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LAND RESOURCE INVENTORY AND LAND USE PLAN OF SOUTH GUJARAT REGION FOR SUSTAINABLE AGRICULTURE

ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur – 440 033, Maharashtra

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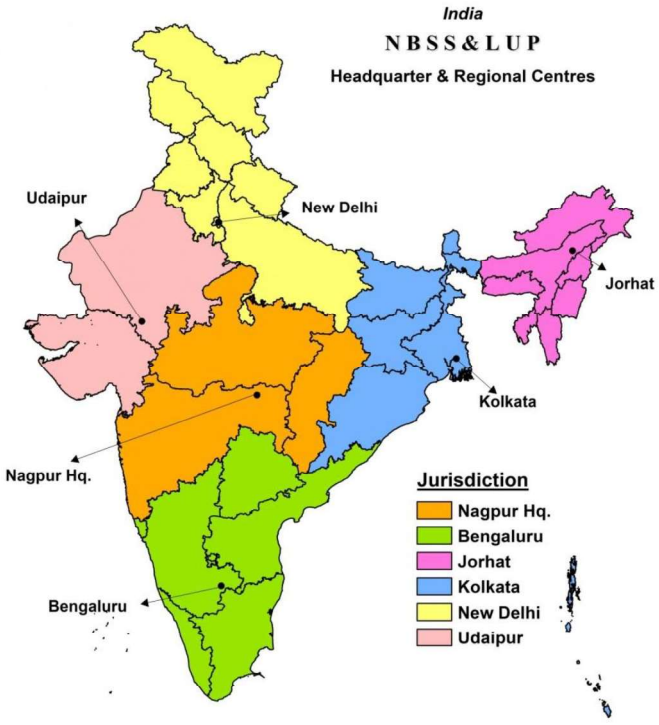
About the ICAR-NBSS&LUP

The ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP), Nagpur, a premier institute of the Indian Council of Agricultural Research (ICAR) was set up in the year 1976. The Bureau has five Regional Centres at Bangalore, Delhi, Kolkata, Jorhat and Udaipur. The ICAR-NBSS&LUP, Regional Centre, Udaipur caters to the needs of western part of the country and covers Rajasthan and Gujarat states for soil survey, characterization, classification and mapping.

The objective of the Bureau is to provide research inputs and prepare soil resource maps at the state and district level for land evaluation, land use planning, land resource management and database management using GIS for optimizing land use on different kinds of soils in the country. The Bureau has been engaged in carrying out agro-ecological and soil degradation mapping at the country, state, and district levels for qualitative assessment and monitoring of soil health towards viable land use planning. The research activities of the Bureau have resulted in identifying soil potentials and problems and the various applications of soil survey with the ultimate objectives of sustainable agriculture development. The Bureau has the mandate to correlate and classify soils of the country and maintain a National Register of all the established soil series.

The Institute is also imparting in-service training to staff of the soil survey agencies in the area of Soil Survey, Land Evaluation, and Soil Survey Interpretation for Land Use Planning.



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Executive Summary

India has achieved self-sufficiency in food grains production through the Green Revolution. However, this success has led to significant environmental challenges, including degradation of natural resources, deterioration of ecosystem services, increasing aridity and water scarcity, loss of soil fertility, waterlogging, pollution, intensified pest and disease issues, and socioeconomic problems exacerbated by climate change. Despite these challenges, India aims for an agricultural growth rate of 4% annually and seeks to double farmers' incomes. To achieve the targets a thorough understanding of soil characteristics, extent, distribution, and limitations is essential for optimizing land use. Land resource inventory provides insights into the mapped area's potentialities and constraints, which is crucial for effective land management. The lack of location-specific data and situation-specific recommendations has led to the failure of many agricultural development schemes in India.

The comprehensive report on ***"Land Resource Inventory and Land Use Plan of South Gujarat Region for Sustainable Agriculture"*** provides an in-depth analysis of the region's soil and water resources, aimed at facilitating sustainable land use and agricultural planning. This initiative was undertaken by ICAR-NBSS&LUP, Nagpur, and its Regional Centre, Udaipur, with the objective of creating detailed digital soil information to support sustainable development. The key objectives of the report are to develop scientific inventory and database of soil resources, identification of constraints and potentials of the region, and to develop comprehensive land use plans that consider crop suitability and soil and water conservation techniques.

