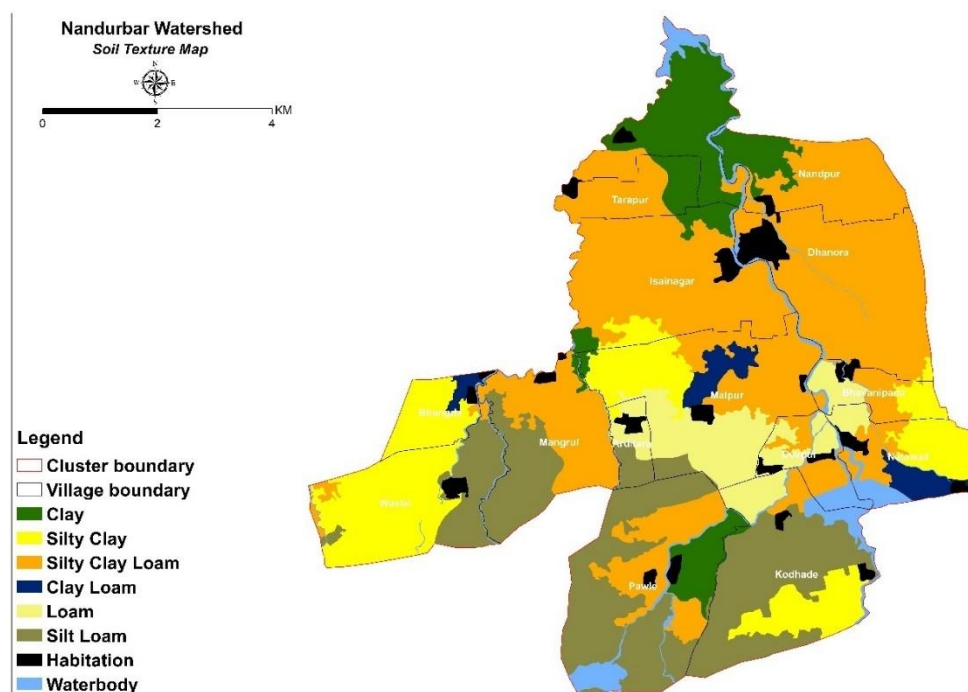


Fig. 4.8: Soil texture map of Nandurbar watershed

4.5.5 Soil reaction

Soil reaction or pH, a measure of acidity or alkalinity, is crucial for plant health and growth because it directly impacts nutrient availability, microbial activity, and overall soil health, influencing crop yields and suitability. The pH value also helps to determine the quantity of various amendments to be added to the soils for ameliorating acidity or alkalinity. Soils of the watershed have been grouped into four soil reaction classes (Table 4.14, Fig. 4.9).

The data revealed that soils in watershed are prevalence Neutral in reaction (pH 6.5 - 7.5) covering an area of about 57% followed by moderately alkaline (pH 8.0 - 9.0), Slightly Alkaline (pH 7.5-8.0) and slightly acidic (pH 6.0-6.5).

Table 4.14. Soil pH distribution in Nandurbar watershed

S. No.	Soil pH	Area (ha)	TGA (%)
1	Slightly Acidic (6.0 - 6.5)	336.4	5.4
2	Neutral (6.5 - 7.5)	3542.9	57.0
3	Slightly Alkaline (7.5 - 8.0)	789.8	12.7
4	Moderately Alkaline (8.0 - 9.0)	1077.7	17.3
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
	Total	6219.2	100.0

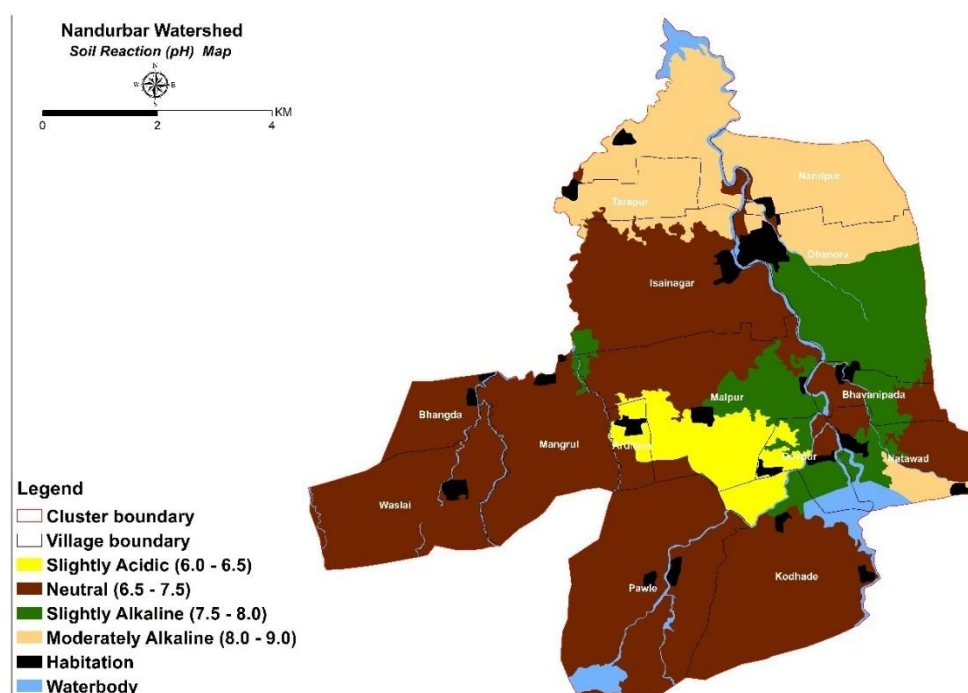


Fig. 4.9: Soil pH map of Nandurbar watershed

4.5.6 Soil salinity

Soil salinity, measured through the electrical conductivity of a solution within a unit distance, represents the content of soluble salts in the matrix. Soil conductivity is an index to measure soil water-soluble salt, which is an important indicator of mineral nutrients in the topsoil that can be quickly utilized by plants and is a factor to determine whether salt ions in soil limit crop growth. The EC of the soils of the watershed were well within the permissible limit of salinity (Table 4.15) and Fig 4.10. The soil salinity status of the watershed (Table 4.10) shows that the majority of the area, 92.4%, falls under the normal salinity class (EC < 1 dS/m), indicating minimal risk of salt-induced crop stress. The predominance of normal soils suggests that salinity is not a major constraint for agricultural activities in the Nandurbar watershed and most areas are suitable for crop cultivation without additional salinity management measures.

Table 4.15. Soil salinity classes in Nandurbar watershed

S. No.	Electrical conductivity (dSm ⁻¹)	Area (ha)	TGA (%)
1	Normal (< 1)	5746.9	92.4
2	Habitation	197.3	3.2
3	Waterbody	275.0	4.4
	Total	6219.2	100.0

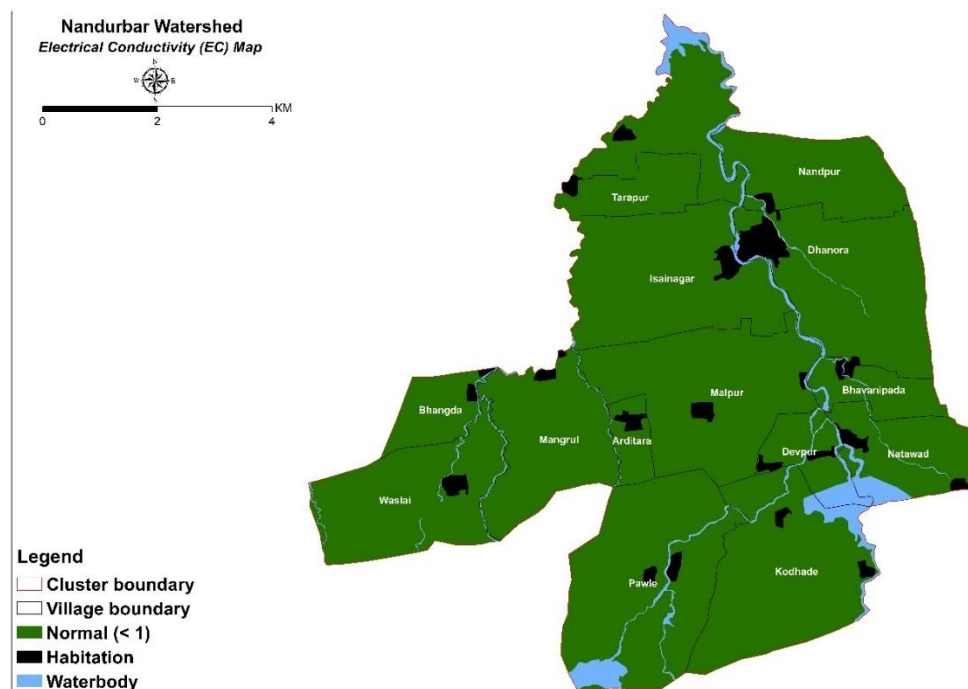


Fig. 4.10: Soil EC map of Nandurbar watershed

4.5.7 Calcium carbonate (CaCO₃) content

The soils of the watershed are generally calcareous in nature with the CaCO₃ content ranging from moderate to very high (>10%). Semi-arid climatic features with low rainfall and high PET favour release of substantial amount of alkali bicarbonates and carbonates into the soil solution, thereby rendering the soils calcareous. As can be inferred from Table 4.16 and Fig. 4.11, a large part of the watershed area (54%) contains more than 10% CaCO₃ in soil, which could pose problems to normal crop growth. Soils with high (5–10%) CaCO₃ occupy 27.4%, while moderately high (2–5%) soils cover 10.5% of the area. Medium (1–2%) calcareous soils account for 0.6% of the watershed.

Table 4.16. Extent of calcareousness in soils of Nandurbar watershed

S. No.	CaCO ₃ content (%)	Area (ha)	TGA (%)
1	Medium (1.0 - 2.0)	34.7	0.6
2	Moderately High (2.0 - 5.0)	651.6	10.5
3	High (5.0 - 10.0)	1703.3	27.4
4	Very High (> 10.0)	3357.3	54.0
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
	Total	6219.2	100.0

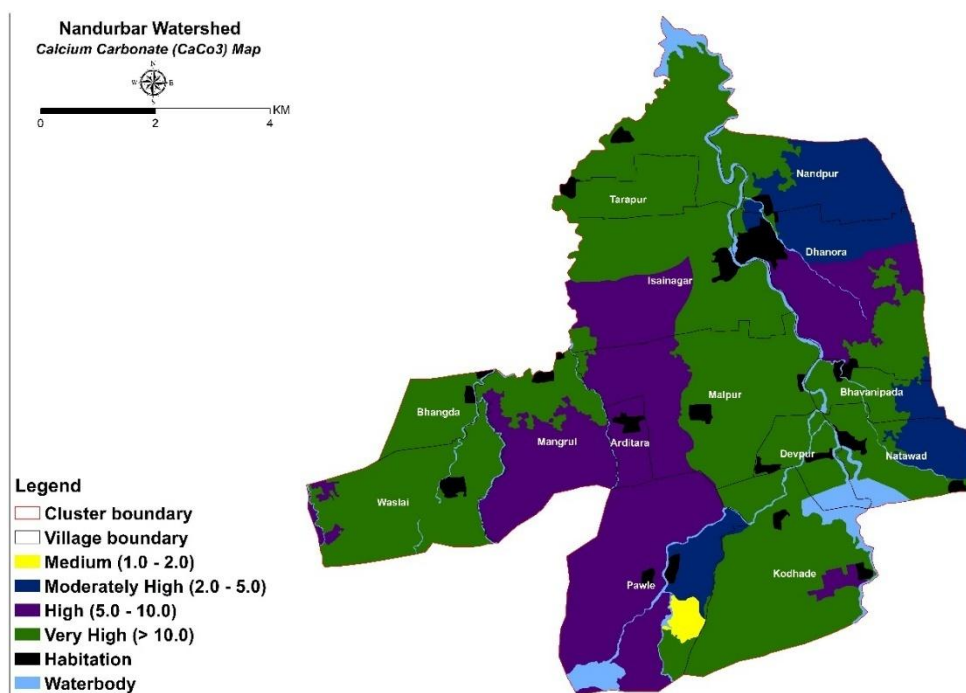


Fig. 4.11: Status of soil calcareousness in Nandurbar watershed

4.5.8 Soil organic carbon

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 Nandurbar watershed supported medium to moderately high SOC content, which can be inferred from Table 4.17 and Fig. 4.12. This is also indicated by the moderate-deep soils and loamy texture prevalent in the watershed. However, maximum area 36% under the high (0.80–1.00%) OC class. This is followed by moderately high (0.61–0.80%) soils at 27% and medium (0.41–0.60%) soils covering 15% of the watershed. Very high (>1.00%) OC soils account for 14% of the area. It is indicated that high and moderately high organic carbon for good fertility in the watershed.

Table 4.17. Soil organic carbon status of Nandurbar watershed

S. No.	Organic carbon (%)	Area (ha)	TGA (%)
1	Medium (0.41 - 0.60)	948	15
2	Moderately High (0.61 - 0.80)	1680	27
3	High (0.80 - 1.00)	2224	36
4	Very High (> 1.00)	895	14
5	Habitation	197	3
6	Waterbody	275	4
	Total	6219	100

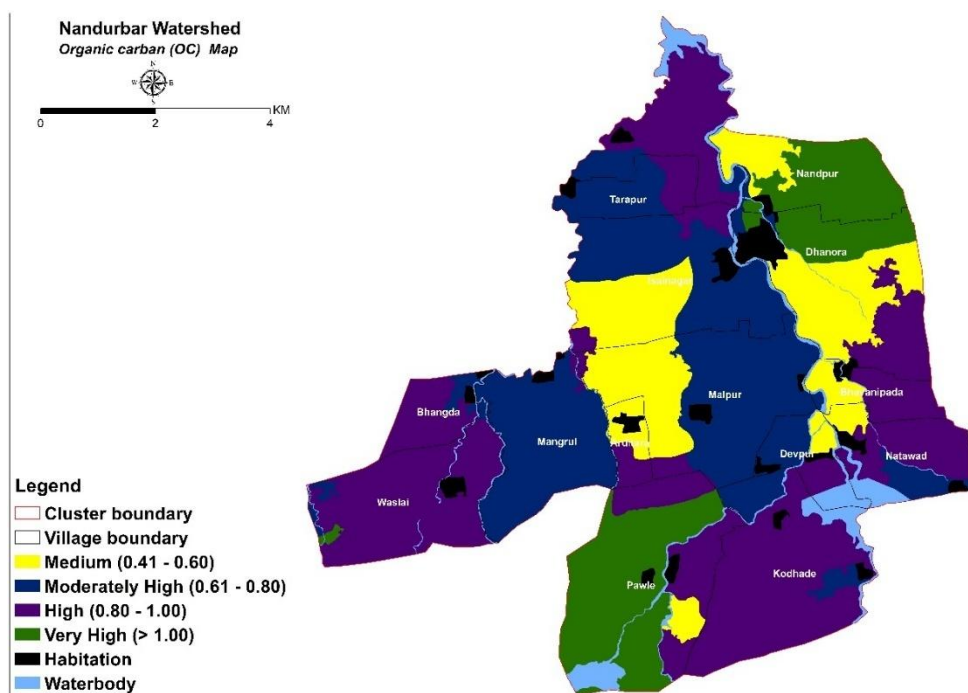


Fig. 4.12: Soil organic carbon map of Nandurbar watershed

4.5.9 Available nitrogen (N)

Available nitrogen content in soils is crucial as it forms the primary building block for plant growth, is essential for producing proteins, amino acids, and chlorophyll to support photosynthesis, plant health and yield. The agricultural soils of watershed are inherently deficient in available N content. As seen from Table 4.18 and Fig. 4.13, more than three-fourths of the watershed area registered low N values (141-280 kg ha⁻¹) whereas in 2.7% area is very low N content (<140 kg ha⁻¹) is a matter of concern. Therefore, it is advocated to apply the nitrogenous fertilizers as per crop needs to maximize crop yields in the watershed area.

