



GIS Based Spatial Analysis of Soil Characteristics and Their Implication for Agribusiness Decision Making: A Case Study of Satara District, Maharashtra

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Abstract

Soil is a vital natural resource and its spatial variability profoundly influences agricultural productivity and the sustainability of agribusiness. This study presents a GIS based spatial analysis of soil types, depth, and pH in the Satara district of Maharashtra to evaluate their impact on agribusiness decision making. Analysis using multi layered GIS datasets including maps of soil texture and depth reveals significant variations across the district's eleven tehsil. Key findings indicate that loamy (34.15%) and clayey (29.91%) soils predominate in the district, while very shallow soils cover the largest area (34.07%). Calcareous soils occupy approximately 32% of the area and soil pH ranges from acidic in the western highlands to neutral alkaline in the central and eastern plains. The western Tehsil (Mahabaleshwar, Jaoli and Patan) feature shallow, clayey soils with an acidic tendency whereas the central and eastern talukas (Karad, Koregaon and Phaltan) contain deep clayey soils suitable for intensive crop cultivation.

This study demonstrates that the integration of GIS based soil parameters enables precise zoning for crop suitability targeted input management, and risk assessment. Recommendations include cultivating sugarcane and cotton in deep clayey regions pearl millet and pulses in shallow alluvial areas and orchards in the western hilly tracts. This information assists farmers the agro-industry and policymakers in implementing precision agriculture and soil conservation strategies, as well as making informed investment decisions. The research facilitates evidence based agricultural planning across geographically diverse regions and aligns with national objectives regarding sustainable agriculture and the doubling of farmers' income.

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Keywords: GIS, Soil Spatial Analysis, Soil Texture, Soil Depth, Crop Suitability, Agribusiness.

Introduction:

The social, economic and political development of any region depends on its natural and human resources. Natural resources encompass various elements such as air, water, soil, flora, and fauna. On the other hand human resources are based on factors like technology, skills, and literacy. A country's natural and human wealth constitutes its national wealth. Soil is a vital natural resource and planning for its proper utilization is essential. Indeed, soil is a crucial natural resource upon which human activities depend. Despite its importance soil quality has been deteriorating recently due to widespread misuse creating an urgent need for soil conservation. Soil is viewed as the foundation of life on Earth and fertile soil serves as the backbone of agriculture and food production. The fertile high quality soil promotes vigorous plant growth and ensures excellent crop yields. Plants derive nutrients from two natural sources within the soil organic matter and minerals (Sonawane V. R. et al., 2020;2020). Soil organic matter not only provides nutrients and a habitat for soil dwelling organisms but also helps retain water among soil particles. Nutrients play a role in binding soil particles together. The chemical properties of soil are primarily determined by its organic matter colloidal characteristics reactivity acidity or alkalinity and structural attributes. Chemical components are crucial for maintaining the proper balance of nutrients in the soil. Furthermore soil is regarded as a reservoir of nutrients for agriculture. The chemical, physical and biological properties of soil influence the generation of soil nutrients. That is why these three components are considered essential for the proper functioning of soil. Soil is a mixture of various minerals, organic matter, gases, microorganisms and other substances and its functioning depends on the combination of these components (Gadekar, D. J et al., 2024).

Soil is a fundamental natural resource that underpins agricultural productivity, food security, and rural livelihoods. Its physical, chemical, and biological properties directly influence crop suitability, nutrient availability and water holding capacity and overall ecosystem services. In India, where agriculture is the backbone of the economy and a major source of employment, understanding spatial variations in soil types is crucial for sustainable land management and informed decision making (Kharde M. N 2022). Geographic Information Systems (GIS) have emerged as powerful tools for spatial analysis in agriculture. By integrating diverse datasets such as remote sensing imagery, soil surveys, topographic features, climatic data, and field observations GIS generates detailed maps of soil properties, identifies patterns of variation and supports precision agriculture practices. Through capabilities like visualization interpolation e.g., Inverse Distance Weighting and overlay analysis GIS facilitates site-specific recommendations for crop selection, fertilizer application, irrigation and erosion control. This approach shifts management practices from traditional uniform methods to data driven location specific strategies that enhance productivity while minimizing environmental degradation (Tupe B.K 2010).

GIS based soil analysis offers immense benefits to agribusiness decision making processes, encompassing farm operations, supply chain management, input investment, market linkages and risk assessment. Accurate spatial maps assist stakeholders such as farmers, cooperatives, policymakers, and agribusiness companies in optimizing resource allocation, forecasting yields, mitigating risks associated with climate and land degradation, promoting soil health management and supporting sustainable intensive agriculture. In the context of Maharashtra's agricultural economy and national objectives regarding precision farming and food security, such analysis bridges spatial data gaps and enhances resilience against challenges like land degradation and climate change (Aggag, A.M., Alharbi, A. 2022)

This study employs GIS technology to conduct a spatial analysis of soil types in the Satara district, mapping their distribution, properties and suitability. It evaluates the implications for agribusiness and provides actionable insights for crop planning, soil conservation, and economic decision support. The findings aim to contribute to evidence based policies designed to enhance agricultural sustainability and productivity in similar semi-arid, geographically diverse regions. Soil serves as the foundation of the agricultural system, directly influencing crop growth, yield potential, water retention capacity, nutrient cycling and ecosystem resilience. In India where the agricultural sector employs nearly half the workforce and forms the core of the rural economy, understanding the spatial distribution of soil properties is essential for sustainable land use planning and climate resilient agribusiness (Medhe R.S et al., 2024;2024)

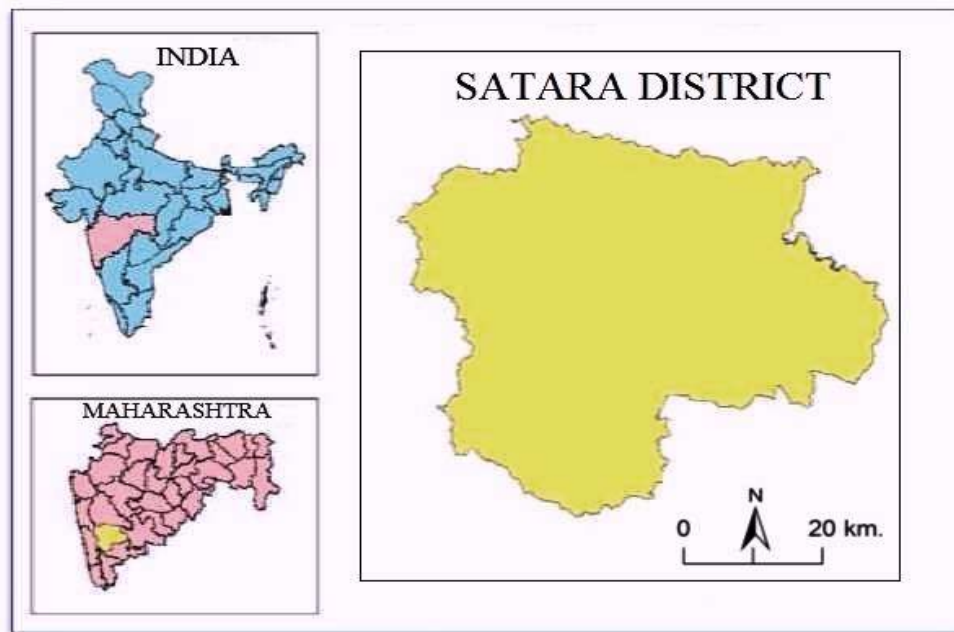
Geographic Information Systems (GIS) have become essential tools for modern agricultural research. By integrating remote sensing data, field surveys and thematic layers, GIS facilitates detailed mapping, overlay analysis and spatial modelling. Techniques such as Inverse Distance Weighting (IDW) and Multi Criteria Decision Analysis assist researchers in creating high resolution soil maps and gaining actionable insights for precision agriculture. This shift from uniform management to site specific management significantly improves resource use efficiency and reduces environmental degradation.