The project followed a systematic three-tier approach on:

1. **Baseline Data Compilation**: Included soil-site characteristics, landforms, and land use patterns.
2. **Digital Soil Mapping**: Involved soil surveys, laboratory analysis, and modeling of soil properties.
3. **District-wise Land Use Plan Generation**: Focused on crop suitability analysis, development of agricultural land use plans, and soil and water conservation strategies.

The South Gujarat region, located between 20° 07' N to 22° 14' N latitude and 72° 44' E to 74° 19' E longitude, covers a total geographical area of 21,338 km². The region consists of seven districts: Bharuch, Dang, Narmada, Navsari, Surat, Tapi, and Valsad, making up 10.87% of Gujarat's total geographical area. The proximity to the Arabian Sea significantly influences the climate, soil, and vegetation, resulting in diverse topography and soil types. The soil resources of South Gujarat are diverse and fertile, significantly contributing to the region's agricultural productivity and economic activities. This area features a variety of soil types due to its varied topography, climatic conditions, and proximity to the Arabian Sea. Predominantly, the soils in the region are alluvial, which is highly fertile and support the cultivation of a wide range of crops, including rice, sugarcane, cotton, and various fruits and vegetables. In the coastal regions, the soil tends to be saline due to seawater intrusion. Black soils are also found in parts of South Gujarat, particularly in the regions bordering the Deccan Plateau.

The spatial distribution of important soil characteristics, including soil depth, texture class, sand, silt, clay, available water capacity (AWC), pH, electrical conductivity (EC), soil organic carbon (SOC), and calcium carbonate ($CaCO_3$) content, across different districts in South Gujarat is explained in the report. The soils are deep (100-150 cm), covering 901.30 thousand ha (42.24% of TGA), followed by moderately shallow (13.86%) and moderately deep soils (12.77%). The soil textures are clay (785.61 thousand ha, 36.82% of TGA) and clay loam (29.12%). Most of the region (1084.17 thousand ha, 50.81%) has an AWC in the range of 8-10%. The particle size distribution indicates that 1258.96 thousand ha (59.00% of TGA) contains 20-40% sand, 1075.30 thousand ha (50.39%) contains 20-35% silt, and 899.01 thousand ha (42.13%) contains 35-45% clay. The majority of the region is moderately alkaline (644.34 thousand ha, 30.20%) in terms of soil pH, followed by neutral (348.38 thousand ha, 16.33%), slightly alkaline (326.07 thousand ha, 15.28%), slightly acidic (190.57 thousand ha, 8.93%), and moderately acidic (44.55 thousand ha, 2.09%). To optimize pH for a wider range of crops, consider adding organic matter or gypsum to manage alkalinity, especially in areas with pH more than 7.8. The EC is generally low (<2 dSm^{-1}) in 69.59% area of the region, indicating no significant salinity hazard. The low salinity levels suggest minimal need for salinity

management practices. However, regular monitoring is essential to maintain this status. The SOC content varies, with the majority of the areas having medium (0.5-0.75%) range (709.62 thousand ha, 33.26% of TGA) and moderately high (0.75-1.0%) range (430.0 thousand ha, 20.15%). With SOC mostly in the medium range, incorporating organic residues or cover crops can help to maintain or increase SOC levels, and improving soil structure and fertility. About 10.94% and 8.81% of TGA have >1.0% and <0.5% SOC content, respectively. The $CaCO_3$ content is mostly 5-15% (42.57% of TGA) and 1-5% (27.66% of TGA), posing a risk for crop growth due to potential subsoil sodicity development. The non-arable lands (26.82%) classified as other areas (built-up, river, water bodies, forest, and swamp/marshy/littoral/ mangrove areas) should be protected and managed to ensure ecological balance and support biodiversity.

The South Gujarat region comprises seven districts, each exhibiting distinct soil characteristics. In Bharuch district, the soils are deep (100-150 cm), with clay and clay loam soils texture, slightly to moderately alkaline pH, and low to medium SOC content. Soils of Dang and Narmada districts are moderately shallow (50-75 cm) in nature. Dang's soils have clay and clay loam texture, moderately acidic to slightly acidic pH, and high to very high SOC content whereas soils of Narmada district contain clay loam texture, slightly acidic to slightly alkaline pH, and medium to high SOC content. Navsari and Surat districts are characterized by deep soils, clay and clay loam in texture, with a majority of the area having neutral to moderately alkaline pH and medium to high SOC content. In Tapi district, soil depth ranges from moderately shallow to moderately deep (75-100 cm) with clay soil texture, neutral to slightly alkaline pH, and medium to high SOC content. Valsad has deep soils, mainly clay loam in texture, with slightly acidic to slightly alkaline pH and medium to high SOC content. A significant portion of South Gujarat has an AWC of 8-10%, indicating moderate to high water retention capacity suitable for various agricultural practices.