Table 4.18: Available N content in soils of Nandurbar watershed

S. No.	Available N (kg ha ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 140)	165.3	2.7
2	Low (141 - 280)	5581.5	89.7
3	Habitation	197.3	3.2
4	Waterbody	275.0	4.4
	Total	6219.2	100.0

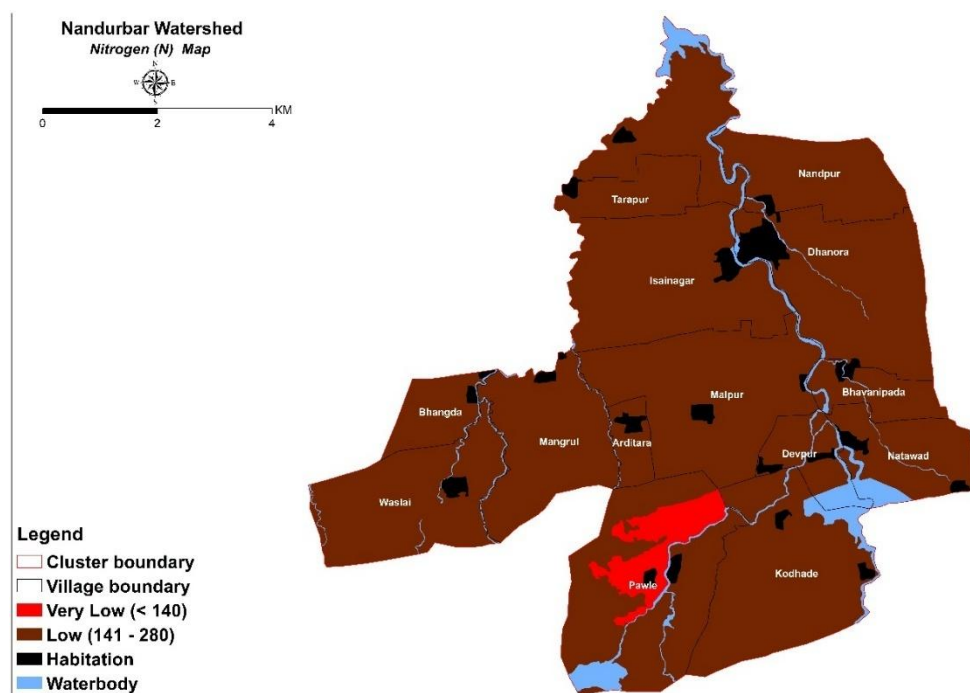


Fig. 4.13: Available soil nitrogen map of Nandurbar watershed

4.5.10 Available Phosphorous (P)

Among the three major nutrients, phosphorus (P) plays an important role to complete the life cycle of a plant; its functions start right from the stimulation of root growth to proper seed filling and seed setting. It also plays a vital role in photosynthesis, carbohydrate breakdown and transfer of energy in the form of ATP and ADP compounds in various metabolic processes. The P content of the agricultural soils of the watershed (Table 4.19, Fig. 4.14) ranged from very low (<15 kg ha⁻¹) to very high (>80 kg ha⁻¹), with the highest area was under very low P status (48.7%) followed by medium (18.5%) and low (14.7%). The vast majority (two-third) of the area under very low to low status points to the fact that the farmers are not adequately applying phosphatic fertilizers to soils, and/or substantial amounts of applied fertilizer P is fixed in the soils owing to their calcareous nature.

Table 4.19: Available P content in soils of Nandurbar watershed.

S. No.	Available P (kg ha ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 15)	3030.0	48.7
2	Low (16 - 30)	916.2	14.7
3	Medium (31 - 50)	1150.9	18.5
4	High (66 - 80)	497.7	8.0
5	Very High (> 80)	152.2	2.4
6	Habitation	197.3	3.2
7	Waterbody	275.0	4.4
	Total	6219.2	100.0

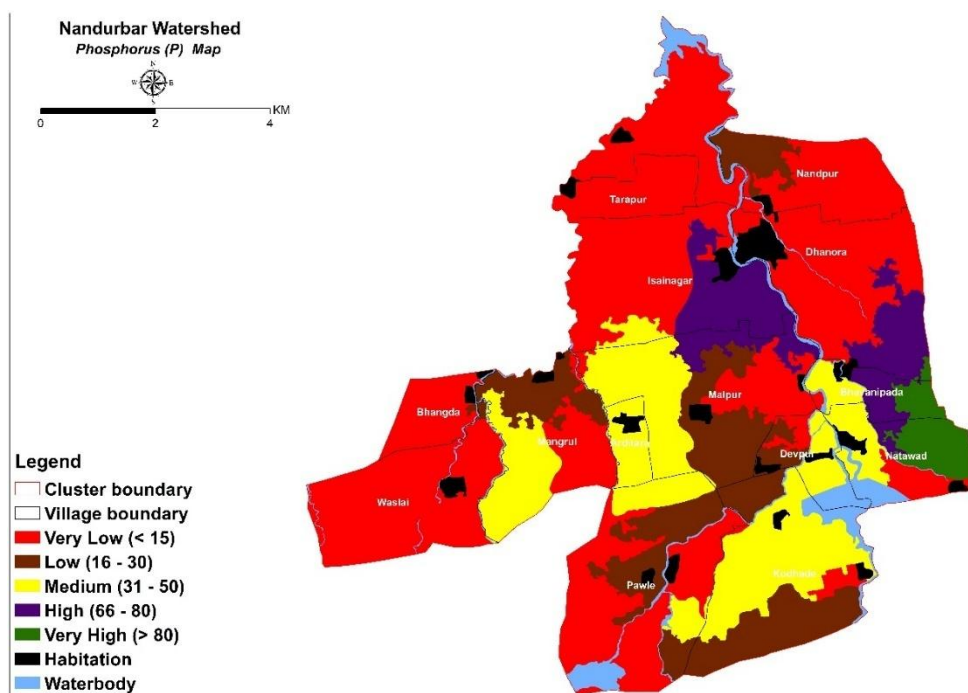


Fig.4.14: Available soil Phosphorus map of Nandurbar watershed

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. Six classes of available K status (Table 4.20, Fig. 4.15) were observed in the watershed soils. Surprisingly, largest area 31.2% under the very high (>360 kg/ha) K class. This is followed by low (121–180 kg/ha) soils covering 23.4% and medium (181–240 kg/ha) soils at 12%. Moderately high (241–300 kg/ha) and high (301–360 kg/ha) K soils account for 9.9% and 7.4%, respectively. Very low (<120 kg/ha) K soils occupy 8.6% of the watershed area. It is indicated that large portions of the watershed have adequate potassium for crop growth, targeted fertilization may be required in areas with low or very low K to optimize agricultural productivity.

Table 4.20: Available K content of soils of Nandurbar watershed

S. No.	Available K (kg ha ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 120)	533.8	8.6
2	Low (121 - 180)	1453.3	23.4
3	Medium (181 - 240)	744.4	12.0
4	Moderately High (241 - 300)	614.8	9.9
5	High (301 - 360)	458.5	7.4
6	Very High (> 360)	1942.0	31.2
7	Habitation	197.3	3.2
8	Waterbody	275.0	4.4
	Total	6219.2	100.0

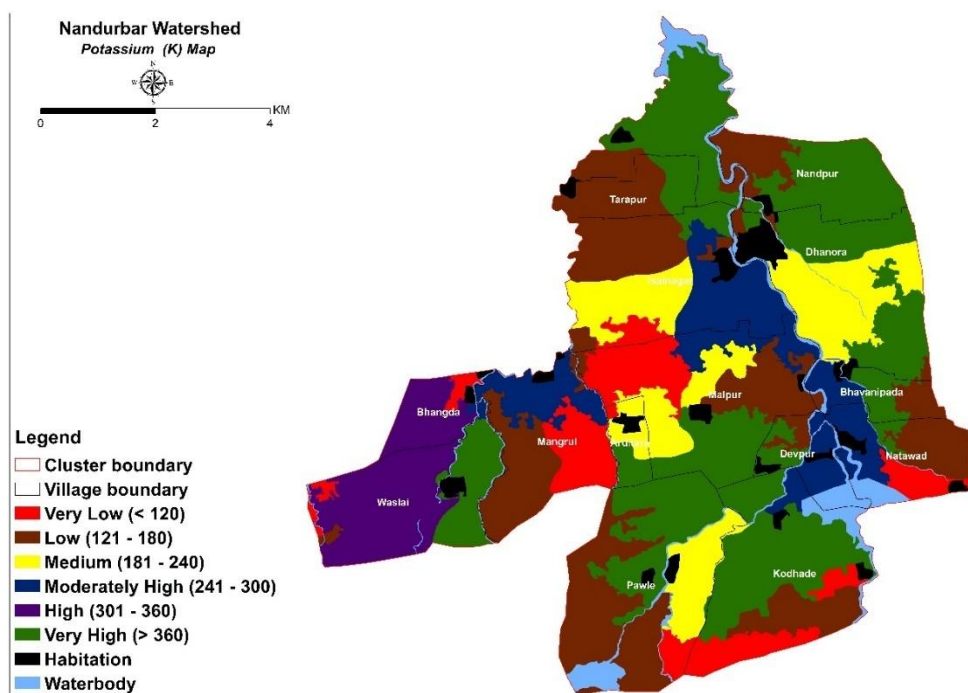


Fig. 4.15: Available soil Potassium map of Nandurbar watershed

4.5.12 Micronutrient status of soils

Micronutrients are involved in vital plant processes like photosynthesis, enzyme activation, and nitrogen fixation. Deficiencies in any of these micronutrients can lead to poor plant development, reduced yields, and lower quality crops. Proper micronutrient management is particularly important in maintaining soil fertility by optimizing the efficiency of fertilizers. Five classes of available Fe were found in the watershed. Table 4.21 and Fig. 4.16 indicates that about 80% of the watershed area is very high Fe. Followed 6.5% is very low and 5.6% moderately high calling for immediate attention in terms of its soil or foliar application through different fertilizer products. On the other hand, about a quarter of the watershed area was categorized as very high (>10.5 mg kg⁻¹) in DTPA-extractable Fe. Approximately 10% of the watershed was found to be deficient in plant-available Mn content, while the majority of the area is adequately supplied with Mn (Table 4.22, Fig. 4.17). Soils of the entire watershed are sufficient with respect to DTPA-extractable Cu (Table 4.23, Fig. 4.18), whereas more than 65% of the soils exhibit deficiency in available Zn (Table 4.24, Fig. 4.19), necessitating external Zn fertilization by the farmers.

Table 4.21: Available Fe content in the soils of Nandurbar watershed

S. No.	Available Fe (mg kg ⁻¹)	Area (ha)	TGA (%)
1	Very Low (< 2.5)	402.5	6.5
2	Moderately High (6.5 - 8.5)	349.7	5.6
3	Very High (> 10.5)	4994.7	80.3
4	Habitation	197.3	3.2
5	Waterbody	275.0	4.4
	Total	6219.2	100.0

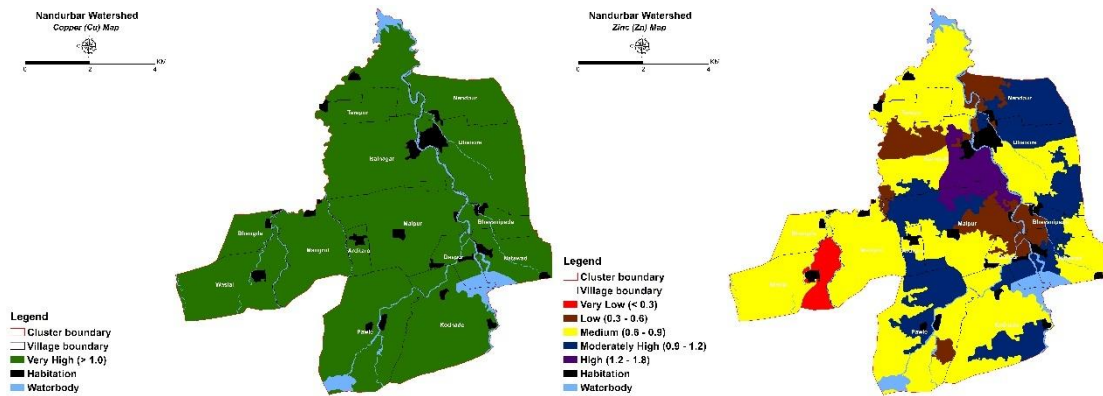


Fig. 4.18: DTPA-extractable soil Cu map of Nandurbar watershed

Fig. 4.19: DTPA-extractable soil Zn map of Nandurbar watershed

4.6 Surface Runoff

Surface runoff plays a critical role in shaping the hydrology and water availability of any watershed, including Nandurbar Taluka villages cluster watershed of Nandurbar district. Although the region receives an average annual rainfall of 942.5 mm over the period 2014 to 2024, the hydrological response across the landscape is highly variable. Water scarcity is not observed across the entire area. Many regions and settlements near rivers and streams often have adequate water for domestic and agricultural needs due to localized recharge and surface water access. However, some zones face frequent challenges such as:

- Seasonal drying of local sources post-monsoon
- Topsoil erosion during high-intensity rain events
- Rapid drainage from unbunded, degraded slopes

These conditions necessitate a detailed evaluation of runoff to understand how much rainfall is lost as direct surface flow and to identify opportunities for effective water conservation measures.

The primary aim of this study was to estimate the seasonal and annual runoff potential for 2014–2024 using the SCS-Curve Number (CN) method, incorporating actual rainfall, verified land use, and soil data. This analysis is crucial for quantifying the difference between rainfall received and water retained, which informs the planning of water harvesting and recharge structures.

Daily rainfall records were collected from IMD, and field surveys were conducted to verify local land use and soil characteristics. Runoff was calculated for each monsoon season using the CN method, considering antecedent moisture conditions based on rainfall distribution patterns.

Runoff was generally highest in July and August, coinciding with intense rainfall periods. Local water retention structures, crop management practices, and banded fields reduce immediate surface flow, allowing a portion of rainfall to infiltrate into the soil.

Therefore, the estimated runoff represents potential runoff, highlighting areas where water losses are highest and where conservation interventions would be most effective.