Study Area:

Satara district in Maharashtra is situated between 17°05' and 18°11' North latitudes and 73°45' and 74°45' East longitudes, covering an area of 10,195.48 square kilometres. Located within Maharashtra's Western Ghats region, this district serves as an ideal case study for this type of analysis. Spanning eleven tehsils the district exhibits significant diversity in its physiography, ranging from the rocky and high rainfall terrain of the Western Ghats in the west to the plateau and plain regions in the east. Factors such as 'Deccan Trap' basaltic rock, varied landforms,

uneven rainfall distribution, and erosion processes have resulted in significant diversity and complexity regarding soil types and their composition.

Map no 01: Location map in study area



Aims And Objective

GIS Based Spatial Analysis of Soil Characteristics and Their Implication for Agribusiness Decision Making. This is the main objective of the research.

To fulfill the main objective of this research, the following various aims have been adopted.

1. Analyze the spatial distribution of soil types, depth, and pH using GIS.
2. To assess tehsil wise crop suitability based on integrated soil parameters.
3. To evaluate implications for agribusiness planning, precision agriculture and sustainable development in Satara District.

Methodology

This study adopts a GIS based spatial analysis approach combining secondary data.

Data Sources:

1. Soil types, depth maps and soil pH consequent from district level soil surveys.
2. Ancillary layers, Topographic maps, administrative boundaries tehsil level.
3. Existing GIS databases for validation.

GIS Tools and Techniques:

1. **Software used:** ArcGIS / QGIS for spatial analysis and mapping.
2. **Data processing:** Digitization, georeferencing, and projection standardization (WGS 84 / UTM).
3. **Spatial interpolation:** Inverse Distance Weighting (IDW) and Kriging methods for generating continuous soil property surfaces where point data was available.
4. **Overlay analysis:** Multi-layer integration of soil types, depth and pH maps to create composite suitability zones.
5. **Area calculation:** Zonal statistics and tabulation for tehsil wise quantification of soil categories.

Analytical Framework:

1. Quantitative analysis of area statistics for each soil parameter.
2. Tehsil wise comparative assessment of soil suitability for major crops using established soil crop compatibility criteria.
3. Integration of Soil depth and soil types data to refine nutrient management and crop recommendations.

This methodology ensures a robust reproducible and geographically explicit assessment of soil resources for informed agricultural business planning.

Table no 01: Researches Methodology

Component	Description
Study Area	Satara District, Maharashtra 17°05' to 18°11' N and 73°45' to 74°45' E, covering 10,195.48 sq. km across 11 tehsils.
Research Design	GIS-based spatial analysis using secondary soil data and multi-criteria overlay technique.
Data Sources	1. Soil Texture & Depth Maps (District Soil Survey)

	2. Topographic, rainfall and administrative boundary layers 3. Satellite imagery for validation
GIS Software	ArcGIS / QGIS
Data Processing	Digitization, georeferencing, projection (WGS 84), layer alignment
Spatial Analysis Techniques	1. Inverse Distance Weighting (IDW) & Kriging for interpolation 2. Zonal Statistics for area calculation 3. Multi-layer Overlay Analysis (Soil Types, Depth and pH)
Crop Suitability Analysis	Weighted overlay and rule based classification using soil crop compatibility criteria
Tehsil-wise Analysis	Zonal statistics extracted for all 11 tehsils
Limitations	Reliance on secondary data; recommends high-resolution village-level validation for future studies

LIMITATIONS:

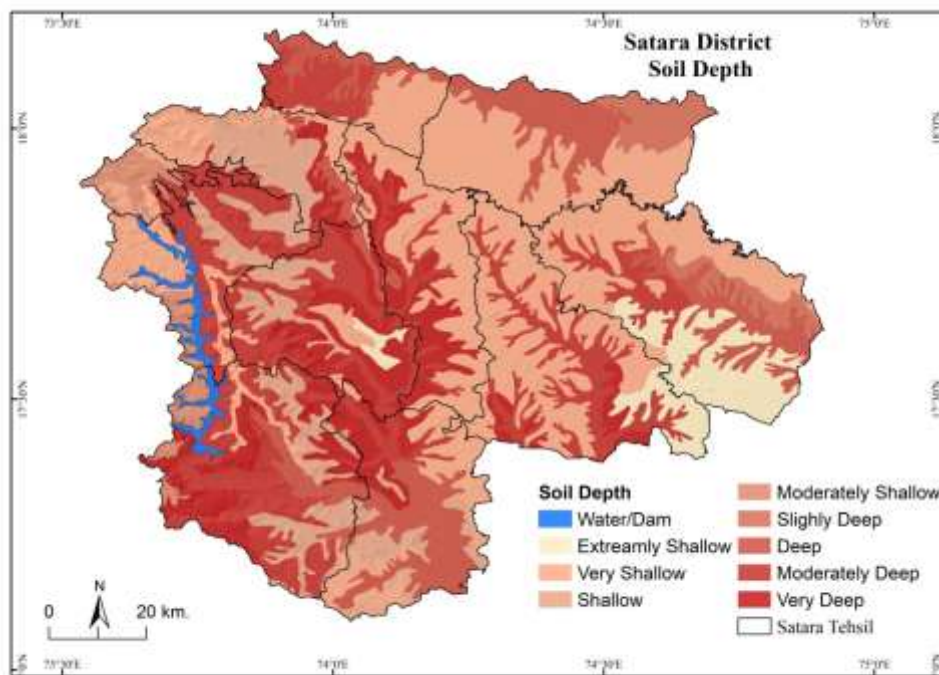
This study is primarily based on available secondary GIS layers and aggregated district level data.