The detailed study of land resources of South Gujarat region indicated various agricultural constraints, like soil erosion due to deforestation and improper land management, depletion of soil fertility from intensive farming, soil salinity and alkalinity affecting crop growth, reliance on monsoon rains for irrigation, leading to crop failures during dry spells. Considering the potentials and constraints of the

region comprehensive land use options have been suggested. Recommendations were made for highly and moderately suitable areas. Detailed crop suitability assessments were conducted for major crops such as rice, wheat, sugarcane, cotton, pigeon pea, chickpea groundnut and fruit crops. Alternative cropping/farming systems and soil conservation strategies were proposed for non-arable lands.

The report emphasizes the integration of various data sets, including digital soil attribute maps, land use information, and climatic data, to generate district-level agricultural land use plans. The plans incorporate crop suitability, soil and water conservation techniques, and infrastructure availability to prioritize specific interventions and enhance productivity and profitability in the region. The land resource inventory and land use plan for the South Gujarat region provide a robust framework for sustainable agricultural development. The region can achieve enhanced agricultural productivity and environmental sustainability by addressing soil and water management challenges and optimizing land use based on scientific data.

Chapter 1

Introduction

Agriculture contributes 19.9% to India's total Gross Domestic Product (GDP) and provides employment to a large proportion of the country's population (Periasamy and Shanmugam, 2022). About 70% of its rural population still relies on agriculture as their primary source of income. Though India has achieved 'self-sufficiency' in food grains production through green revolution (Abrol and Sangar, 2006), it introduced a host of environmental challenges including natural resource degradation and deterioration of ecosystem services, further aggravated by climate change. Agriculture sector is currently faced with three major challenges– sustaining food and nutrition security, adaptation and mitigation of climate change, and sustainable use of land and water resources. The role of researchers, therefore needs to be re-oriented to meet these challenges through the state-of-the-art, cost-effective and environment friendly scientific tools for achieving the sustainable development goals.

Soil is one of the most valuable, life-supporting natural resources provides food, fuel, fiber, and fodder, and regulates water and nutrient supply to crops. Rising human and animal population coupled with the shrinking per capita land and water availability is threatening the quantity and quality of land resources, adversely affecting agricultural productivity and ecological sustainability. Optimal management of land resources with minimal negative environmental impact is essential not only for sustainable development but also for human survival. In-depth, site-specific knowledge of soils with respect to their extent, distribution, characteristics, use potential, and limitations is, therefore, extremely important to enable the stakeholders in taking judicious land use decisions. Contrary to this, poor knowledge on location specific soil information and of situation-specific recommendations has historically led to the failure of many agriculture-related development schemes in the country. In this context, land resource inventory (LRI) is the best tool to identify the potentials and limitations of land for its optimum utilization.

Generation of LRI calls for regular assessment, monitoring, and mapping of soil at various scales. ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP) has published LRI products at the state, district, and block levels at different scales. Demand for LRI products by researchers and policy makers have rapidly increased in the recent years. Regular monitoring of soil properties at spatial and temporal scale with conventional methods is a time-and cost- consuming task. Thus, although the Bureau's soil resource maps (SRM) were widely accepted by academicians, researchers, and planners, they were produced by using coarse resolution satellite products available at the time. Recent availability of high-resolution satellite images, digital elevation models (DEM), and other secondary data has allowed

researchers to characterize soil features using remote sensing and GIS techniques. Advanced regression models and machine learning algorithms have made it possible to capture land variability with a small number of soil samples while maintaining high accuracy. This led to the development of a hybrid standard operating protocol (SOP) for the preparation of LRI and land use plans (LUPs), wherein conventional survey is integrated with advanced tools.

The Bureau is currently involved in the development of regional LRI information through digital soil mapping (DSM), which is being widely accepted due to its practical advantages over the polygon-based maps. The basic principle of DSM revolves around the soil-forming factors (Jenny, 1941) *viz.* climate, organism, topography/relief, parent material, and time. Variables significantly influencing soil properties are used to develop a predictive function, which is then applied to larger area with previously existing data and parameters, derived from satellite imagery and DEM, thereby saving time, labour and cost. Information generated through LRI on soils and water resources, are used to assess crop suitability for advocating alternate land use options. Recently, ICAR-NBSS&LUP has published LRI/DSM reports of Vidarbha region of Maharashtra (Nagaraju *et al*. 2022), Bundelkhand region of central India (NBSS&LUP and SLUSI, 2022) and Bikaner division (Mina *et al*. 2023) of western Rajasthan. This technical report is the fourth in the series of LRI and LUP products developed through DSM, and cover the South Gujarat region.