Table 4.25 Details of Monthly (June-Oct) runoff (mm) for the period 2014-2024

Year/Month	June		July		Aug		Sept		Oct	
	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)
2014	14.6	0.0	297.3	85.5	187.5	28.4	110.2	9.2	18.4	0.0
2015	158.3	11.7	311.1	145.3	40.7	0.0	319.5	164.4	0.7	0.0
2016	63.0	0.4	234.0	30.9	256.1	54.5	155.4	7.1	44.6	0.0
2017	137.8	5.1	368.1	93.9	139.4	0.8	96.4	9.2	16.8	0.0
2018	145.0	18.2	239.0	32.1	195.6	43.0	47.9	0.0	0.0	0.0
2019	82.1	1.4	443.5	154.9	612.3	367.8	225.3	22.4	24.8	0.0
2020	213.1	16.7	199.8	22.2	507.8	198.8	184.6	33.9	10.5	0.0
2021	59.8	0.0	163.3	25.5	100.9	4.0	366.6	92.7	16.8	3.1
2022	58.3	0.0	441.7	149.3	268.7	86.7	152.0	23.4	85.2	1.1
2023	119.0	42.2	327.6	85.2	70.1	0.0	291.3	99.7	0.0	0.0
2024	172.3	30.8	360.2	88.4	483.7	238.2	234.7	48.1	72.1	1.1
Average	111.2	11.5	307.8	83.0	260.3	92.9	198.5	46.4	26.4	0.5

As shown in Table 4.25, the analysis of surface runoff in Nandurbar Taluka reveals important patterns regarding rainfall distribution and water loss. Monthly runoff data from June to October over the period 2014–2024 indicate that runoff is consistently highest in July and August, reflecting the peak monsoon period when rainfall intensity is greatest. On average, July records a runoff of 83 mm, while August averages 92.9 mm. In contrast, runoff in June and October is minimal, averaging 11.5 mm and 0.5 mm respectively, as early monsoon rains are largely absorbed by dry soils and late monsoon rains are lower in volume. The inter-annual variability in runoff is significant, with certain years such as 2019 experiencing very high runoff in August of 367.8 mm due to heavy rainfall events, whereas years like 2016 and 2017 show much lower runoff corresponding to relatively moderate rainfall. This demonstrates that runoff is concentrated in a few months and is highly sensitive to rainfall intensity.

The relationship between annual rainfall and runoff further illustrates the hydrological characteristics of the taluka. The average annual rainfall for the cluster is 942.5 mm, of which approximately 240.2 mm, or 25.5 percent, is lost as surface runoff. Some years, such as 2015 and 2019, exhibit higher runoff percentages of 37.6 and 39.0 percent respectively, reflecting the occurrence of intense rainfall events, whereas other years, including 2016 and 2017, show lower runoff percentages of 12.3 and 13.9 percent due to more evenly distributed rainfall. These results indicate that while the taluka receives moderate rainfall, a notable portion of it is lost as runoff, particularly during short, intense rainfall episodes. Understanding these patterns is critical for planning water conservation and watershed management interventions, as the data highlight the periods and locations where runoff is most significant and where storage or infiltration structures could be most effective in improving water availability.

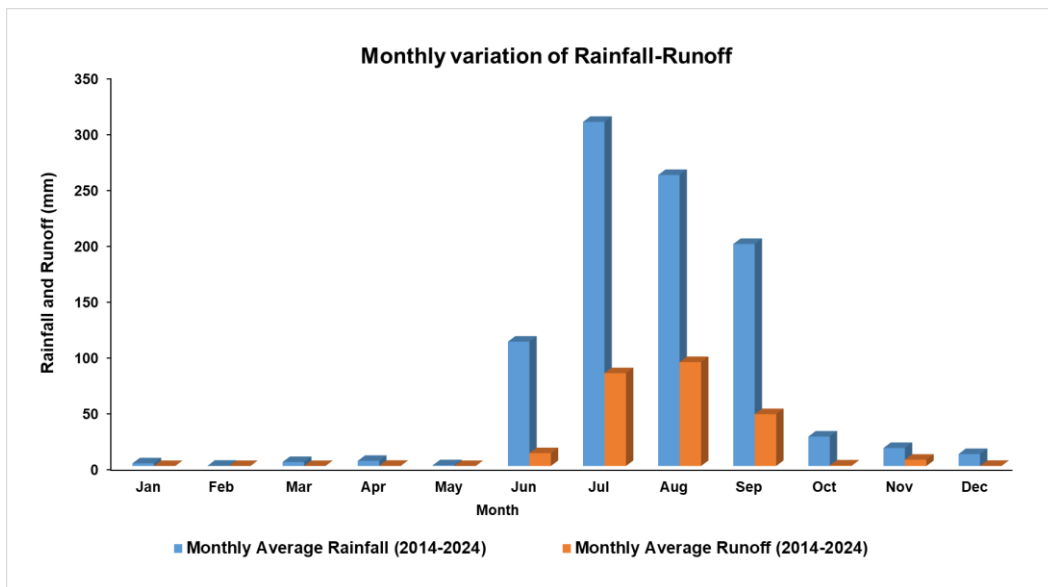


Fig 4.20: Monthly variation of rainfall-runoff in Nandurbar watershed

Table 4.26. Relationship between rainfall and runoff

Year	Rainfall (mm)	Runoff (mm)	No. of Runoff Events	Runoff (%)
2014	650.5	123.1	17	18.9
2015	855.9	321.4	16	37.6
2016	753.8	92.9	13	12.3
2017	785.8	109.1	22	13.9
2018	627.5	93.3	17	14.9
2019	1402.3	546.5	31	39.0
2020	1174.2	272.7	37	23.2
2021	777.2	125.5	19	16.1
2022	1006.6	260.3	24	25.9
2023	1007.6	290.6	21	28.8
2024	1326.2	406.5	38	30.7
Average	942.5	240.2	23.2	25.5

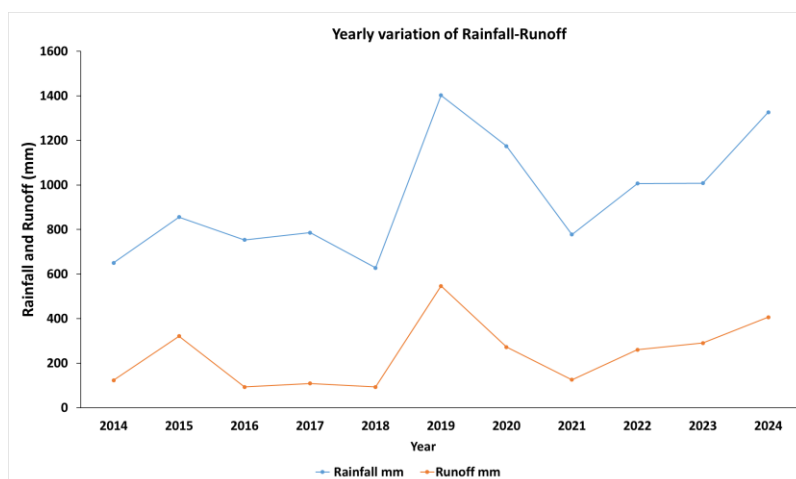


Fig 4.21: Yearly variation of rainfall-runoff in Nandurbar watershed

4.7 Mapping of Groundwater Potential Zones

Groundwater Potential Zonation (GWPZ) is a crucial step in understanding the spatial distribution of groundwater resources within the Nandurbar Taluka cluster watershed. It enables the identification of areas where groundwater recharge is naturally high, moderate, or limited. This analysis supports the planning of water conservation structures, optimizes groundwater extraction, and reduces dependence on surface water during non-monsoon months. By delineating potential zones, planners and local authorities can prioritize interventions to enhance water availability for domestic, agricultural, and livestock use. The results of the GWPZ analysis also provide insights into areas prone to water stress, allowing targeted groundwater recharge measures where they are most needed.

To address these challenges, a comprehensive Groundwater Potential Zonation map was developed for the 14-village cluster watershed within Nandurbar Taluka. The detailed Groundwater Potential Zonation map that classifies the cluster watershed into five categories: Very Good, Good, Moderate, Poor, and Very Poor groundwater potential zones. This classification provides a clear spatial understanding of areas with varying groundwater recharge potential and availability.

The result shows a clear spatial variation in groundwater availability across the cluster watershed. Very good groundwater potential zones, covering about 3.2% of the total area, are predominantly confined to river courses and areas adjoining major water bodies, reflecting strong riverine recharge influence. Good groundwater potential zones cover nearly 21.6% of the watershed and occur at a short distance from these water bodies, suggesting transitional zones that may be influenced by lateral seepage. Moderate groundwater potential zones constitute the largest share of the watershed, occupying about 36.6% of the area and are widely distributed across the central parts. Poor groundwater potential zones account for approximately 30.9% of the watershed and are mainly located away from river channels, particularly in the southern and western regions. Very poor groundwater potential zones cover around 7.7% of the area and are scattered in zones with minimal surface water influence. These five groundwater potential classes represent relative conditions within the watershed based on integrated thematic layers, rather than precise or universally applicable groundwater availability. Overall, the spatial pattern clearly indicates improved groundwater potential in river and waterbody-influenced areas, while regions distant from these features are dominated by moderate to poor groundwater conditions.

The delineation of groundwater potential zones provides critical spatial insights that can enhance watershed management strategies under the Pradhan Mantri Krishi Sinchayee Yojana Watershed Development Component 2.0 (PMKSY-WDC 2.0). This information supports data-driven decision-making for the design and implementation of groundwater recharge structures, soil moisture conservation techniques, and land treatment measures. It also aids in identifying priority micro-watersheds requiring urgent conservation efforts to improve groundwater availability. Moreover, the map highlights areas where alternative water supply strategies may be necessary due to poor groundwater potential.

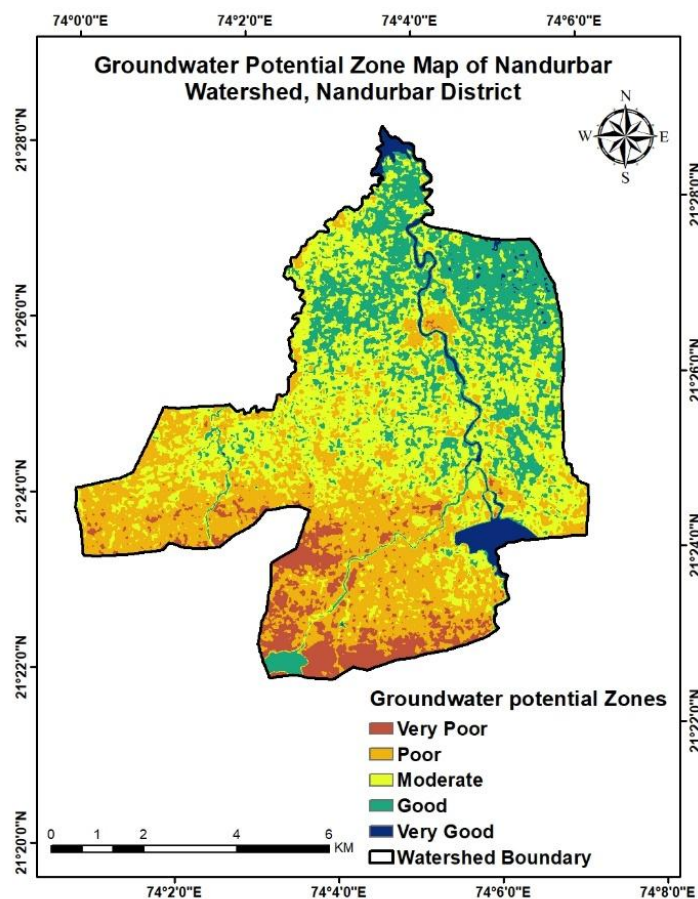


Fig. 4.22. Ground water potential zones in Nandurbar watershed

4.8 Evaluation of Soil-Site Suitability for Crops

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

The suitability of soils for crop cultivation was determined based on the criteria proposed by Naidu et al. (2006). The concept of land utilization types and the classification system for land evaluation categorizes land into different hierarchical levels, namely orders, classes, sub-classes, and units. Two major orders are recognized: ‘S’ (Suitable) and ‘N’ (Not suitable), representing the general suitability status of land. Under the suitable order (S), three classes S1, S2, and S3 indicate high, moderate, and marginal suitability, respectively, while the not suitable order (N) includes two classes N1 and N2 representing current and permanent unsuitability. The assignment of these classes is based on the degree of land limitations affecting crop production.

The major land limitations considered in this evaluation exercise include those

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

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

4.8.1 Soil-Site Suitability for Rice Cultivation

The soils of the watershed were evaluated for rice cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.27. The results indicate that only 152.2ha (2.5%) of the watershed area TGA provides favourable soil and site conditions for optimal crop growth and is highly suitable (S1) for rice. The moderately suitable (S2) category covers 2341.2ha, wherein minor soil and environmental constraints may reduce crop productivity. Around one-third of the watershed was found to be marginally suitable (S3) for the crop, reflecting moderate to severe limitations related to soil and terrain parameters that may restrict yield potential unless appropriate agronomic management practices are adopted.

About 22.2% of the watershed area is not suitable (N) for rice cultivation due to severe soil and site constraints. Therefore, it is suggested that nearly one-third of the watershed may be put under rice cultivation, and in marginally suitable areas.

Table 4.27 Area under suitability sub-classes for Rice cultivation

S. No.	Rice	Area (ha)	Percent (%)
1	Highly Suitable (S1)	152.2	2.5
2	Moderately Suitable (S2)	2341.2	37.6
3	Marginally Suitable (S3)	1871.1	30.1
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
Total		6219.2	100

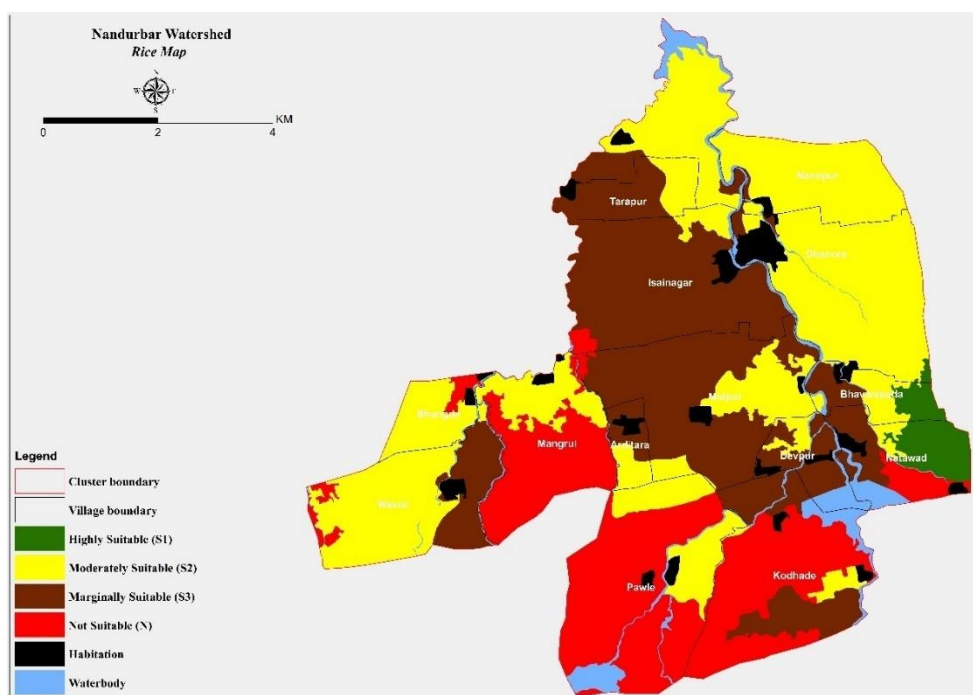


Fig. 4.23 Soil site suitability map for Rice cultivation

4.8.2 Soil-Site Suitability for Wheat Cultivation

The suitability for wheat cultivation across the watershed presented (Table 4.28, Fig. 4.24). Areas covering 764.9 (12.30%), 2303.7 (37.0%) and 1295.9 (20.8%) ha have been classified under highly suitable (S1), moderately suitable (S2) and marginally suitable (S3) categories, respectively. 1382.4 ha (22.2%) of the area is classified as not suitable (N) for wheat cultivation due to severe soil and environmental limitations.