Result and discussion:

Soil is a fundamental pillar of agricultural productivity, food security and sustainable rural development. Regional variations in soil texture, depth, nutrient status, pH levels and organic matter content significantly influence crop suitability, productivity potential, water holding capacity and susceptibility to degradation. In India where agriculture is a source of livelihood for millions and contributes significantly to the national economy, accurate information regarding soil distribution is essential for evidence based agribusiness planning and policy formulation (**Soniya Sonkar 2021**). Satara district is situated in the Western Ghats region of Maharashtra, exhibits diverse geographical and agro climatic characteristics, making it highly suitable for such studies. The district features varied landforms ranging from the hilly Western Ghats to plateaus and plains and its soil is influenced by basaltic rock. Soil types include medium to deep black cotton soils in the eastern plains suitable for sugarcane, cotton, wheat and sorghum light or red loamy soils found on slopes and in the western region suitable for paddy, sorghum and laterite soils in upland areas. Factors such as uneven rainfall distribution heavy rainfall in Ghat areas like Mahabaleshwar versus low rainfall in drought prone zones, temperature fluctuations and the risk of erosion lead to significant regional variations in soil depth, texture e.g., clay vs. loam, nutrient status macro nutrients like nitrogen, phosphorus, and potassium, as well as micro nutrients, organic carbon, pH, and salinity. Studies reveal significant variations across the different tehsils. Nutrient deficiency, the loss of topsoil due to erosion, and the consequent impact on crop productivity are among the major challenges. Geographic Information Systems (GIS) have revolutionized regional analysis in agriculture by integrating multi layered datasets such as remote sensing data, soil surveys, landforms and climatic factors. GIS enables the creation of high resolution thematic maps and facilitates overlay analysis, suitability modelling and interpolation techniques like Inverse Distance Weighting or Kriging. These tools promote 'precision agriculture' by providing location specific recommendations for crop selection, fertilizer management, irrigation planning and soil conservation measures. This data driven approach facilitates a shift from generalized recommendations toward land use strategies that are appropriate, efficient, and sustainable based on local conditions. Situated in the transition zone of the Western Ghats, Maharashtra's Satara district serves as an excellent example of the region's complex geographical and soil diversity. The district's terrain extends from the rugged Western Ghats in the west to the plateaus and plains in the east, resting primarily on the basalt rock formations of the Deccan Traps. Consequently, the interaction between climate slope and parent rock has resulted in the formation of diverse soil types.

Table 2 shows the soil depth in Satara district, while Map 2 illustrates the geographical distribution of these soil depths in Satara district. These indicate that the greatest soil depth is found primarily in the south-western part of the district, significant soil depth is also observed in parts of the north-eastern and north and south regions, whereas the remaining areas generally exhibit moderate soil depth.

Map no 02: Soil Depth in study area

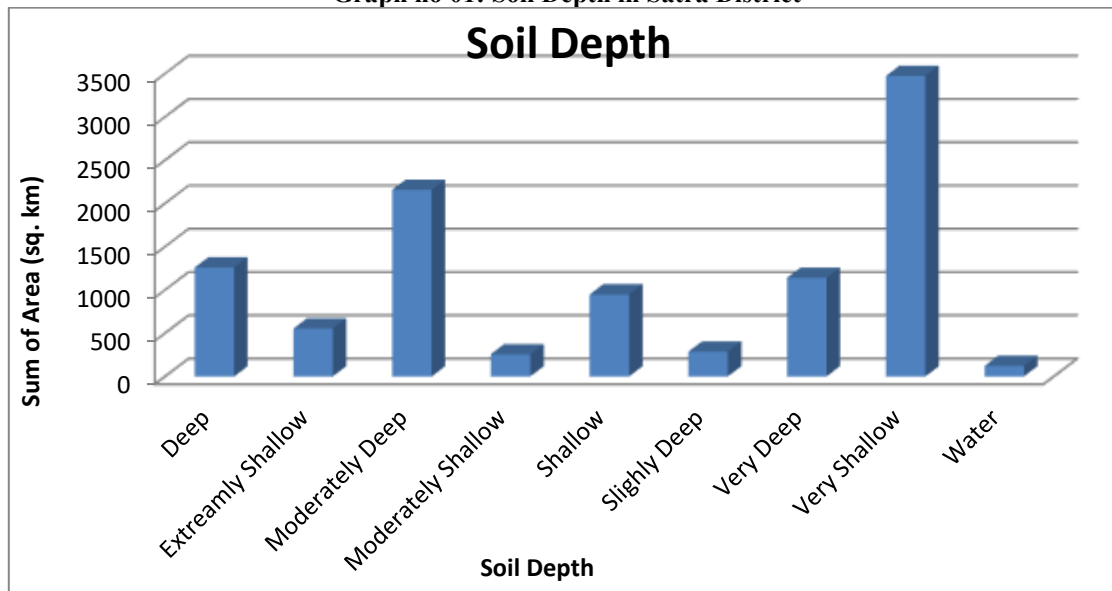


A study of soil depth in Satara district reveals the following distribution, the largest area is covered by 'Very Deep' soil, geographical are about 3,473.3 Sq km (34.07%) this is followed by 'Moderately Deep' soil, which covers 2,156.48 Sq km (11%), the smallest area is occupied by 'Slightly Deep' soil.

Table no 02: Soil Depth with area in Satara District

Soil Depth	Area (sq. km)	Percentage (%)
Deep	1259.3	12.35
Extremely Shallow	553.59	5.43
Moderately Deep	2156.48	21.15
Moderately Shallow	256.36	2.51
Shallow	947.88	9.30
Slightly Deep	286.6	2.81
Very Deep	1140.03	11.18
Very Shallow	3473.3	34.07
Water	121.93	1.20
Grand Total	10195.48	100.00

Graph no 01: Soil Depth in Satara District



Main Causes of Soil Depth Variation in Satara District

The terrain of Satara district exhibits great diversity, extending from the steep slopes of the Western Ghats (Sahyadri mountain ranges) in the west to the plains and river valleys such as the Nira river valley in the east. Consequently, significant variations in soil depth are observed. This is primarily attributed to the following factors.

1. Topography and Slope:

a) Steep slopes and hill ranges in western and sub-mountain areas (Western Ghats) promote rapid runoff and erosion, resulting in shallow to very shallow soils. Gentler plains and valleys allow greater soil accumulation, leading to moderately deep to very deep soils.

2. Erosion (Water Erosion Dominant):

a) Heavy monsoon rains cause significant soil loss on slopes. Deforestation, overgrazing, and intensive land use accelerate this, especially in upland or hilly regions. Very shallow soils are common where erosion has removed topsoil over time.

3. Parent Material and Geology:

a) Predominantly basaltic rocks (Deccan Traps). Weathering of basalt produces black soils that can be deep in plains but remain shallow on ridges or plateaus. With the Variations in rock type e.g., alluvium in river basins vs. residual soils on hills influence depth.

4. Climate and Rainfall:

a) Orographic rainfall is higher in the west (Western Ghats), intensifying erosion there. Eastern parts are relatively drier or scarcity zones with better soil accumulation in some areas.