The Gujarat state, situated on the west coast is the fifth largest Indian state, covering around 196,244 km^2 and houses 60.4 million people (Census, 2011). It is divided into 33 districts and 252 talukas. The state possesses the longest sea coast spanning 1600 km. Gujarat is endowed with great diversity of ecosystems ranging from deserts, scrublands, grasslands, deciduous forests, wetlands, mangroves, coral reefs, estuaries, and gulfs. About 33.5% of the state's geographical area is already subjected to varying degrees of soil erosion (Chinchmalatpure, 2018). Gujarat exhibits humid, sub-humid and semi-arid to arid climatic conditions, with annual rainfall varying from 311 (Kachchh district) to 3200 mm (Dang district). The state comprises five distinct regions, namely (1) South Gujarat (South Gujarat and South Gujarat Hills), (2) Central Gujarat, (3) North Gujarat, (4) Saurashtra Peninsula (North Saurashtra and South Saurashtra), and (5) Kachchh.

South Gujarat is one of the wettest regions of India. It comprises of seven districts *viz.* Bharuch, Dang, Narmada, Navsari, Surat, Tapi and Valsad, with a total geographical area of 21.34 lakh ha (10.9% of state TGA) and a population of 12.29 million (20.4% of the state). Rice, sugarcane, cotton, pigeon pea, chickpea, mango, sapota, and banana

are the major crops of South Gujarat. However, more than 25 per cent area of the region suffers from various soil-related issues (nutrient imbalance, nutrient depletion, salinization *etc.*) which are comparatively higher compared to the state level.

Considering the foregoing, the ICAR-NBSS&LUP, Nagpur, along with its Regional Centre, Udaipur conducted the DSM for southern region of Gujarat for sustainable agricultural land use planning. The Project was carried out in accordance with the newly established SOP (NBSS&LUP, 2021). The goals of the study were to: (a) create scientific inventory/database of soil resources of South Gujarat; (b) identify soil constraints and potentials; (c) formulate comprehensive agricultural land use plans that consider crop suitability and soil and water conservation. The data products generated through this elaborate exercise are expected to equip stakeholders, particularly policy makers, wasteland developers, and farmers, with the ability to identify hotspots that require immediate interventions and to channel development activities in the region based on scientific input.

Chapter

2

South Gujarat Region: An Insight

South Gujarat region of Gujarat state, located between 20° 07' 20.37" N to 22° 14' 32.27" N latitude and 72° 44' 24.09" E to 74° 19' 56.44" E longitude with a total geographical area (TGA) of 21,338 km^2 comprises seven districts *viz.* Bharuch, Dang, Narmada, Navsari, Surat, Tapi and Valsad. South Gujarat region covers 10.87% TGA of Gujarat state (Figure 2.1). Geographically, South Gujarat is characterized by its proximity to the Arabian Sea, which influences its climate, soil and vegetation. The region is blessed with a varied topography, encompassing forests, fertile plains, and coastal areas. The Western Ghats form the eastern boundary of South Gujarat, providing breathtaking views and serving as a habitat for diverse flora and fauna. One of the most iconic features of South Gujarat is its coastline, which stretches along the Arabian Sea. South Gujarat region experiences a semi-arid to tropical climate with low to high rainfall and moderate temperature. In the Western Ghats, the weathering of basaltic rocks contributes to the formation of Inceptisols and Vertisols in plains and lateritic soils in hilly terrain (Pal *et al.* 2012). Overall, the climatic conditions, soils, and weathering of parent materials in South Gujarat region interact to create a diverse and dynamic landscape that supports agriculture, biodiversity, and human habitation (GSI, 2010). Understanding these factors is essential for sustainable land use and resource management in the region. Important district-wise demographic statistics of the region is presented in table 2.1.