Table 4.28 Area under suitability sub-classes for Wheat cultivation

S. No.	Wheat	Area (ha)	Percent (%)
1	Highly Suitable (S1)	764.9	12.3
2	Moderately Suitable (S2)	2303.7	37.0
3	Marginally Suitable (S3)	1295.9	20.8
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
Total		6219.2	100

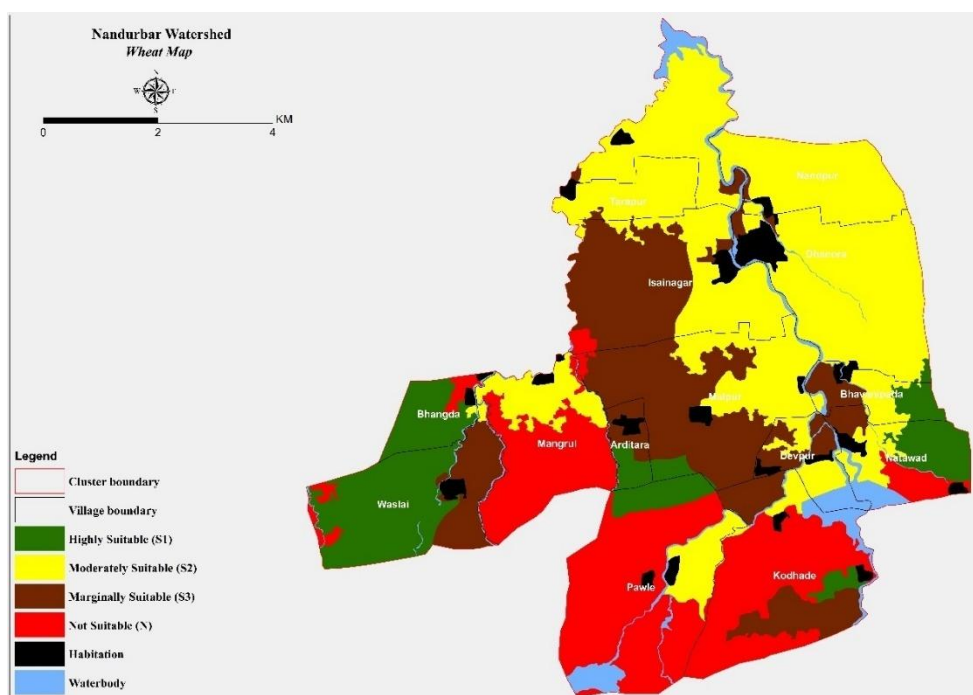


Fig. 4.24 Soil site suitability map for Wheat cultivation

4.8.3 Area under suitability sub-classes for Maize Cultivation

129.3 ha (2.1%) of the watershed area was found to be highly suitable (S1) and 38.0% area was moderately (S2) suitable for maize, providing optimal and/or manageable conditions for crop growth and productivity. Almost one-third of the watershed can only marginally suitable maize crop, indicating moderate to severe soil, terrain and environmental constraints limiting crop productivity. 1382.4 ha (22.2%) of the area is unsuitable for the crop (Table 4.29) (Fig 4.25).

Table 4.29 Area under suitability sub-classes for Maize cultivation

S.No.	Maize	Area (ha)	Percent (%)
1	Highly Suitable (S1)	129.3	2.1
2	Moderately Suitable (S2)	2364.1	38.0
3	Marginally Suitable (S3)	1871.1	30.1
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
Total		6219.2	100

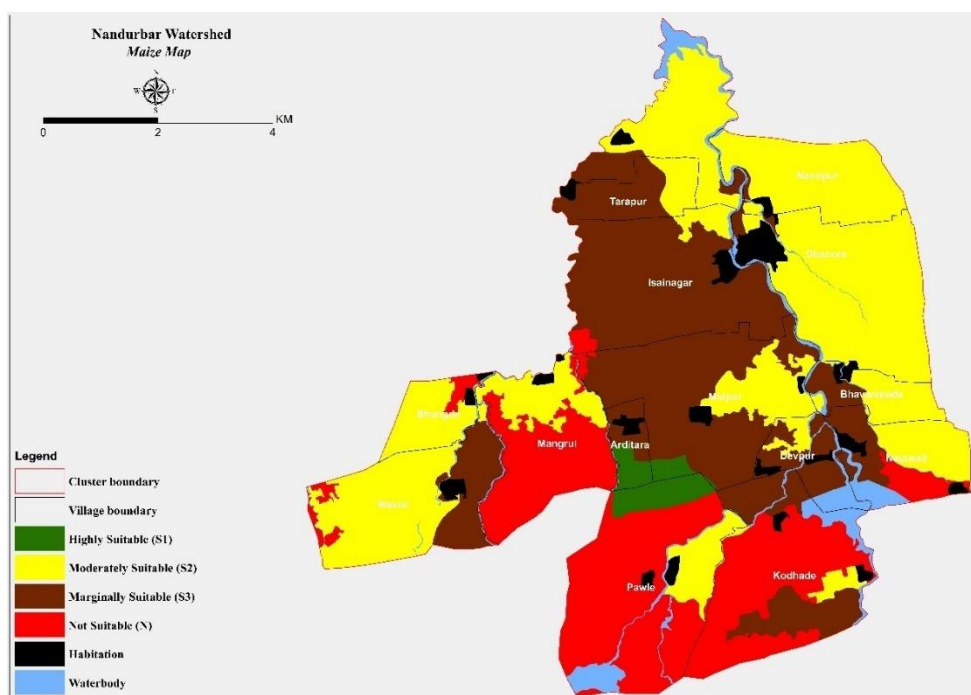


Fig. 4.25 Soil site suitability map for Maize cultivation

4.8.4 Soil-Site Suitability for Sorghum (Jowar) Cultivation

The soils of the watershed were evaluated for sorghum cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.30 and Fig 4.26. The results indicate that about 994.7ha (16%) of the watershed area TGA) provides favorable soil and site conditions for optimal crop growth and is highly suitable (S1) for sorghum. The moderately suitable (S2) category covers 1498.7 ha (24.1%), wherein minor soil and environmental constraints may reduce crop productivity. Around One-third of the watershed was found to be marginally suitable (S3) for the crop, reflecting moderate to severe limitations related to soil and terrain parameters that may restrict yield potential unless appropriate agronomic management practices are adopted.

22.2% of the watershed area is not suitable (N) for sorghum cultivation due to severe soil and site constraints. Therefore, it is suggested that nearly one-fourth of the watershed may be put under sorghum cultivation, and in marginally suitable areas, appropriate agronomic and soil and water management interventions may be adopted.

Table 4.30 Area under different suitability sub-classes for Sorghum cultivation

S. No.	Jowar	Area (ha)	Percent (%)
1	Highly Suitable (S1)	994.7	16.0
2	Moderately Suitable (S2)	1498.7	24.1
3	Marginally Suitable (S3)	1871.1	30.1
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
Total		6219.2	100

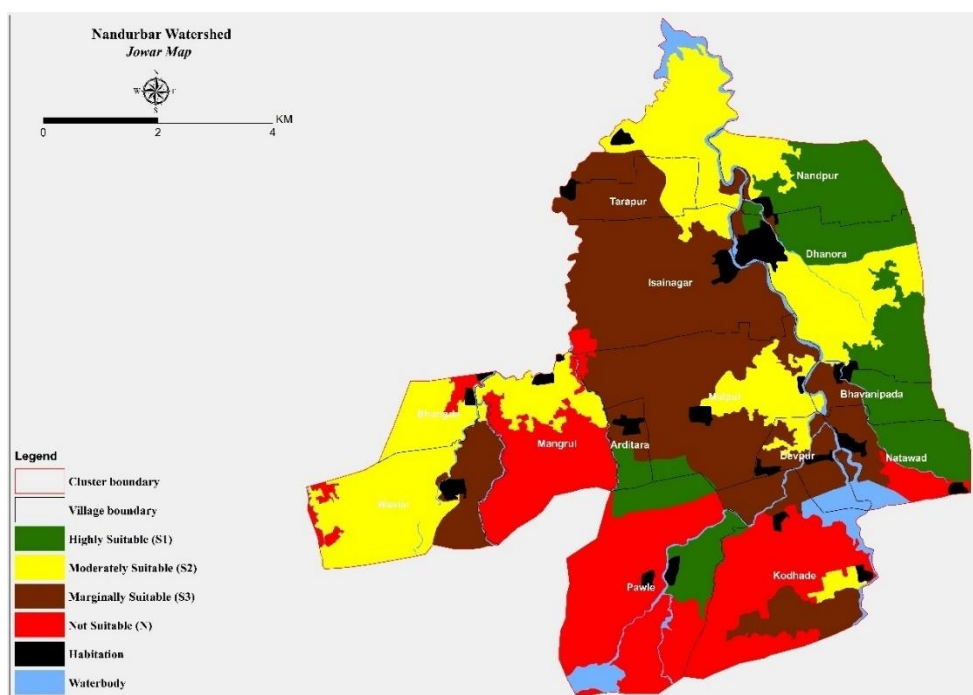


Fig. 4.26 Soil site suitability map for Sorghum (Jowar) cultivation

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

The spatial distribution of suitability classes in respect of pearl millet is presented in Table 4.31 and Fig. 4.27. Areas identified as highly suitable (S1) extend over 768.5 ha, constituting 12.4% of the total geographical area, indicating favourable soil and environmental conditions for pearl millet production. Pearl millet could be cultivated in about 25.5% (1584.4 ha) of the watershed area is moderately suitable(S2) category and 32.3% of the watershed area (2011.6 ha) with manageable limitations, as these areas provide relatively stable conditions for crop establishment and growth. 22.2% of the total geographical area (TGA) is classified as not suitable (N) for pearl millet cultivation, covering 1382.4 ha of the watershed. About, suggesting that pearl millet could be cultivated with caution in major portions of the watershed by following recommended management practices.

Table 4.31 Area under suitability sub-classes for Pearl millet (Bajra) cultivation

S. No.	Bajra	Area (ha)	Percent (%)
1	Highly Suitable (S1)	768.5	12.4
2	Moderately Suitable (S2)	1584.4	25.5
3	Marginally Suitable (S3)	2011.6	32.3
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
	Total	6219.2	100.0

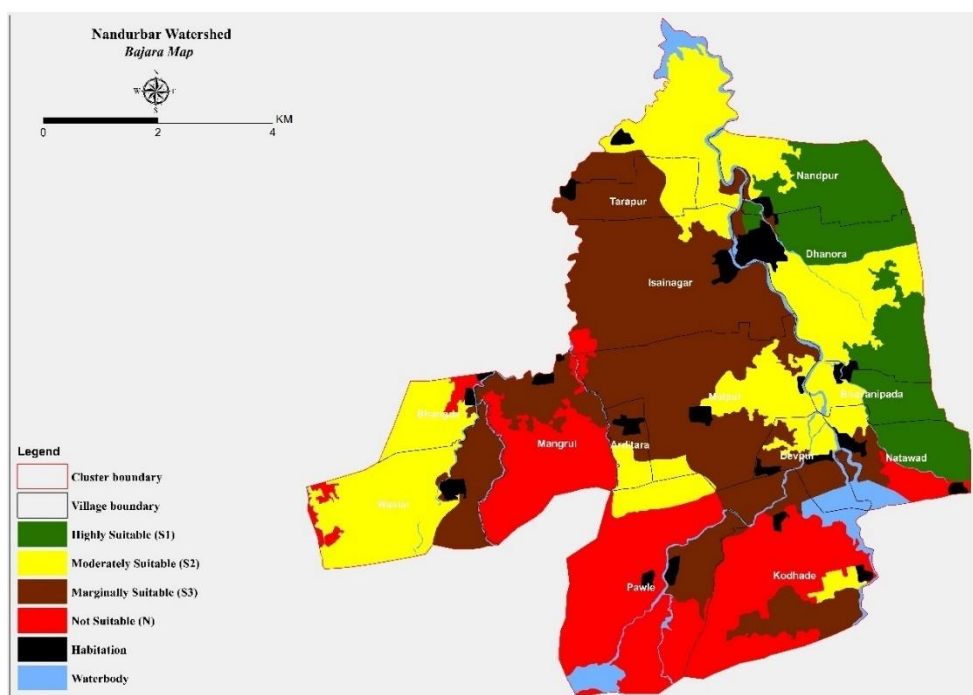


Fig. 4.27 Soil site suitability map for Pearl millet (Bajra) cultivation

4.8.6 Soil-Site Suitability for Green gram Cultivation

A larger proportion of the watershed, 37% (2303.6 ha), is categorized as marginally suitable (S3), wherein crop yields would be constrained by soil and site factors, resulting in reduced productivity under normal management practices. Green Gram can be cultivated in about 28.6% of the watershed area (1779.4 ha) with manageable limitations, as these areas provide relatively stable conditions for crop establishment and growth. Only 4.5% (281.4 ha) area of watershed are highly suitable(S1) for crop cultivation. The remaining watershed area is not conducive to green gram cultivation, as can be inferred from Table 4.32 and Fig. 4.28. The dominance of marginal and unsuitable land emphasizes the need for careful site selection when planning chickpea cultivation within the watershed.