5. Land Use and Human Factors:

a) Agriculture, grazing, and deforestation reduce vegetation cover, increasing erosion and limiting soil formation. Plains often have deeper black cotton soils suitable for crops like sugarcane hilly areas have lighter/reddish shallow soils.

Implications

a) **Agricultural Challenges:** Shallow soils limit root growth, water storage, and nutrient availability lower productivity, higher drought risk.

b) **Management Suggestions:** Contour bunding, terracing, afforestation, and conservation tillage on slopes can help reduce erosion and build soil depth over time.

Map No. 3 illustrates the soil types found in Satara district, where six primary soil varieties are observed. It is evident from the map that clayey soil is predominant in the western and south-western regions, while loamy soil is found in the central and west central areas conversely, loamy calcareous soil is characteristic of the northern region. These soil types have been shaped by the local topography, climate, rainfall, and vegetation.

Map no 03: Soil Types in study area

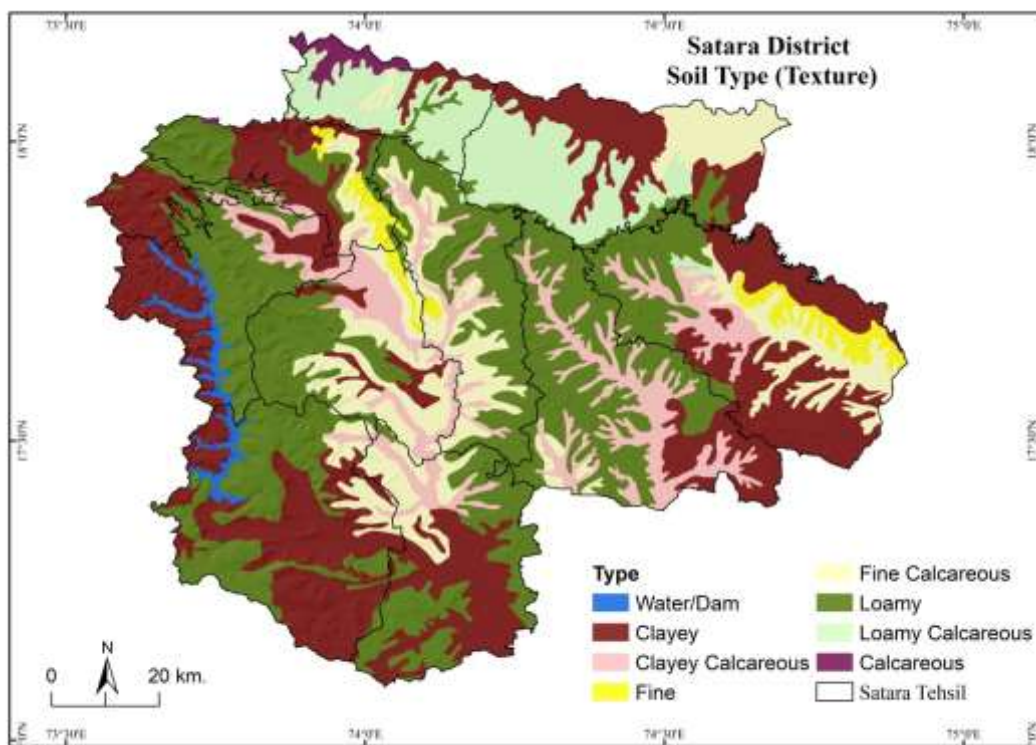
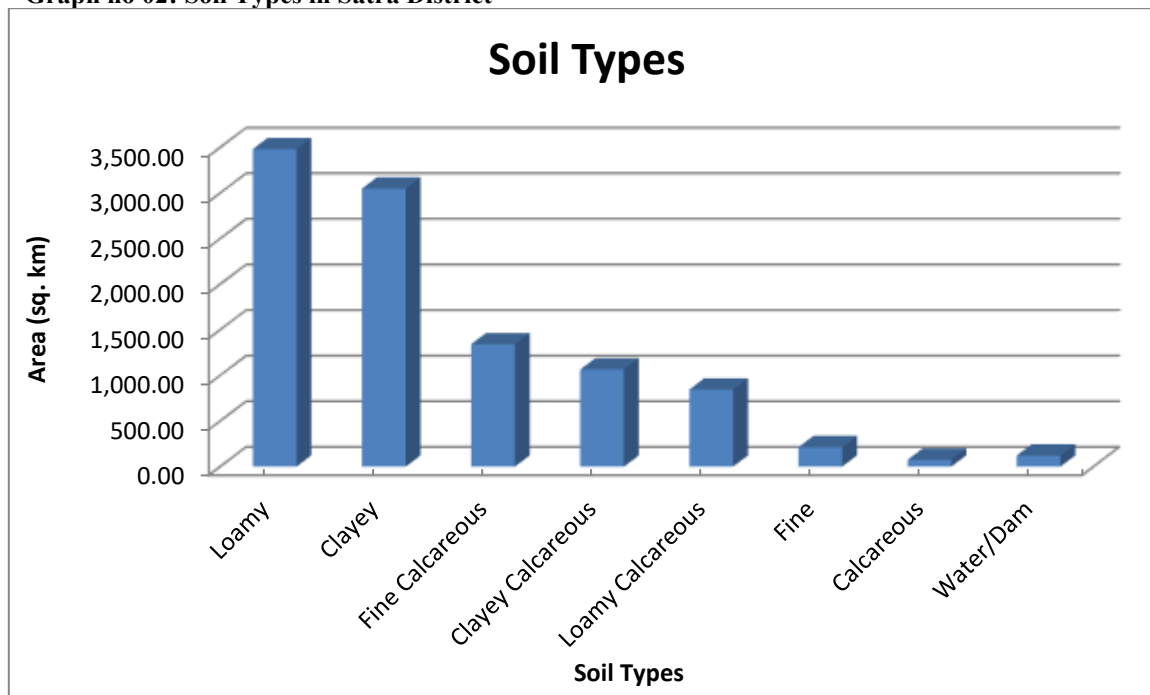


Table no 03: Soil Types with Area in Satara District

Soil Type	Area (sq. km)	Percentage (%)
Loamy	3,481.75	34.15
Clayey	3,049.55	29.91
Fine Calcareous	1,341.87	13.16
Clayey Calcareous	1,065.74	10.45

Loamy Calcareous	845.05	8.29
Fine	214.01	2.10
Calcareous	75.57	0.74
Water/Dam	121.93	1.20
Grand Total	10,195.48	100.00

Graph no 02: Soil Types in Satara District



Main Causes of Soil Type Variation in Satara District:

Satara district lies in the Deccan Plateau region, primarily underlain by **Deccan Trap basalts**. Soil formation is influenced by the interplay of geology, topography, climate and erosion processes.

1. Parent Material (Geology):

a) **Deccan Trap basalts** weather into clay rich soils, especially **clayey** and **fine** types. Basalt is rich in minerals that produce montmorillonite clays leading to black cotton soils (Regur) in many areas. As well as the Variations in basalt composition and weathering intensity create loamy vs. clayey textures.