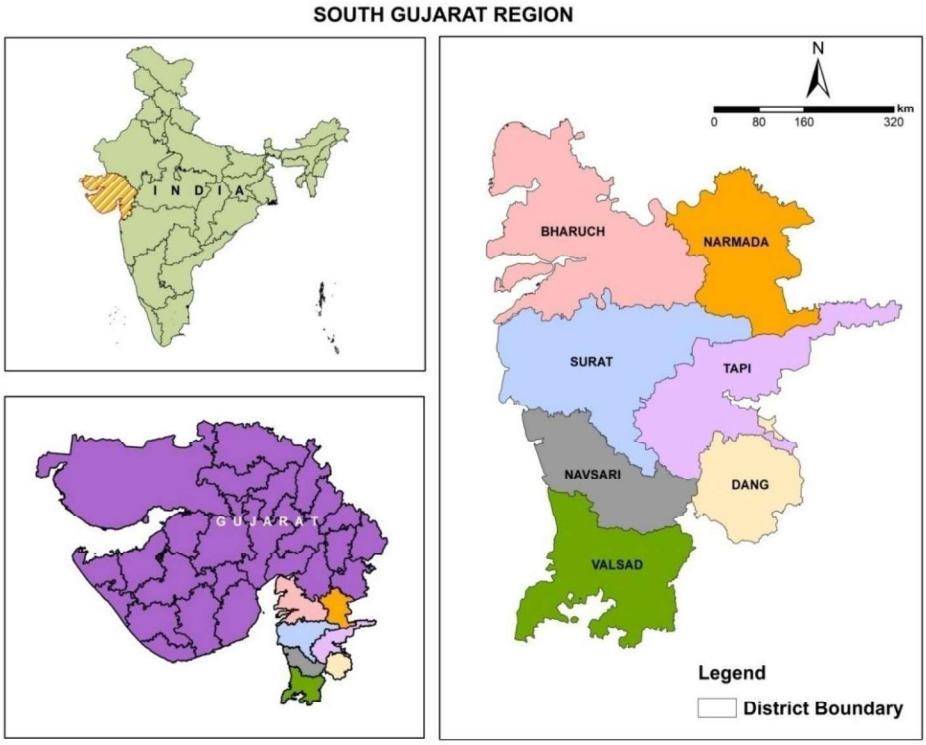

Figure 2.1: Location map of South Gujarat region

Chapter 3

Methodology

A comprehensive protocol was followed for regional agricultural land use planning for the South Gujarat region, which has three stages:

1. Compilation of baseline data, including soil-site characteristics, agro-ecological regions and sub regions, landforms, land use patterns, land degradation, sea water inundation on west coast, and incorporation of legacy soil data from the South Gujarat region.
2. Digital soil mapping of South Gujarat region
    a) Soil survey and sampling
    b) Laboratory analysis of soil samples
    c) Modeling and mapping of soil properties
3. Generation of district-wise land use plan
    a) Crop suitability analysis
    b) Development of agricultural land use plan
    c) Development of soil and water conservation plan

Compilation of baseline data and legacy soil data of South Gujarat region

Various maps illustrating the current condition of the South Gujarat region, including agro-ecological regions, land use/land cover, and parent material, were either generated internally at the Bureau using existing data or sourced from entities such as ESRI and the Geological Survey of India. Baseline data on land use statistics, cropping area, crop production and productivity and irrigation status were accessed from various government sources. The databases originated from Soil Resource Mapping projects conducted at 250k and 50k as well as from Land Resource Inventory based projects undertaken by the Bureau/other organizations, including postgraduate and Ph.D. theses and research papers.

Soil Survey and Sampling

A detailed soil survey of the Bharuch, Navsari, Surat and Valsad districts was carried out at 1:10,000 scale using conventional approach of soil survey. In conventional approach, Landform and landscape ecological units maps (LEU's) were used as a base maps and traversed the area to understand the corresponding variability in soils (soil-landform relationship). The soil survey used a transect approach from higher to lower elevations, covering all identified LEUs. The LEU map was created by integrating landform, slope and land use. In the Dang, Narmada and Tapi districts, detailed soil survey was carried out following the NBSS&LUP-2021; Standard Operating Protocol. In this survey, terrain mapping units (TMUs) map and sampling framework were used

Chapter

4

Soil Resources of South Gujarat Region

This chapter presents a detailed analysis of soil properties across various districts and talukas, highlighting their spatial distribution, potentials and limitations for selecting suitable crops and land uses. It also identifies constraints and problems that require prioritized interventions. Additionally, the chapter provides comprehensive soil information for the South Gujarat region to support sustainable land use management. Detailed maps showing various soil properties in the South Gujarat region are included in Annexure 1.