Table 4.32 Area under suitability sub-classes for Green gram cultivation

S. No.	Green gram	Area (ha)	Percent (%)
1	Highly Suitable (S1)	281.4	4.5
2	Moderately Suitable (S2)	2303.6	37.0
3	Marginally Suitable (S3)	1779.4	28.6
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
Total		6219.2	100.0

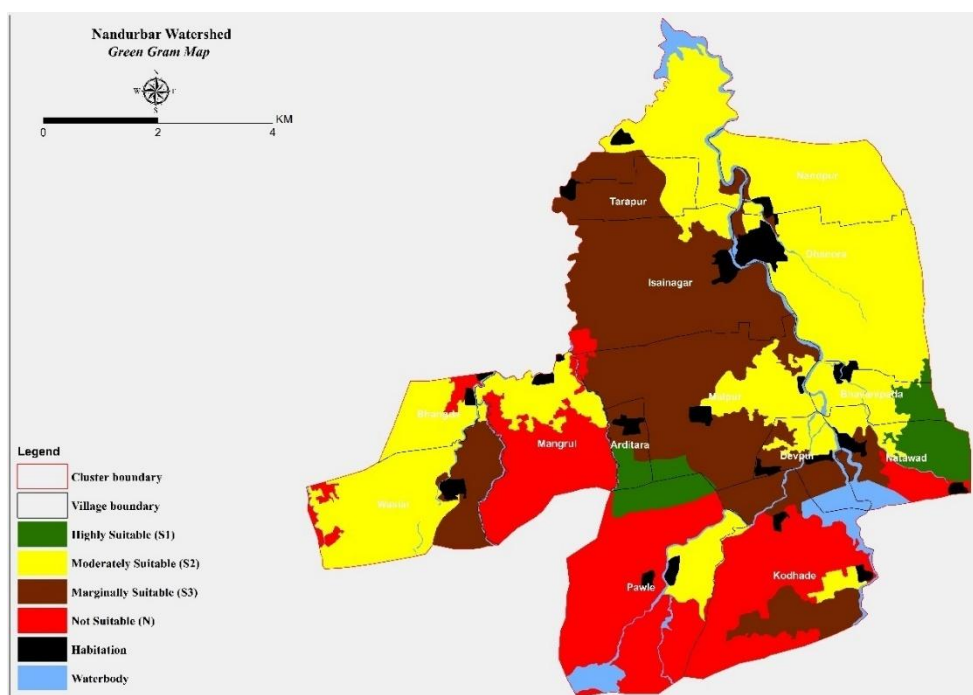


Fig. 4.28 Soil site suitability map for Green gram cultivation

4.8.7 Soil-Site Suitability for Black gram Cultivation

The soil-site suitability analysis for black gram cultivation reveals a wide variation in land capability across the watershed. Areas identified as highly suitable (S1) extend over 281.4 ha, constituting 4.5% of the total geographical area, indicating favourable soil and environmental conditions for black gram production.

Black Gram can be cultivated in about 37% of the watershed area (2303.6 ha) with manageable limitations, as these areas provide relatively stable conditions for crop establishment and growth. 28.6% area of the watershed is categorized as marginally suitable (S3), wherein crop yields would be constrained by soil and site factors, resulting in reduced productivity under normal management practices. The remaining watershed area is not conducive to black gram cultivation, as can be inferred from Table 4.33 and Fig. 4.29.

Table 4.33 Area under suitability sub-classes for Black gram cultivation

S. No.	Black gram	Area (ha)	Percent (%)
1	Highly Suitable (S1)	281.4	4.5
2	Moderately Suitable (S2)	2303.6	37.0
3	Marginally Suitable (S3)	1779.4	28.6
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
	Total	6219.2	100.0

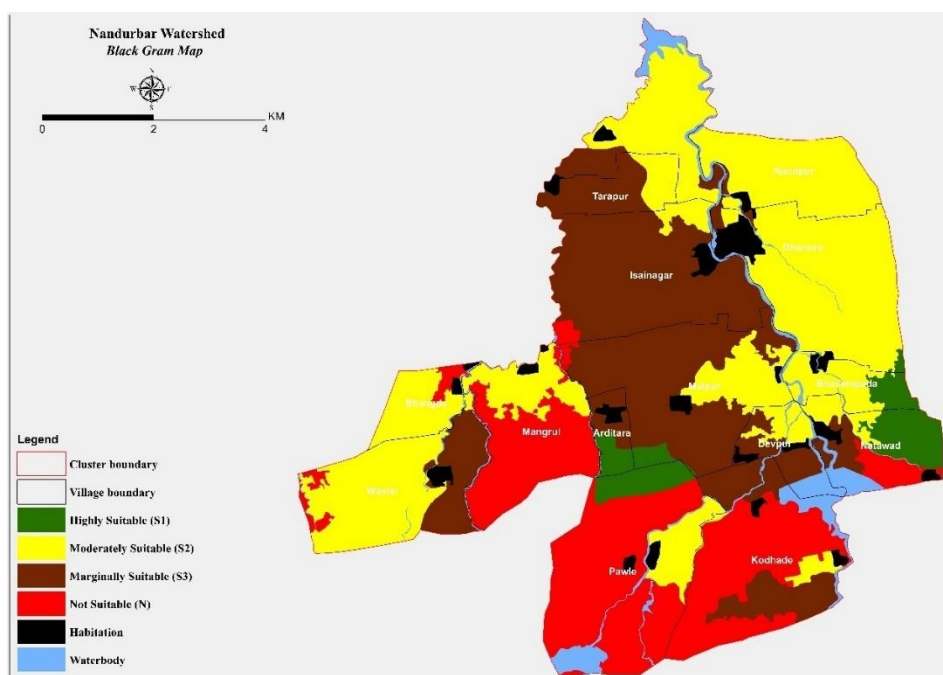


Fig. 4.29 Soil site suitability map for Black gram cultivation

4.8.8 Soil-Site Suitability for Pigeon Pea Cultivation

1121.28 ha (18.0%) of the watershed area is moderately suitable (S2), and another 2221.8 ha (35.7%) is marginally suitable for pigeon pea cultivation. While the former class represents areas with more acceptable conditions for crop growth, the latter would permit cultivation after following recommended conservation or ameliorative measures. About 38.7% of the watersheds was identified as not suitable (N) for pigeon pea cultivation due to severe soil and site limitations (Table 4.34, Fig. 4.30).

Table 4.34 Area under suitability sub-classes for Pigeon pea cultivation

S. No.	Pigeonpea	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1121.3	18.0
2	Marginally Suitable (S3)	2221.8	35.7
3	Not Suitable (N)	2403.8	38.7
4	Habitation	197.3	3.2
5	Waterbody	275.0	4.4
	Total	6219.2	100

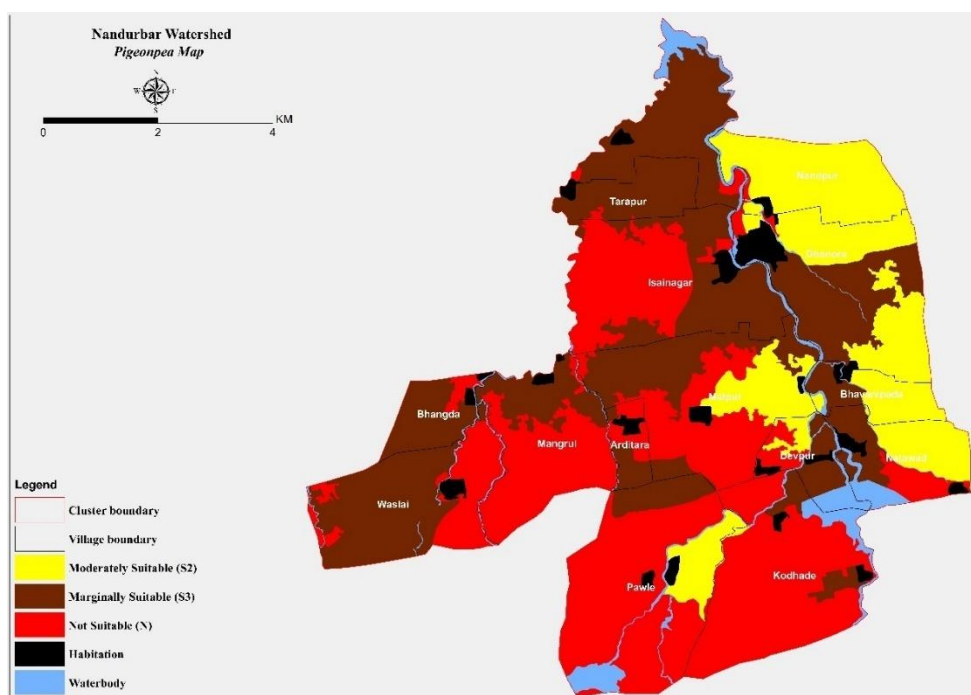


Fig. 4.30 Soil site suitability map for Pigeon pea cultivation

4.8.9 Soil-Site Suitability for Soybean Cultivation

Soil-site evaluation results for soybeans show a varied distribution of suitability classes across the watershed (Table 4.35, Fig. 4.31). Areas categorized as highly suitable (S1) cover 129.3 ha, accounting for about 2.1% of the total geographical area, indicating favorable soil and site conditions for achieving good crop performance. An additional 41% of the area is occupied under moderately suitable (S2) class, representing zones where soybean cultivation is feasible, although certain soil or site constraints may influence yield levels. The marginally suitable (S3) category extends over 1688.2 ha (or 27.1%), suggesting the presence of noticeable limitations that may restrict optimum crop growth. About 22.2% of the watershed is not suitable (N) for soybean cultivation. These results most favorable for soybean cultivation in the watershed by following recommended package of practices.

Table 4.35 Area under suitability sub-classes for Soybean cultivation

S. No.	Soybean	Area (ha)	Percent (%)
1	Highly Suitable (S1)	129.3	2.1
2	Moderately Suitable (S2)	2547.0	41.0
3	Marginally Suitable (S3)	1688.2	27.1
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
Total		6219.2	100

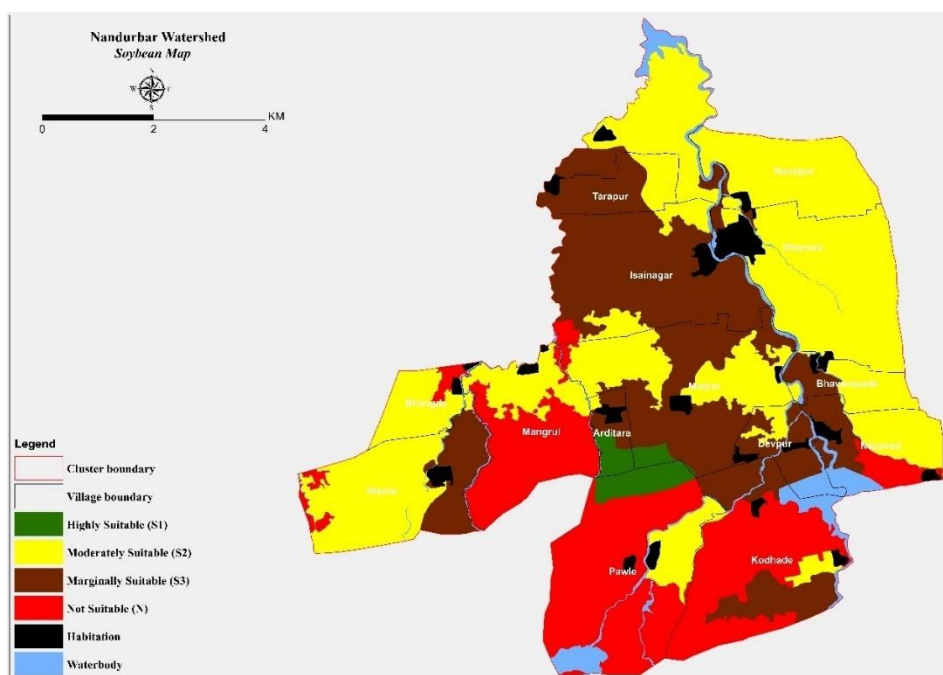


Fig. 4.31 Soil site suitability map for Soybean cultivation

4.8.10 Soil-Site Suitability for Cotton Cultivation

The soil-site evaluation for cotton cultivation shows areas categorized as highly suitable (S1) cover 616.3ha, accounting for about 9.9 % of the total geographical area, indicating favorable soil and site conditions for achieving good crop performance. 634.3 ha (10.2%) of the total geographical area is classified as moderately suitable (S2), these areas provide acceptable conditions for cotton cultivation, though certain soil and site constraints may affect crop performance.

A large portion of the watershed, covering 2797.6 ha (45%), falls under the marginally suitable (S3) category (Table 4.36, Fig. 4.32), indicating the presence of moderate limitations that may restrict yield potential. Furthermore, 1698.8 ha (27.3%) of the area is categorized as not suitable (N) for cotton cultivation due to severe soil and site-related constraints. Overall, the assessment indicates that nearly one-third of the watershed is unsuitable for cotton cultivation, while about one-tenth of the area exhibits moderate suitability.

Table 4.36 Area under suitability sub-classes for Cotton cultivation

S. No.	Cotton	Area (ha)	Percent (%)
1	Highly Suitable (S1)	616.3	9.9
2	Moderately Suitable (S2)	634.3	10.2
3	Marginally Suitable (S3)	2797.6	45.0
4	Not Suitable (N)	1698.8	27.3
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
Total		6219.2	100

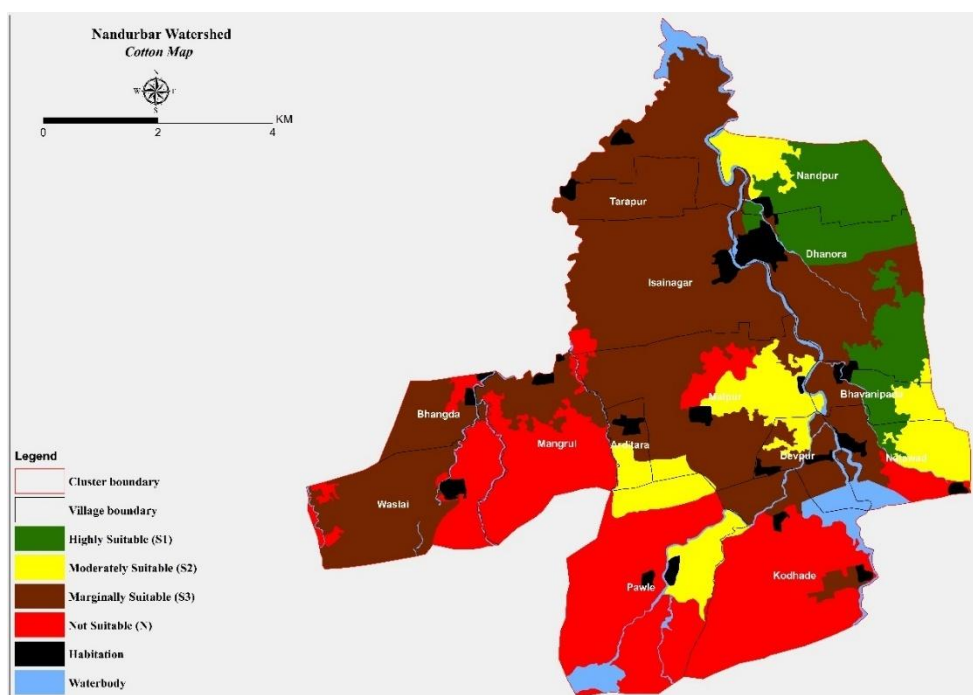


Fig. 4.32 Soil site suitability map for Cotton cultivation

4.8.11 Soil-Site Suitability for Sugarcane Cultivation

Like cotton, about one-fifth of the watershed area is moderately suitable for sugarcane (Table 4.37). These areas represent zones where sugarcane cultivation can be practiced with moderate limitations. Another 21.5% (1334.5 ha) of the area is marginally suitable (S3), indicating the presence of noticeable constraints that may affect crop establishment and productivity. In contrast, a dominant share of the watershed, accounting for 50.8% cannot be put under sugarcane due to severe soil and site limitations. The distribution of suitability classes (Fig. 4.33) indicates that a large portion of the watershed does not support profitable/sustainable sugarcane cultivation.