2. Topography and Landscape Position:

a) **Western Ghats and Sub-mountain areas (Steep Slopes):** Higher erosion leads to shallower, lighter **loamy** or reddish soils with less accumulation.

b) **Plains and valleys (Eastern and Central Parts):** Gentler slopes allow greater soil deposition, resulting in deeper **clayey** and **calcareous** soils.

c) **River Basins** (e.g., Krishna, Koyna) have alluvial influences contributing to loamy textures.

3. Climate and Rainfall:

a) Orographic effect in the west brings heavy monsoon rains intense chemical weathering of basalt clay formation and leaching, but also erosion on slopes and Eastern parts (rain-shadow) are drier slower weathering but better preservation of calcareous (lime-rich) characteristics.

4. Calcareous Nature:

a) High calcium carbonate content from basalt weathering leads to **fine calcareous**, **clayey calcareous** and **loamy calcareous** soils. These often show effervescence with acid and are common in semi-arid to sub humid zones with limited leaching.

5. Erosion and Human Factors:

a) Water erosion on slopes removes finer particles, leaving loamy or skeletal soils. With the Deforestation, agriculture and overgrazing accelerate erosion and influence soil depth/texture. Traditional land use e.g., sugarcane in black clayey soils further modifies surface layers.

Implications for Agriculture:

a) **Clayey soils:** High water or nutrient retention but poor drainage prone to cracking when dry soil.

b) **Loamy soils:** Better balanced for most crops due to good drainage and workability.

c) **Calcareous soils:** Can cause micronutrient deficiencies (e.g., iron, zinc) due to high pH.

Highlights Soil Analysis in study Area:

While studying the texture of the land, it was mainly found that: In the areas where this land is found, its area is mainly loamy soil 3,481.75 Sq. km (34.15%) is found and loamy soil covers a geographical area of 3,049.55 sq. Km (29.91%) is found. It includes significant calcareous soil types such as fine calcareous, clay calcareous and

poita calcareous, covering about 32% of the total area. While studying the depth of land, it was mainly found that 3,473.30 sq km. of very shallow lands in this area. (34.07%) proportion is highest. It is followed by medium deep (21.15%) and deep soils. Soil pH studies mainly found that soil pH ranges from acidic in western tehsils to neutral alkaline in eastern tehsils which affects nutrient availability.

This regional diversity in soil types directly influences decision-making within the agricultural sector. It enables farmers and stakeholders to make optimal choices regarding crop selection, fertilizer application, irrigation planning and market related strategies. For instance, the deep clayey soil found in the Karad and Koregaon talukas is highly suitable for sugarcane and cash crops conversely the shallow yet fertile alluvial or loamy soil in the western tehsils provides favourable conditions for cereals, pulses, and horticultural crops like Mahabaleshwar strawberries.

Tehsil wise Crop Suitability

A geographical study of Satara district regarding crop suitability divides the area into three sections: the western, central and eastern parts. This study identifies the specific tehsils included in each section and determines which crops are suitable for cultivation in these areas, based on factors such as soil texture, soil depth and soil pH.

1. Western Parts (Tehsil Name is Mahabaleshwar, Jawali, Patan and Wai): Emphasis on cereals (coarse grains), rice, pulses, and horticulture (strawberries, vegetables) due to shallow and loamy soils.
2. Central Parts (Tehsil Name is Satara, Koregaon and Karad): Highly favourable for crops like sugarcane, onions, wheat, and maize due to deep, clayey soils.
3. Eastern Parts (Tehsil Name is Phaltan, Man, Khatav): Production of sorghum (Jowar), pearl millet (Bajra), cotton and pulses, supported by proper management of calcareous and shallow soils.

The provided GIS based Soil Types Map of Satara District vividly illustrates this spatial variability:

Clay content is high in large areas, particularly in the eastern and central regions while the soil retains nutrients effectively, water drainage can be problematic. Silt rich soil is widespread, offering a balanced texture ideal for diverse cropping systems. Additionally, calcareous silty and calcareous silty clay soils indicate areas with high calcium content, whereas fine textured calcareous soils and calcareous bands are noted for their high lime richness. Fine textured soil (dark yellow) is found in specific areas and reservoirs or dams are marked in blue.

This has far reaching implications for the decision making process in agribusiness. Soil maps generated using GIS empower farmers, cooperative societies, input suppliers, financial institutions and policymakers.

1. Optimize crop planning; for instance, cultivate sugarcane and cotton in deep clay soils, while growing coarse grains and pulses in light textured (alluvial or loamy) soils.
 2. Plan fertilizer management and soil amendments based on localized soil nutrient deficiencies.
 3. Assess the risks and insurance requirements associated with investments in soil health.
 4. Formulate supply chain systems and market strategies aligned with production areas.
 5. Support government initiatives such as 'Soil Health Cards,' precision farming, and climate resilient agriculture.
- This GIS based spatial analysis of soils in Satara district provides valuable insights for Maharashtra's agriculture driven state economy and supports national priorities such as doubling farmers' income and achieving sustainable development. The analysis addresses data gaps regarding soil characteristics and fosters informed, resilient agricultural policies across geographically diverse regions transitioning from rain-fed to irrigated farming. Utilizing GIS techniques, the study maps soil types and analyzes their distribution and properties; it evaluates their direct impact on agriculture and presents practical recommendations for enhanced productivity and sustainability.

Observations for Agribusiness Decision Making:

1. **Major Soil Types:** Alluvial or mixed or silt mixed or loamy soil covering Area about 34.15% and clayey soil is 29.91% soils together cover 64.06% of the district's total area. These soils are generally fertile and suitable for intensive cultivation.
2. **Calcareous Soils:** Fine textured calcareous, clayey calcareous and mixed calcareous soils collectively covering area about 31.9%. This indicates a significant presence of soils with high calcium carbonate content this characteristic influences nutrient availability especially phosphorus and pH levels.
3. **Other or Minor Types:** Fine textured and calcareous soils are found in relatively smaller areas but are crucial for site specific management.
4. **Major Classification:** Very shallow soils cover the largest area about 34.07%. This limits the cultivation of deep rooted crops and increases the risk of soil erosion, particularly in the hilly western region.
5. **Deep Soils:** Deep, very deep and moderately deep soils together cover area is 44.68% of the district's area. These soils are highly suitable for intensive farming and high value crops.
6. **Shallow Soils:** Extremely shallow, very shallow, shallow, and moderately shallow soils cover 51.31% of the total area. This creates challenges regarding water holding capacity, nutrient retention, and root growth.
7. **Management Aspects:** In areas with shallow soils, special attention must be paid to soil conservation, moisture retention measures, and the selection of drought tolerant or shallow rooted crops.