4.1 South Gujarat Region

The soil resources of South Gujarat are diverse and fertile, significantly contributing to the region's agricultural productivity and economic activities. This area features a variety of soil types due to its varied topography, climatic conditions, and proximity to the Arabian Sea. Predominantly, the soils in the region are alluvial, which is highly fertile and support the cultivation of a wide range of crops, including rice, sugarcane, cotton, pigeon pea, various fruits and vegetables. In the coastal regions, the soil tends to be saline due to seawater intrusion. Black soils are also found in parts of South Gujarat, particularly in the regions bordering the Deccan Plateau.

The spatial distribution of important soil characteristics (soil depth, texture class, sand, silt, clay, AWC, pH, EC, SOC and $CaCO_3$ content) across the different districts in the South Gujarat region is illustrated in figures 4.1, 4.2, 4.3, 4.4, & 4.5 and detailed in tables 4.1, 4.2, & 4.3. The results of predictive soil properties maps revealed that the soils are deep (100-150 cm depth), covering 901.30 thousand ha (42.24% of TGA), followed by moderately shallow (295.74 thousand ha, 13.86%), and moderately deep soils (272.50 thousand ha, 12.77%). The soil texture is clay (785.59 thousand ha, 36.82% of TGA) and clay loam (621.30 thousand ha, 29.12%). The available water content (AWC) for most of the region (1083.84 thousand ha, 50.80%) is in the range of 8-10%. The particle size distribution shows that 1258.96 thousand ha (59.00%) of the TGA contains 20-40% sand, 1075.30 thousand ha (50.39%) contains 20-35% silt, and 899.01 thousand ha (42.13%) area contains 35-45% clay. In terms of soil pH, the majority of the region is moderately alkaline (644.34 thousand ha, 30.20%), followed by neutral (348.38 thousand ha, 16.33%), slightly alkaline (326.07 thousand ha, 15.28%), slightly acidic (190.57 thousand ha, 8.93%), and moderately acidic (44.55 thousand ha, 2.09%) in nature. The electrical conductivity (EC) is generally low (<2

Chapter

5

District-wise Land Use Plan for South Gujarat Region

The final phase of the land resource inventory (LRI) and land evaluation for the South Gujarat region involved creating comprehensive land use plans for its seven districts, as detailed in this chapter. These plans encompass crop suitability assessments, alternative cropping/farming system plans and soil conservation and water harvesting strategies. Following the analytical hierarchy procedure (AHP), area-specific crop suitability of different crops was determined and identifies the crop-specific highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and non-suitable (N) areas. Crop recommendations were made only for areas, which is classified as highly suitable and/or moderately suitable. For non-arable lands, recreational and other livelihood options are proposed. Various parameters, such as rainfall, temperature, distance to canals, proximity to the Narmada and Tapi river basins, relative slope position, and soil characteristics (including texture, pH, electrical conductivity, soil organic carbon, and calcium carbonate content), were considered in the analytical hierarchical process. These factors were used to develop crop suitability assessments and recommend appropriate land management practices across the South Gujarat region for sustainable land use planning.

5.1 Crop Suitability

In the South Gujarat region, the primary crops cultivated include rice, wheat, sugarcane, cotton, pigeon pea, chickpea, mango, banana, sapota, and groundnut. The suitability of these crops and the potential zones for their cultivation categorized as highly, moderately and marginally suitable, are outlined in table 5.1, 5.2 & 5.3 and figure 5.1, 5.2, 5.3, 5.4 & 5.5. Detailed discussions on district-wise crop suitability of different crops are explained below.

In **Bharuch** district, the highly suitable area for rice crop cultivation is 147.44 thousand ha (31.07%), with moderately suitable land covering 141.44 thousand ha (29.80%), and marginally suitable at 104.51 thousand ha (22.02%). For wheat cultivation, the highly suitable area is 126.92 thousand ha (26.74%), while 142.78 thousand ha (30.09%) is moderately suitable, and 96.02 thousand ha (20.23%) is marginally suitable. The non-suitable area for rice and wheat cultivation is 4.69 and 10.51% of TGA, respectively. For pigeon pea, the highly suitable area is 148.99 thousand ha (31.39%), moderately suitable is 215.18 thousand ha (45.34%), marginally suitable is 29.04 thousand ha (6.12%), and non-suitable is 22.42 thousand ha (4.72%). Chickpea cultivation follows with 201.93 thousand ha (42.55%) area as highly suitable, 85.58 thousand ha (18.03%) area as moderately suitable, and 98.04 thousand ha (20.66%) area as marginally

Annexures

हर कदम, हर डगर
किसानों का हमसफर
भारतीय कृषि अनुसंधान परिषद

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