Table 4.37 Area under suitability sub-classes for Sugarcane cultivation

S. No.	Sugarcane	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1250.6	20.1
2	Marginally Suitable (S3)	1334.5	21.5
3	Not Suitable (N)	3161.9	50.8
4	Habitation	197.3	3.2
5	Waterbody	275.0	4.4
	Total	6219.2	100.0

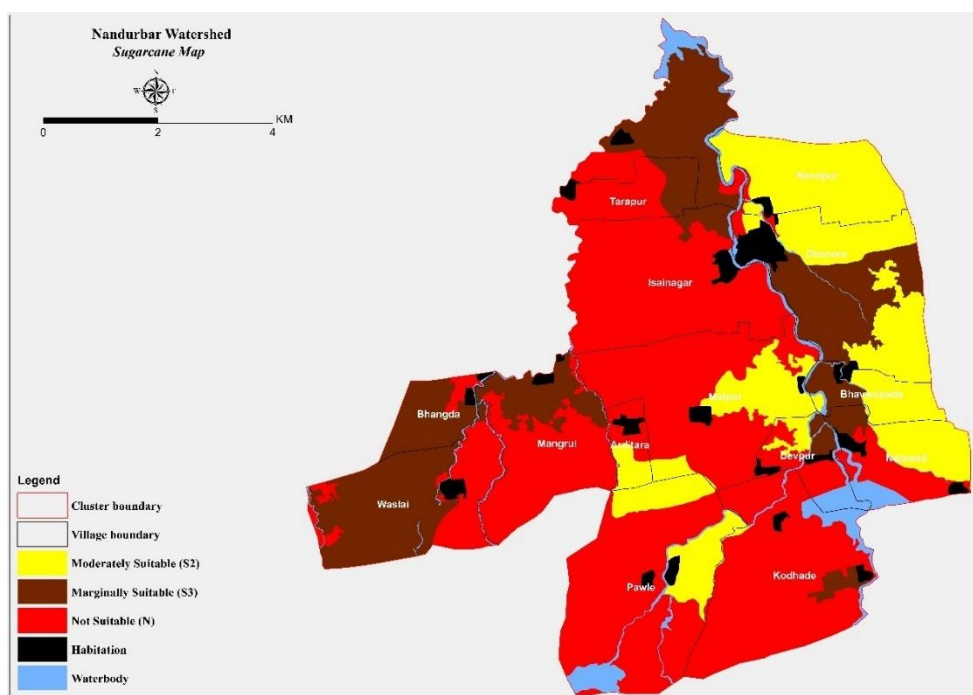


Fig. 4.33 Soil site suitability map for Sugarcane cultivation

4.8.12 Soil-Site Suitability for Lemon Cultivation

The soils of the watershed were evaluated for Lemon cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.38 and Fig. 4.34. The results indicate that 571.6 ha (9.2% of the total geographical area of the watershed) is classified as moderately suitable (S2), certain limitation for lemon growth and productivity. A considerable portion of the watershed (around one-third of the area) is categorized as marginally suitable (S3), reflecting moderate to severe constraints related to soil properties and terrain slope, which may restrict yield potential unless appropriate management practices are adopted.

About 50.8% of the watershed area is not suitable (N) for Lemon cultivation due to severe limitations associated with rocky soil, topography, waterlogging, steep slope and alkalinity of soil. Overall, the evaluation suggests that while limited soil is suitable for lemon cultivation.

Table 4.38 Area under suitability sub-classes for Lemon cultivation

S. No.	Lemon	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	571.6	9.2
2	Marginally Suitable (S3)	2013.5	32.4
3	Not Suitable (N)	3161.9	50.8
4	Habitation	197.3	3.2
5	Waterbody	275.0	4.4
	Total	6219.2	100.0

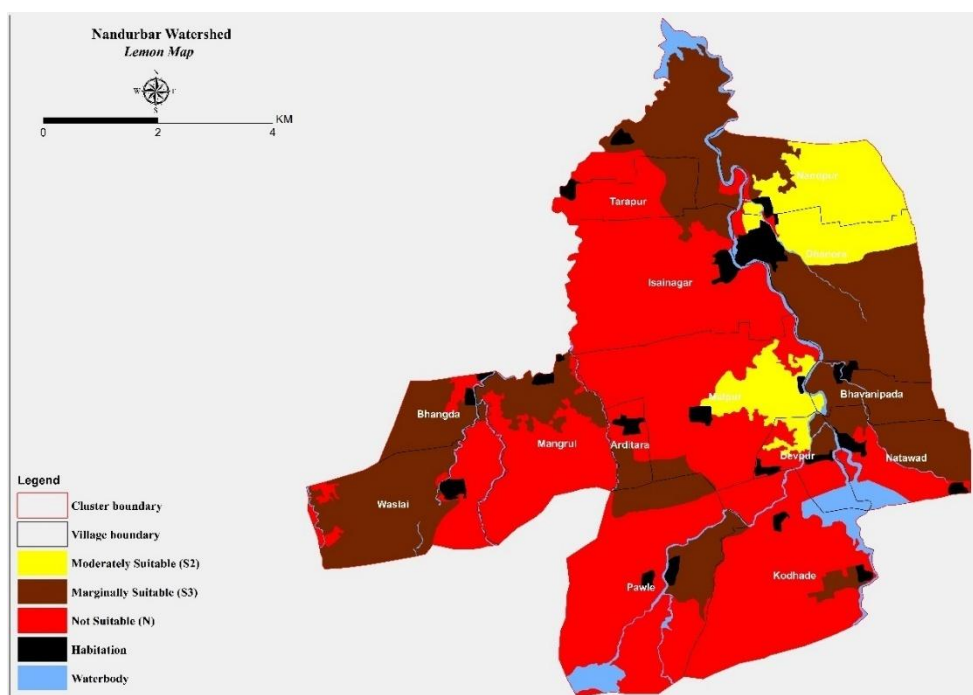


Fig. 4.34 Soil site suitability map for Lemon cultivation

4.8.13 Soil-Site Suitability for Papaya Cultivation

15.6% of the watershed area were categorized under moderately suitable(S2) occupy 969.1ha, respectively, for papaya cultivation, whereas 26.0% of area was found to be marginally suitable (S3), reflecting moderate to severe constraints primarily associated with soil and environmental factors, which may restrict yield potential without appropriate management practices. papaya is not recommended in around half of the watershed (Table 4.39, Fig. 4.35)

Table 4.39 Area under suitability sub-classes for Papaya cultivation

S. No.	Papaya	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	969.1	15.6
2	Marginally Suitable (S3)	1615.9	26.0
3	Not Suitable (N)	3161.9	50.8
4	Habitation	197.3	3.2
5	Waterbody	275.0	4.4
	Total	6219.2	100.0

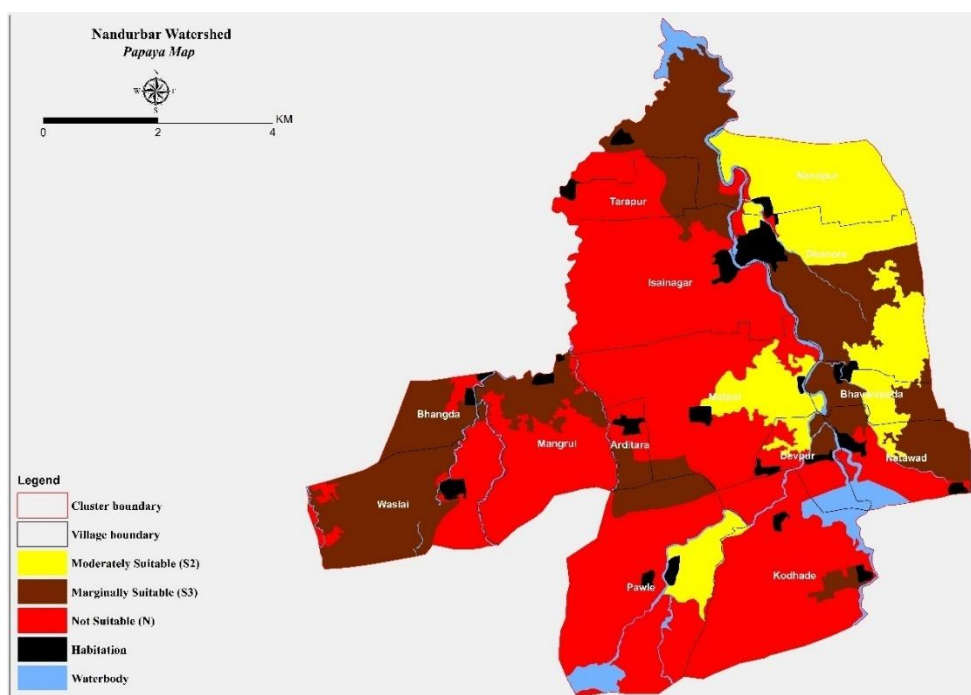


Fig. 4.35 Soil site suitability map for Papaya cultivation

4.8.15 Soil-Site Suitability for Banana Cultivation

The soils of the study area were evaluated for their suitability for banana cultivation based on crop-specific requirements. The spatial distribution of suitability classes is presented in Table 4.40 and Fig. 4.36. The assessment indicates that a major portion of the total geographical area (TGA), *i.e.* 50.8% is not suitable (N) for banana cultivation, covering 3161.9 ha. These areas are constrained by soil limitations, topographic conditions, and moisture availability.

Areas classified as marginally suitable (S3) occupy 1334.5 ha, representing 21.5% of the TGA. These zones exhibit moderate to severe constraints, which may restrict optimal crop performance and require appropriate soil and water management interventions. Moderately suitable (S2) areas cover 1250.6 ha, accounting for 20.1% of the TGA, and offer relatively favorable conditions for banana cultivation, although certain limitations related to soil fertility, drainage, or terrain may still exist.

Table 4.40 Area under suitability sub-classes for Banana cultivation

S. No.	Banana	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	1250.6	20.1
2	Marginally Suitable (S3)	1334.5	21.5
3	Not Suitable (N)	3161.9	50.8
4	Habitation	197.3	3.2
5	Waterbody	275.0	4.4
	Total	6219.2	100.0

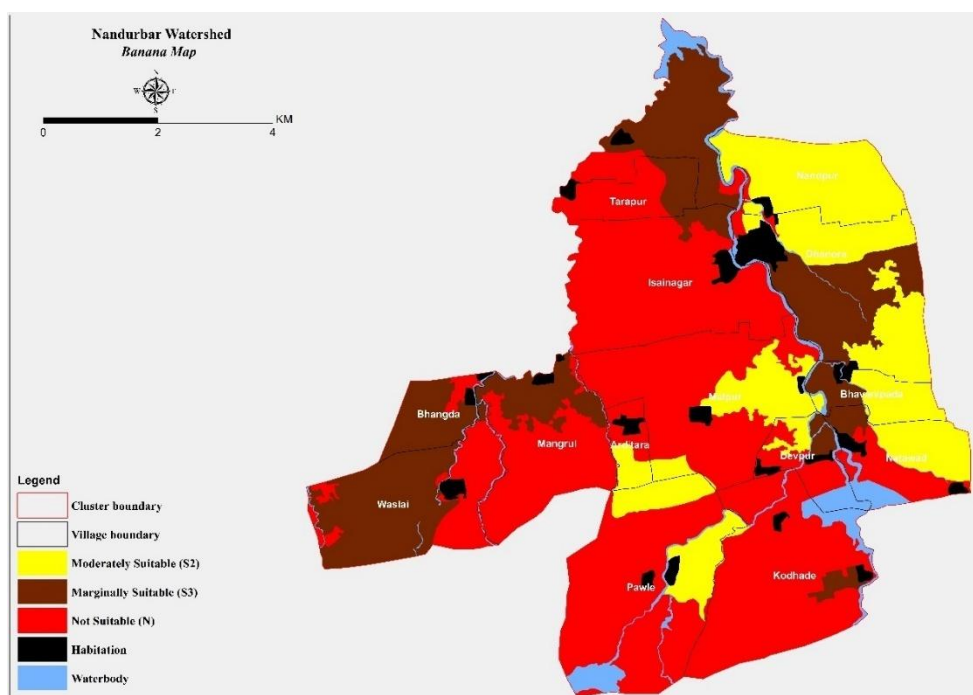


Fig. 4.36 Soil site suitability map for Banana cultivation

4.8.15 Soil-Site Suitability for Mango Cultivation

The soils of the watershed were evaluated for mango cultivation based on crop-specific requirements. The distribution of suitability classes is presented in Table 4.41 and Fig. 4.37. The results indicate that only 86.7ha (1.4% of the total geographical area of the watershed) is classified as moderately suitable (S2), providing certain limitations for mango growth and productivity. A considerable portion of the watershed (around one-fifth of the area) is categorized as marginally suitable (S3), reflecting moderate to severe constraints related to soil properties and terrain slope, which may restrict yield potential unless appropriate management practices are adopted.

70.1% of the watershed area is not suitable (N) for mango cultivation due to severe limitations associated with rocky soil, topography, waterlogging, steep slope and alkalinity of soil. Overall, the evaluation suggests that while limited soil is suitable for mango cultivation.

Table 4.41 Area under suitability sub-classes for Mango cultivation

S. No.	Mango	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	86.7	1.4
2	Marginally Suitable (S3)	1299.0	20.9
3	Not Suitable (N)	4361.2	70.1
4	Habitation	197.3	3.2
5	Waterbody	275.0	4.4
	Total	6219.2	100.0

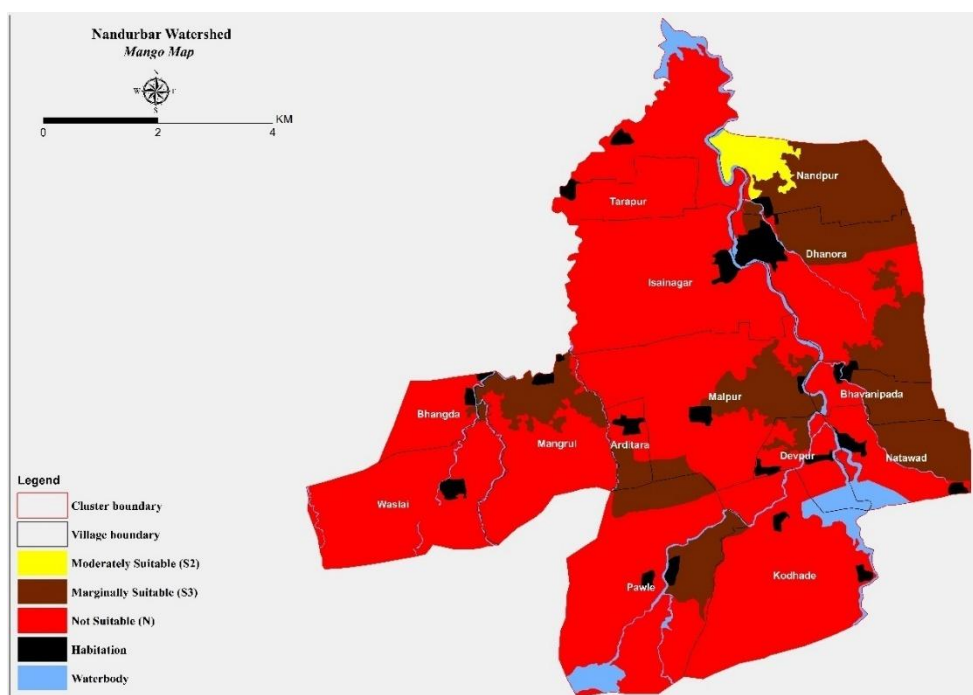


Fig. 4.37 Soil site suitability map for Mango cultivation

4.8.16 Soil-Site Suitability for Onion Cultivation

The soil-site suitability analysis for onion cultivation reveals a wide variation in land capability across the watershed (Table 4.42, Fig. 4.38). Areas identified as highly suitable (S1) extend over 129.3 ha, constituting 2.1% of the total geographical area, indicating favorable soil and environmental conditions for onion production.