TEHSIL WISE CROP SUITABILITY IN SATARA DISTRICT BASED ON GIS SOIL TEXTURE, SOIL DEPTH:

Satara district comprises 11 Tehsils exhibiting geographical, social, economic, and demographic diversity. The western Tehsils was Mahabaleshwar, Jawali, Patan, Wai, Satara, and parts of Khandala receive heavy rainfall. Consequently, this region is characterized primarily by clayey or calcareous clayey soils, soil depths ranging from very shallow to shallow, and pH levels varying from relatively acidic to neutral. In contrast, the central and eastern Tehsils are Karad, Koregaon, Phaltan, Man and Khatav predominantly feature clayey or calcareous clayey soils, medium to very deep black soils, and pH levels ranging from neutral to alkaline.

The variation in crop production and cultivation areas across Satara district depends primarily on local soil characteristics, such as soil type, depth, and pH levels.

1. Mahabaleshwar (Hilly, High Rainfall area):

A. **Dominant Soils:** Loamy, Fine, Very Shallow to Extremely Shallow, Lateritic influence and soil **pH** is More acidic (higher % acidic samples).

B. **Suitable Crops:** In this region based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types , depth and pH levels, the following crops can be cultivated.

- a) **Horticulture:** Strawberry (famous), vegetables, spices, flowers.
- b) **Field Crops:** Rice (paddy in valleys), Ragi, Vari, other millets, Jowar.
- c) **Others Crops:** Groundnut, pulses (Tur, Udid), potato.

2. Jaoli (Western Hilly area):

A. **Dominant Soils:** Loamy, Loamy Calcareous, Very Shallow to Shallow and soil **pH** is Acidic to neutral (higher acidic percentage).

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types , depth and pH levels, the following crops can be cultivated.

- a) Rice (paddy major), Millets (Ragi, Sava), Jowar, Bajra.
- b) Pulses, Groundnut.
- c) Horticulture: Vegetables, fruits in suitable pockets.

3. Patan (Western Transition area)

A. **Dominant Soils:** Mix of Loamy & Clayey, Shallow to Moderately Deep and soil **pH** is mostly neutral.

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types , depth and pH levels, the following crops can be cultivated.

- a) Rice, Jowar, Wheat.
- b) Sugarcane (irrigated areas), Groundnut, Maize.
- c) Pulses (Tur, Gram), Onion.

4. Wai (Western-Central area)

A. **Dominant Soils:** Loamy to Clayey Loamy, Moderately Shallow too Deep in valleys and soil is **pH** Neutral to slightly alkaline.

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types , depth and pH levels, the following crops can be cultivated.

- a) Sugarcane (major), Rice, Jowar, Wheat.
- b) Maize, Groundnut, Onion, Vegetables.
- c) Grapes, Pomegranate (horticulture).

5. Khandala

A. **Dominant Soils:** Mix of Clayey & Loamy, variable depth (some shallow) and soil **pH** is Neutral to alkaline.

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types , depth and pH levels, the following crops can be cultivated.

- a) Sugarcane, Jowar, Bajra.
- b) Wheat, Maize, Groundnut.
- c) Pulses, Onion.

6. Satara (Central area)

A. **Dominant Soils:** Clayey to Loamy, Moderately Deep to Deep and soil **pH** is Mostly neutral (76% neutral).

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types , depth and pH levels, the following crops can be cultivated

- a) Sugarcane, Jowar (Kharif & Rabi), Wheat.
- b) Maize, Onion (district leader), Vegetables.
- c) Pulses, Groundnut.

7. Koregaon (Central and Irrigated area)

A. **Dominant Soils:** Clayey, Deep to Very Deep black soils and soil **pH** is Neutral to alkaline (high alkaline %).

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types , depth and pH levels, the following crops can be cultivated.

- a) Sugarcane (very high potential), Jowar, Wheat, Maize.

- b) Onion, Vegetables, Soybean.
- c) Famous **Koregaon Rajma** (Waghya Ghevda special rajma).
- d) Cotton in suitable pockets.

8. Karad (Central and Highly Irrigated area)

A. **Dominant Soils:** Clayey, Deep to Very Deep soil **pH** is Neutral to slightly alkaline.

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types, depth and pH levels, the following crops can be cultivated.

- a) Sugarcane (dominant cash crop), Jowar, Wheat.
- b) Maize, Soybean, Groundnut.
- c) Onion, Vegetables, Banana.

9. Phaltan (Eastern Plains area)

A. **Dominant Soils:** Clayey, Fine Calcareous, Moderately Deep and soil **pH** is alkaline tendency.

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types, depth and pH levels, the following crops can be cultivated.

- a) Jowar (major), Bajra, Wheat.
- b) Sugarcane (irrigated), Cotton, Groundnut.
- c) Pulses (Gram, Tur), Maize.

10. Man (Maan) (Eastern side Drought-prone area)

A. **Dominant Soils:** Clayey to Loamy Calcareous, variable depth (many shallow to moderately deep) and soil **pH** Neutral to alkaline.

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types, depth and pH levels, the following crops can be cultivated.

- a) Jowar, Bajra, Pulses (Gram).
- b) Groundnut, Cotton.
- c) Sugarcane in irrigated pockets.

11. Khatav (Eastern side Drought-prone area)

A. **Dominant Soils:** Clayey, Fine Calcareous, Moderately Deep to Shallow and soil **pH** is Neutral to alkaline.

B. **Suitable Crops:** In this region, based on these characteristics, the following crops can be cultivated. The choice of crops for Satara district depends primarily on soil types, depth and pH levels, the following crops can be cultivated.

- a) Jowar (dominant), Bajra, Wheat (Rabi).
- b) Pulses (Gram, Tur), Groundnut.
- c) Cotton, Soybean in suitable areas.

AGRIBUSINESS IMPLICATIONS:

1. GIS overlays indicating soil texture and depth should be utilized for precise crop zoning, seed supply planning, and input recommendations.
2. Western Tehsils region, Focus should be placed on orchards and rain fed farming systems.
3. Central and Eastern Tehsils regions: Focus should be placed on sugarcane processing, onion exports, and commercial farming.
4. Nutrient management particularly phosphorus management in calcareous and alkaline areas should be implemented in conjunction with Soil Health Cards.