The moderately suitable (S2) category occupies the largest share, covering 4008.4 ha (or 64.5% of the area), which reflects land with generally supportive conditions, though certain limitations may influence crop performance. The marginally suitable (S3) class accounts for 226.8 ha (3.7%), suggesting the presence of notable soil and site constraints that may restrict optimal yield levels. Overall, the classification demonstrates that a substantial proportion of the watershed is conducive to onion cultivation under moderate suitability.

Table 4.42 Area under suitability sub-classes for Onion cultivation

S. No.	Onion	Area (ha)	Percent (%)
1	Highly Suitable (S1)	129.3	2.1
2	Moderately Suitable (S2)	4008.4	64.5
3	Marginally Suitable (S3)	226.8	3.7
4	Not Suitable (N)	1382.4	22.2
5	Habitation	197.3	3.2
6	Waterbody	275.0	4.4
Total		6219.2	100

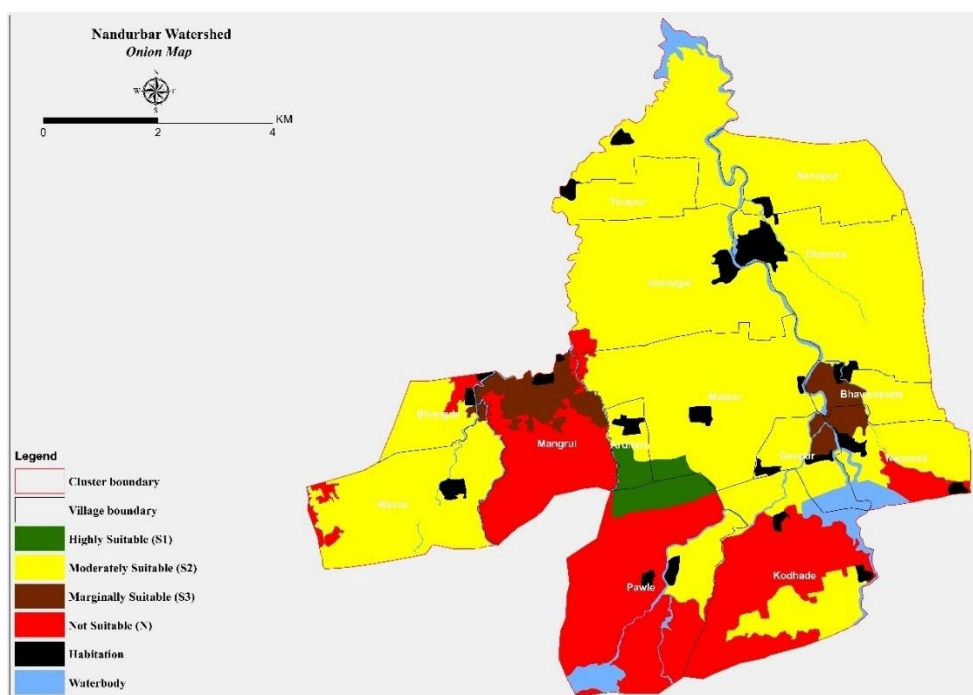


Fig. 4.38 Soil site suitability map for Onion cultivation

4.8.17 Soil-Site Suitability for Garlic Cultivation

4138.4 ha (66.5%) of the watershed area were categorized under moderately (S2) suitable, respectively, for garlic cultivation, whereas 1063.8 ha (17.1%) of area was found to be marginally suitable (S3), reflecting moderate to severe constraints primarily associated with soil and environmental factors, which may restrict yield potential without appropriate management practices. Only 8.8% area of watershed is not suitable(N) for Garlic. Garlic is recommended for cultivation in major portion of the watershed (Table 4.43, Fig. 4.39).

Table 4.43 Area under suitability sub-classes for Garlic cultivation

S. No.	Onion	Area (ha)	Percent (%)
1	Moderately Suitable (S2)	4138.4	66.5
2	Marginally Suitable (S3)	1063.8	17.1
3	Not Suitable (N)	544.7	8.8
4	Habitation	197.3	3.2
5	Waterbody	275.0	4.4
	Total	6219.2	100.0

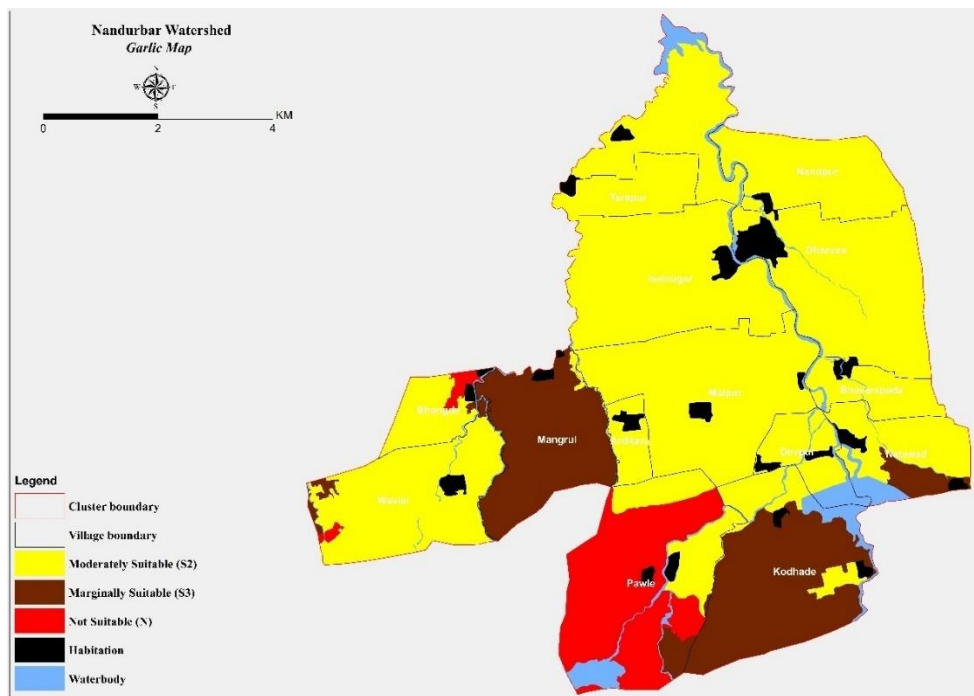


Fig. 4.39 Soil site suitability map for Garlic cultivation

4.9 Morphometric Analysis Nandurbar Cluster

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

Morphometric analysis quantitatively evaluates drainage network characteristics, basin geometry, slope, and relief, which influence runoff generation, erosion, and groundwater recharge. These parameters must be derived from a hydrologically closed unit bounded by natural divides. A watershed represents such a unit, where streams develop hierarchically and drain toward a common outlet, ensuring reliable computation of indices such as drainage density, bifurcation ratio, stream frequency, form factor, and relief ratio.

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

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

Nandurbar, Maharashtra, comprises 14 villages. Together, these villages constitute the study cluster having 1 sub-watershed (Fig. 4.40).

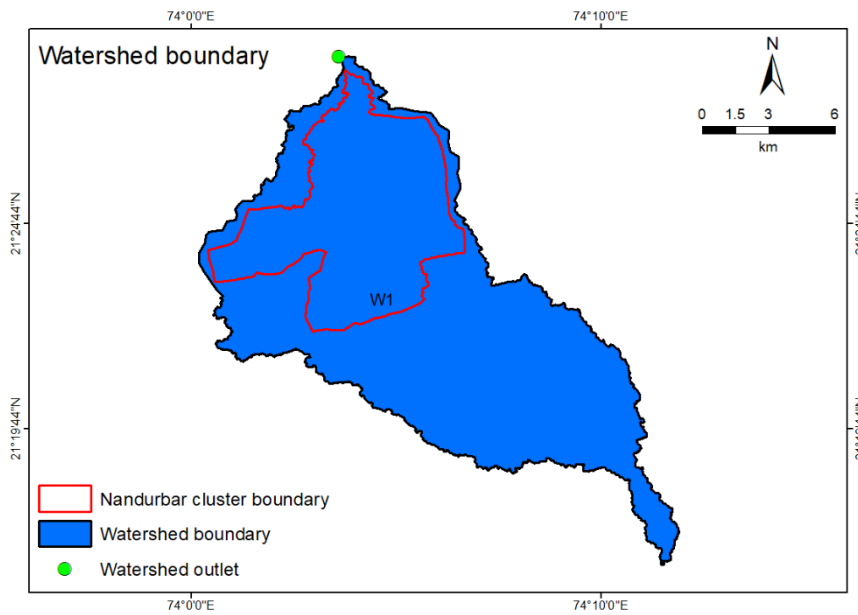
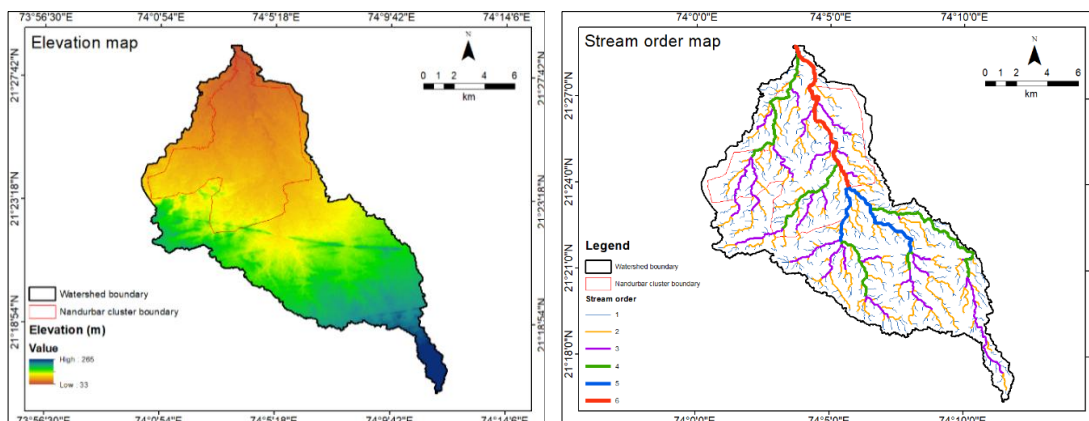


Fig. 4.40: Map of Nandurbar cluster depicted through sub-watershed

Table 4.44: Distribution of area under different sub-watershed, Nandurbar

S. No.	Sub-watershed name	Sub-watershed order	Elevation (m)	Area (km ²)	Flow origination
1	W1	6 th	33-265	181.17	South-east to North
		Total		181.17	

The sub-watershed wise area, their order, elevation range and drainage network are presented in Table 4.44, and in Fig.4.41. Their morphometric characteristics of this sub-watershed are analyzed under three aspects: linear, areal, and relief.



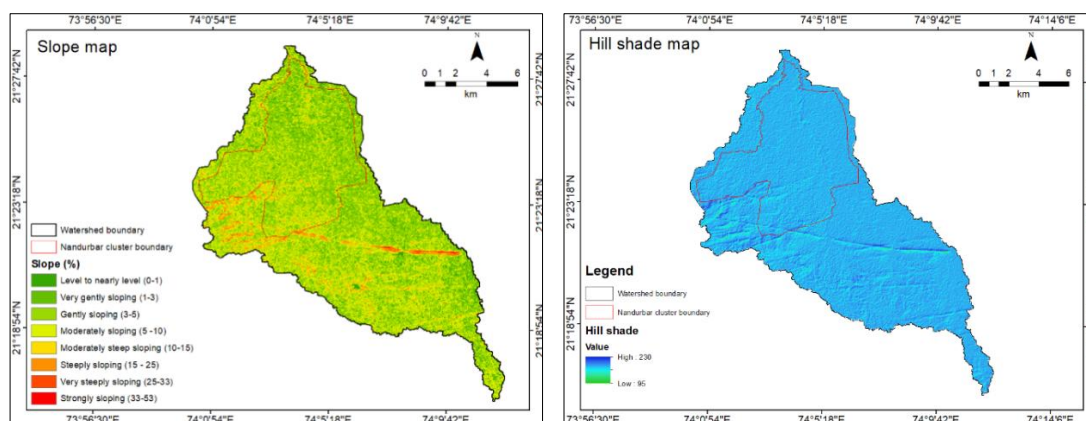


Fig. 4.41: Elevation, stream network, slope and hill shade map of sub-watershed

Linear aspect

Linear morphometric parameters focus on the stream network characteristics and its influence on runoff and watershed behaviour. The morphometric analysis of the sub-watersheds (W1) shows clear variation in drainage characteristics. W1 has the number of streams (811) and total stream length (482.6 km), indicating a well-developed drainage network (Table 4.45). The bifurcation ratio indicated as 3.80, suggesting relatively greater structural influence watershed. Mean channel length and valley length of watershed, reflecting more mature channel development. Channel index of watershed W1 (1.32), indicating greater sinuosity. Basin perimeter of W1 (112.1 km), confirming it as the most extensive sub-watershed.

Table 4.45: Linear morphometric parameters of sub-watersheds, Nandurbar cluster

Sr.no.	Morphometric parameter	Symbol	Unit	W1
1	No. of streams	Nu	No	811
2	Stream length	Lu	km	482.61
3	Bi-furcation ratio	Rb	-	3.80
4	Mean channel length	Cl	km	35.83
5	Valley Length	VI	km	29.41
6	Channel Index	Ci	-	1.32
7	Minimum areal distance	Adm	km	27.23
8	Valley Index	Vi	-	1.08
9	Basin perimeter	P	km	112.12

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 (181.17 km²) and mean basin width is 5.2 km. Form factor (Ff) and elongation ratio (Re) in W1 (0.15 and 0.44), suggesting a comparatively more circular basin. Circularity ratio (Rc) of W1 is 0.34, while compactness coefficient (Cc) as 2.37, reflecting greater basin irregularity. Standard sinuosity index (Ssi) as 1.22, indicating relatively higher channel sinuosity in W1. Drainage parameters show

that stream frequency (Fs) is 4.48 per km² and Drainage density (Dd) as 2.7 km/km². Drainage intensity (Di) follows a similar trend, with the highest value as 1.68. Length of overland flow (Lg) as (0.44 km) indicating shorter runoff travel distance in W1.