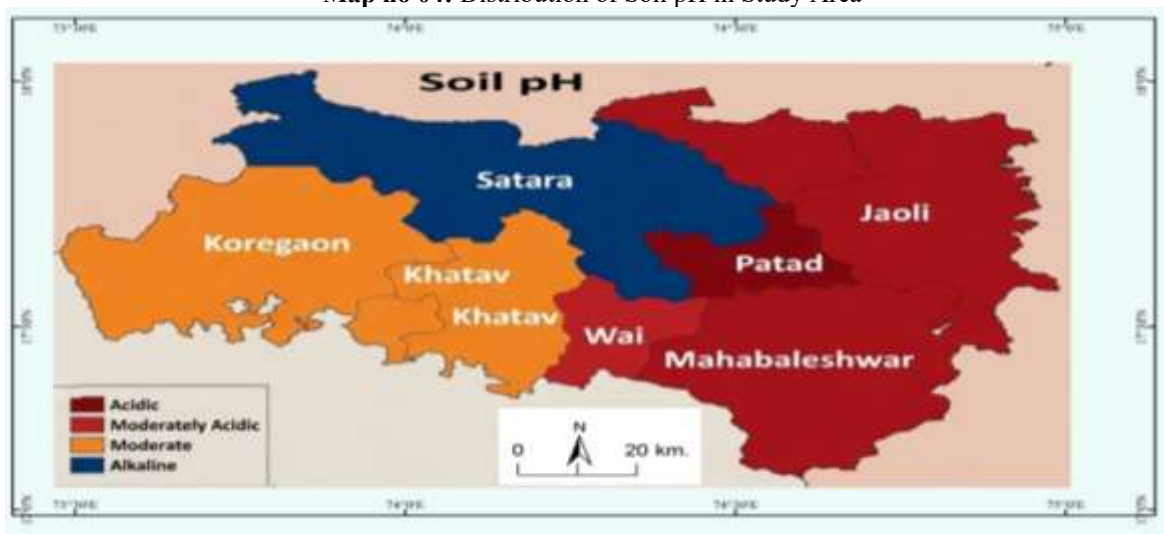
Soil pH Distribution:

Nutrient Availability Essential macronutrients (nitrogen, phosphorus, potassium) dissolve best in slightly acidic to neutral soils. If the pH drops below 5.5, phosphorus becomes largely unavailable if it rises above 7.5, micronutrients like iron and zinc become immobilized. Microbial Activity, Beneficial soil bacteria and fungi which decompose organic matter and aid in natural nitrogen fixation thrive in environments with a balanced pH. Acidic soils significantly slow down these vital nutrient cycles. Toxicity Prevention, in highly acidic soils (pH below 5.5) elements such as aluminium and manganese can dissolve into the soil solution and reach levels toxic to plant roots. Herbicide Effectiveness, Many modern agricultural herbicides break down or function most efficiently at specific pH levels. An unbalanced pH can cause herbicides to fail or damage the intended crop. Based on this, the chemical pH characteristics of certain soils in Satara district can be described as follows. This data has been obtained in an online format from the District Survey and Soil Testing Office Satara.

1. **Highest Acidic Soils:** Jaoli (23.3%) and Mahabaleshwar (12.6%) located in the Western Ghats, it can be seen in this geographical region..
2. **Highest Alkaline Soils:** Koregaon (47.62%) and Khatav (34.43%) eastern plains, it can be seen in this geographical region.
3. **Most Neutral Soils:** Patan (82%), Karad (78.31%), and Satara (76.41%) it can be seen in this geographical region.
4. **Clear East-West Gradient:** Acidic soils dominate western hilly areas neutral to alkaline soils dominate central and eastern parts it can be seen in this geographical region.

Map No. 4 illustrates the geographical distribution of soil pH one of the chemical properties of soil in Satara district. The soils have been classified into four main categories: acidic, moderately acidic, moderate and alkaline. The map reveals that acidic soil is prevalent in Patan tehsil, while moderately acidic soil is generally found in Wai, Mahabaleshwar, Jaoli, and Karad tehsils. Moderate soil is primarily observed in Khatav and Koregaon tehsils, whereas alkaline soil is predominantly found in Satara tehsil.

Map no 04: Distribution of Soil pH in Study Area



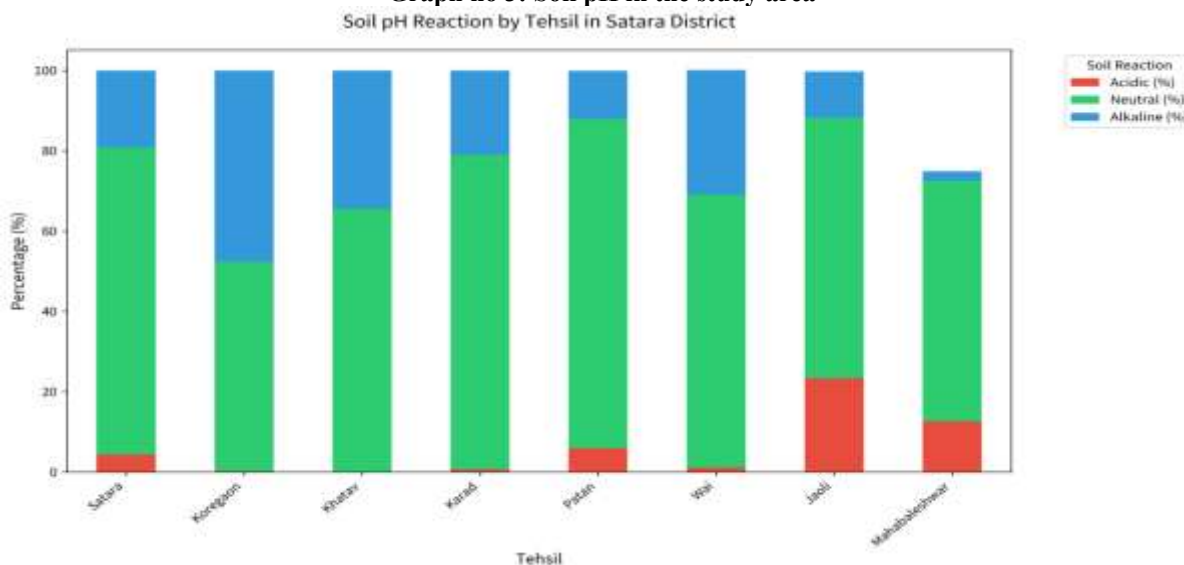
This makes it evident that the soil types and soil depth in Satara district influence the soil's chemical properties specifically its pH level. Furthermore, various factors such as the local topography and vegetation cover are also observed to affect the soil pH. Table no 4 and Graph no 3 present a general classification of soil pH categories by tehsil in Satara district. The data is presented in percentages.

Table no 04: Tehsil-wise Soil pH Distribution

Tehsil	Samples Analyzed	Acidic (%)	Neutral (%)	Alkaline (%)
Satara	10,748	4.37	76.41	19.21
Koregaon	10,407	0.20	52.18	47.62
Khatav	5,042	0.12	65.45	34.43
Karad	6,326	0.63	78.31	21.06
Patan	4,493	5.9	82	12
Wai	6,535	1.1	68	31
Jaoli	4,659	23.3	65	11.5
Mahabaleshwar	2,784	12.6	60	2.3

Source: District Soil Survey & Soil Testing Office, Satara (Aggregated from Studies).

Graph no 3: Soil pH in the study area



In Satara district the soil's chemical properties regarding pH are primarily categorized into three types the characteristics of which are presented below.

1. **Acidic (<6.5):** Limited areas mainly western highlands phosphorus fixation issues lime application recommended.