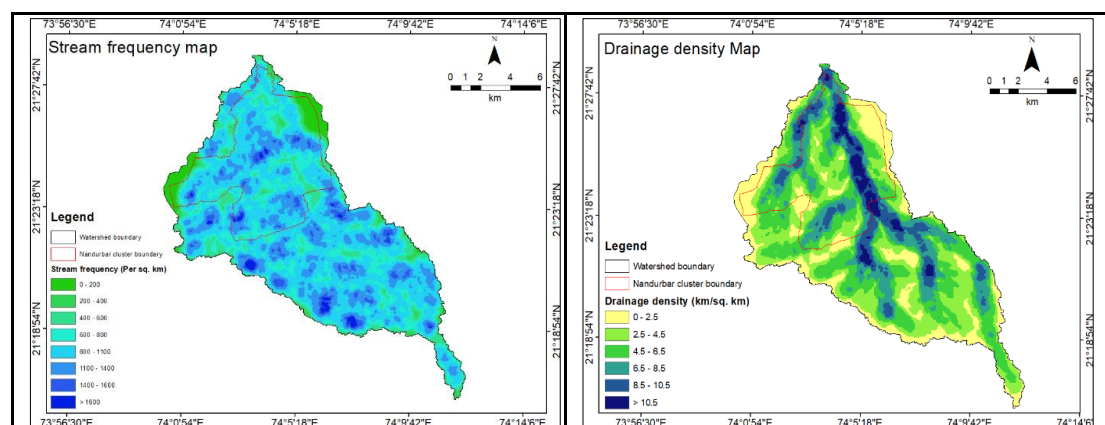


Fig. 4.42: Steam frequency and drainage density map of sub-watershed

Table 4.46: Areal morphometric parameters of sub-watersheds, Nandurbar cluster

Sr. No.	Parameter	Symbol	Method/Formula	Unit	W1
1.	Mean basin width	Wb	$Wb = A/Lb$	km	5.2
2.	Basin area	A	GIS Analysis	km ²	181.17
3.	Relative perimeter	Pr	$Pr = A/P$	km	1.62
4.	Length area relation	Lar	$Lar = 1.4 * A^{0.6}$	km ²	31.69
5.	Lemniscate's	k	$K = Lb^2/A$	-	6.6
6.	Form factor	Ff	$Ff = A/Lb^2$	-	0.15
7.	Elongation ratio	Re	$Re = 2/Lb * (A/\pi)^{0.5}$	-	0.44
8.	Circularity ratio	Rc	$Rc = 12.57 * (A/P^2)$	-	0.34
9.	Compactness coefficient	Cc	$Cc = 0.2841 * P/A^{0.5}$	-	2.37
10.	Standard sinuosity index	Ssi	$Ssi = Ci/Vi$	-	1.22
11.	Stream frequency	Fs	$Fs = Nu/A$	Per km ²	4.48
12.	Drainage Density	Dd	$Dd = Lu/A$	km/km ²	2.7
13.	Drainage Intensity	Di	$Di = Fs/Dd$	-	1.68
14.	Length of Overland Flow	Lg	$Lg = A/2 * Lu$	km	0.44

Relief Aspects

The maximum basin height (Z) of W1 (265m) and total basin relief (H) is also maximum as (232 m) (Table 4.47). Relief ratio (Rhl) as W1 (6.8), indicating steeper terrain conditions, while Relative relief ratio (Rhp) of W1 (206.9) suggesting higher relief intensity in W1. The ruggedness number (Rn) of watershed W1 (0.42), reflecting more dissected and erosion-prone terrain. Similarly, the Melton ruggedness number (MRn) is shown in W1 (17.2), indicating comparatively higher susceptibility to runoff and erosion processes.

Table 4.47: Relief morphometric parameters of sub-watersheds, Nandurbar cluster

Sr. no.	Parameters	Symbol	Methods/Formula	W1
1.	Height of at basin mouth	z	DEM	33
2.	Maximum height of the basin	Z	DEM	265
3.	Total basin relief	H	$H = Z - z$	232
4.	Relief ratio	R_{hl}	$R_{hl} = H / L_b$	6.8
5.	Relative relief ratio	R_{hp}	$R_{hp} = H * 100 / P$	206.9
6.	Ruggedness number	R_n	$R_n = D_d * (H/1000)$	0.42
7.	Melton Ruggedness number	MR_n	$MR_n = H / A^{0.5}$	17.2

The slope distribution of sub-watershed W1 shows that the terrain is mainly characterized by gentle to moderate slopes. The gently sloping class (3-5%) occupies the largest proportion of the watershed, covering 38.47% of the total area, followed by the moderately sloping class (5-10%), which accounts for 32.07%. The very gently sloping class (1-3%) covers 11.75%, while level to nearly level areas (0-1%) occupy 8.67% of the watershed. Moderately steep slopes (10-15%) represent 5.83% of the area, whereas steeply sloping land (15-25%) accounts for 2.81%. Very small portions of the watershed fall under very steep slopes (25-33%), covering 0.32%, while strongly sloping areas (33-50%) are almost negligible. Overall, the slope pattern indicates that W1 is predominantly dominated by gently to moderately sloping terrain with limited areas of steep slopes.

The sub-watersheds, W1 exhibits a relatively well-developed drainage network characterized by a high number of streams, greater total stream length, and moderate bifurcation ratio, indicating significant structural control and efficient drainage development. The high stream frequency (4.48 km⁻²) and drainage density (2.7 km km⁻²) in W1 suggest greater runoff generation potential and lower infiltration capacity, thereby increasing the susceptibility to soil erosion. The relatively shorter length of overland flow (0.44 km) further indicates rapid concentration of runoff towards the drainage channels. Relief parameters such as basin relief, relief ratio, ruggedness number, and Melton ruggedness number indicate moderately dissected terrain with higher erosion potential. Although the watershed is dominated by gently sloping (38.47%) and moderately sloping (32.07%) areas, the presence of moderately steep slopes and an irregular basin shape enhance surface runoff concentration during rainfall events. Therefore, the sub-watersheds, W1 requires relatively stronger soil and water conservation interventions focusing on runoff regulation and erosion control. Structural measures such as check dams, gabion structures, gully plugs, and percolation tanks should be implemented along the drainage network to reduce peak flow and sediment transport, while contour bunding, graded bunds, and vegetative barriers are recommended in gently sloping agricultural areas to enhance infiltration and soil moisture retention. In moderately sloping zones, staggered contour trenches, strip cropping, and broad bed and furrow (BBF) systems can effectively reduce runoff velocity and soil loss, thereby improving overall watershed stability and groundwater recharge.

4.10 Soil and Water Conservation Measures

Soil and water conservation (SWC) planning is crucial for the sustainable management of land resources, enhancing agricultural productivity, and mitigating land degradation in regions where factors such as soil depth, slope, and rainfall runoff pose challenges to cultivation. Conservation planning becomes especially important in landscapes dominated by agriculture, where soil erosion, surface runoff, and limited water storage capacity can negatively affect crop growth and land performance. Implementing appropriate SWC measures helps maintain soil structure, improve moisture retention, and support livelihood stability by increasing the efficiency and resilience of cultivated land. Such planning relies on physical parameters, including landform characteristics, soil texture and depth, slope variations, and land use patterns, which collectively guide the selection of the most suitable interventions for different terrain types.

The Soil and Water Conservation plan for Nandurbar Taluka has been prepared on the basis of the available land resource dataset, incorporating landform characteristics, soil texture, soil depth, land use and slope classes. The purpose of preparing this plan is to improve soil productivity, enhance groundwater recharge and regulate surface runoff for sustainable land and water management across the taluka. The planning process focused on identifying suitable interventions that match the physical capability and land potential of each area rather than applying uniform measures everywhere.

In the region, where the soils are predominantly loam and silt loam with shallow to moderate depth and slopes mostly ranging from flat to gently undulating, the emphasis has been placed on field bunding, contour bunding and strengthening of existing bunds to ensure safe disposal of runoff. In these cultivable lands, farm ponds and lined farm ponds have been proposed to capture excess rainwater and store it for crop requirements. These interventions cover the largest area in the proposed plan because they directly support moisture storage and reduce runoff losses, particularly in agricultural zones.

Areas with tree cover, plantations and open scrub that fall within moderate to shallow soil depth have been included for afforestation and in-situ moisture conservation works. These activities aim to improve infiltration and restore vegetative cover, especially where structural interventions are not technically appropriate. In very shallow soil depth zones located on rocky surfaces such as hills, ridges, escarpments, mesa and pediment areas, the focus has been on biological measures and runoff moderation rather than heavy engineering structures. Here, stone lines and small moisture retention techniques help to reduce erosion and protect the fragile landscape.

Built-up regions with higher slope gradients have been prioritized for rooftop rainwater harvesting to minimize direct runoff and enhance water availability within settlements. Along seasonal drainage lines and nala systems, measures such as cement nala bunds, earthen nala bunds, desilting and renovating existing water bodies have been proposed to regulate water flow and increase storage. Stream bank plantation has also been included to provide long-term stabilization and reduce erosion along natural channels.

In unbunded cultivated fields located on slopes, conservation bench terraces have been recommended to reduce soil loss and retain moisture through controlled contour-based land shaping. Small portions of the landscape have also been planned under horticulture with moisture conservation measures, depending on soil depth suitability. Other essential works such as road-related runoff management and miscellaneous local-requirement interventions have also been included according to site conditions.

Overall, the plan covers more than six thousand hectares distributed across different conservation activities according to land capability and technical feasibility. The proposed measures collectively aim to reduce soil erosion, increase infiltration, improve water availability and enhance agricultural productivity. The plan represents a balanced combination of engineering structures and biological conservation approaches based entirely on the spatial resource dataset of Nandurbar Taluka.

Table 4.48 Proposed soil and water conservation (SWC) plan for Nandurbar watershed

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

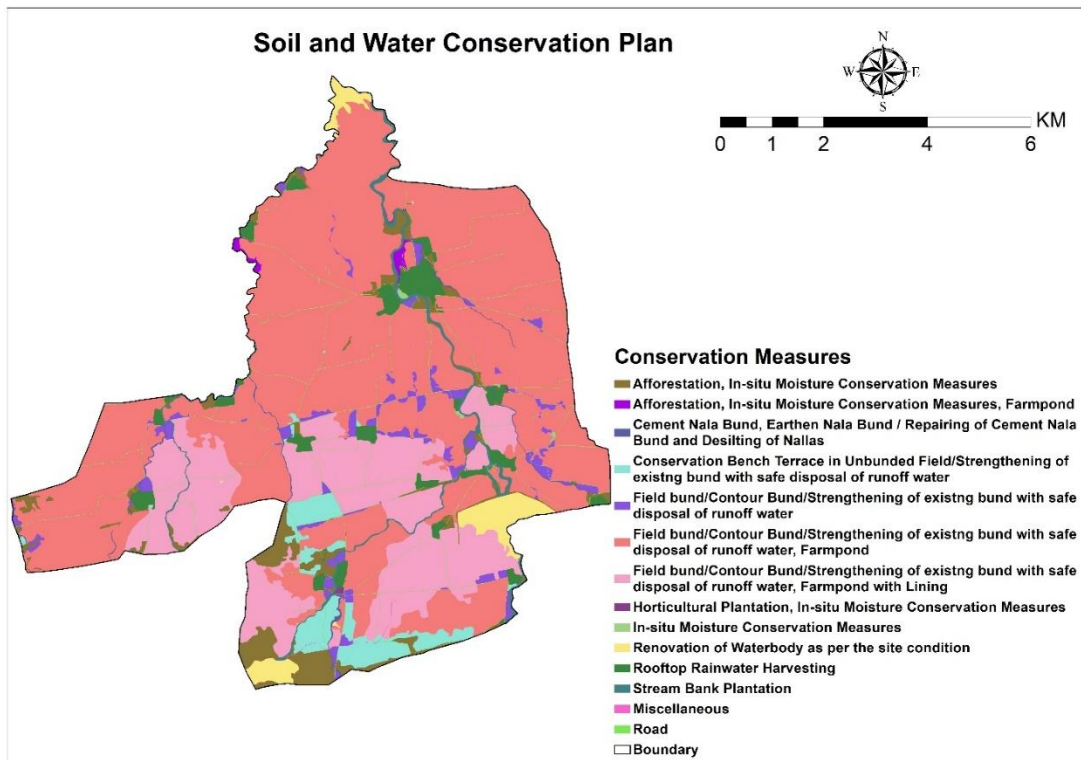


Fig. 4.43: Soil and water conservation measures proposed for Nandurbar watershed

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

- The Land Resource Inventory (LRI) and watershed assessment for the Nandurbar village cluster watershed was undertaken by ICAR–National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur, to support scientific planning and implementation under the Pradhan Mantri Krishi Sinchayee Yojana – Watershed Development Component (PMKSY-WDC 2.0).
- The study watershed lies within the Tapi River basin in Nandurbar Taluka of Nandurbar district, Maharashtra, and is characterized by semi-arid to sub-humid climatic conditions, receiving an average annual rainfall of about 943 mm, predominantly during the southwest monsoon season.
- The socio-economic profile of the watershed indicates that the local economy is largely agriculture-dependent, with the majority of the population residing in rural areas and a significant proportion belonging to tribal communities, whose livelihoods are closely linked with rainfed agriculture and natural resources.
- The geology of the area is dominated by Deccan Trap basalt formations, while the terrain is generally undulating to moderately hilly. The major geomorphic units identified include pediments (about 60%) and pediplains (about 32%), which strongly influence soil formation, drainage characteristics, and agricultural potential.
- The soils of the watershed are predominantly silty clay loam and silt loam in texture, generally well drained with moderate moisture holding capacity. However, spatial variability exists in soil depth, texture, drainage conditions, and fertility status, which affects land capability and crop suitability across the watershed.
- Agriculture in the watershed is largely monsoon-dependent, with a diversified cropping system dominated by seasonal crops. Irrigation is limited and mainly supported by private open wells and borewells, leading to uneven water availability across agricultural lands.
- The overall cropping intensity of the watershed was estimated to be about 133%, indicating moderate utilization of agricultural land with limited expansion of irrigated cropping.
- Key constraints identified in the watershed include rapid surface runoff, soil erosion particularly in pediment and sloping areas, and limited irrigation infrastructure, which collectively contribute to water scarcity and reduced agricultural productivity.

5.2 CONCLUSION

The Land Resource Inventory (LRI) and watershed assessment carried out by ICAR-NBSS&LUP for the Nandurbar village cluster watershed provides a comprehensive and scientifically robust framework for natural resource planning and management under the PMKSY-WDC 2.0 programme. The study adopted a systematic and integrated methodology, involving pre-field spatial analysis, detailed soil surveys, laboratory characterization of soil samples, and GIS-based spatial interpretation, which enabled the generation of high-resolution thematic datasets and maps representing soil resources, terrain characteristics, land capability, crop suitability, and groundwater potential zones.

The findings indicate that the watershed's agricultural system is highly sensitive to rainfall variability, primarily due to the combination of undulating terrain, variable soil depth, and limited irrigation infrastructure. These conditions promote rapid surface runoff and localized soil erosion, which restrict soil moisture availability and agricultural productivity. The dependence on private open wells and borewells further highlights the need for enhanced groundwater recharge and improved water resource management. The outputs of the LRI study, including detailed soil resource maps, soil-site suitability evaluations for crops, groundwater potential zone mapping, and watershed morphometric analysis, provide a strong scientific basis for informed decision-making and location-specific land and water management interventions.

Implementation of the recommended soil and water conservation (SWC) measures, such as in-situ moisture conservation practices, drainage line treatments, water harvesting structures, and vegetative measures, is expected to reduce surface runoff, control soil erosion, improve groundwater recharge, and enhance soil moisture availability across the watershed. Overall, the adoption of these site-specific and scientifically designed interventions will contribute significantly to sustainable land and water resource management, improved agricultural productivity, and enhanced livelihood security of the farming and tribal communities in the Nandurbar village cluster watershed.