2. **Neutral (6.5–7.5):** Dominant in many central areas ideal for most crops.
3. **Alkaline (>7.5):** Common in eastern clayey/calcareous zones potential iron, zinc, and manganese deficiencies; use acidifying fertilizers or organic matter.

Crop Recommendations Considering soil pH:

The suitability of a specific crop depends on the soil pH guidelines regarding crop selection and classification have been formulated based on this soil pH characteristic.

- a. **Optimal pH (6.0–7.5):** Sugarcane, Jowar, Wheat, Maize, Groundnut, Pulses, Vegetables. Cultivating these crops based on this pH level could prove beneficial.
- b. **Tolerates Alkaline (up to 8.5):** Cotton, Barley, and certain millets. Cultivating these crops based on this pH level could prove beneficial.
- c. **Prefers Slightly Acidic:** Rice, Strawberry (Mahabaleshwar), Tea or Coffee (limited high elevation pockets) some millets. Cultivating these crops based on this pH level could prove beneficial.
- d. **Management:** In alkaline zones, apply organic manure, green manuring and micronutrient foliar sprays, in acidic zones use lime. Cultivating these crops based on this pH level could prove beneficial.

Agribusiness Implications:

1. **Precise Input Supply:** Determining the targeted application of specific input mixtures such as lime/gypsum and micronutrients by analyzing pH levels mapped via GIS and overlaying them with data on soil texture and depth.
2. **Crop Selection and Insurance:** Cultivating specific crop varieties that are resistant to nutrient deficiencies in alkaline and calcareous areas.
3. **Soil Health Card:** Integrating pH data to provide site-specific recommendations aimed at boosting productivity and minimizing input wastage planning crops based on an analysis of these factors.
4. **Risk Mitigation:** Conducting soil analysis is essential for determining appropriate cropping patterns, crop protocols and crop varieties especially in shallow soils prone to nutrient leaching and high pH instability.

Primary Causes of Soil pH Differences

A study of soil pH has been conducted in Satara district. Variations in pH levels are observed in the district, and the reasons for this are as follows:

1. Rainfall Gradient & Leaching (Most Important Factor)

Geographically, Satara district is primarily divided into two regions the Western Ghats and the eastern central part. The differing geographical conditions in these two areas result in variations in soil pH, which is the primary reason for this diversity.

- a) **Western Tehsil (Javali, Mahabaleshwar, Wai, and parts of Patan):** Due to the mountainous terrain, these areas experience very high annual rainfall (2000 to 5000 mm). Heavy rainfall causes intense leaching of basic ions calcium, magnesium and potassium rendering the soil acidic.
- b) **Eastern and Central Tehsil (Koregaon, Khatav, Karad):** These areas receive lower rainfall (600 to 1200 mm) rain-shadow region, consequently leaching is reduced and lime (calcium carbonate) is retained. The soil here ranges from neutral to alkaline.

2. Physiography and Drainage:

- a) The hilly terrain and steep slopes in the west (Javali, Mahabaleshwar Tehsil) facilitate rapid water flow and leaching.
- b) The flat plains and valleys in the east-central region allow water to stagnate for longer periods leading to the retention of basic ions.

3. Parent Rock (Geology):

- a) The entire district is underlain by Deccan Trap basaltic rock.
- b) In high-rainfall areas, Basalt undergoes deep weathering and basic ions are leached out resulting in acidic soil.
- c) In low-rainfall areas, Weathering occurs slowly calcium remains in the soil, resulting in an alkaline or calcareous reaction.

4. Vegetation and Organic Matter:

- a) In the dense forests of Mahabaleshwar and Javali, organic acids are produced during the decomposition process, further increasing soil acidity.
- b) In the agricultural plains the influence of natural organic acids is minimal.

5. Human and Managerial Factors:

- a) Soil acidity gradually increases due to the excessive use of nitrogenous fertilizers such as Urea and DAP in areas practicing intensive agriculture.
- b) Groundwater irrigation which is often alkaline in the eastern Tehsil helps maintain a high pH level.
- c) The application of limestone where applicable in acidic regions can neutralize the pH.

Table no 05: Tehsil wise Dominant Causes

Tehsil	pH Trend	Main Causes
Jaoli	Highly Acidic	Highest rainfall, hilly terrain, forest cover, strong leaching
Mahabaleshwar	Acidic	Very high rainfall, high altitude, heavy forest
Patan	Mostly Neutral	Mixed topography, moderate rainfall
Satara	Neutral	Transitional zone

Karad	Neutral	Plains and moderate rainfall
Koregaon	Highly Alkaline	Low rainfall, plain area, calcium retention
Khatav	Alkaline	Rain-shadow zone, black cotton soils rich in lime

Table no 06: Agricultural Implications & Recommendations

pH Category	Tehsils Affected	Implications	Recommendations
Acidic	Jaoli, Mahabaleshwar	Nutrient lockup (P, Ca), toxicity (Al, Mn)	Apply agricultural lime, use lime loving crops
Neutral	Patan, Karad, Satara	Ideal for most crops	Maintain with balanced fertilization
Alkaline	Koregaon, Khatav	Micronutrient deficiencies (Fe, Zn, Mn)	Use gypsum, acidifying fertilizers, organic matter

Based on the soil properties mentioned above, it is evident that there are no obstacles to cultivating suitable crops in Satara Tehsil such crops can indeed be grown there. Based on soil characteristics, Satara district is primarily divided into two zones and adopting the corresponding crop patterns can prove beneficial.

- **Acidic zones:** Rice, potato, millets, tea/coffee (Mahabaleshwar) Adopting the recommended crop package for this region could prove beneficial.
- **Neutral/Alkaline zones:** Sugarcane, wheat, cotton, sorghum (major crops in Satara) Adopting the recommended crop package for this region could prove beneficial.

RECOMMENDATIONS:

Based on the GIS-based spatial analysis of soil texture, depth, and pH in Satara District, the following recommendations are proposed for different stakeholders to enhance agribusiness decision-making, productivity and sustainability.

1. Crop Zoning and Suitability Recommendations

A. Develop GIS-based Crop Suitability Maps: Overlay soil texture, depth, and pH layers to create tehsil level suitability zones, Prioritize.

a. **High-Potential Zones** (Deep Clayey & Loamy soils in Karad, Koregaon, Satara): Sugarcane, Onion, Banana, Maize, Soybean, and Wheat. Cultivating these crops in this region could prove profitable, or they can be grown here.

b. **Medium-Potential Zones** (Moderately Deep Loamy soils in Wai, Khandala, Patan): Rice, Groundnut, Vegetables, Grapes, and Pomegranate. Cultivating these crops in this region could prove profitable, or they can be grown here.

c. **Rainfed & Conservation Zones** (Very Shallow & Shallow soils in Mahabaleshwar, Jaoli, Man, Khatav), Millets (Ragi, Jowar, Bajra), Pulses, and short duration drought-tolerant varieties. Cultivating these crops in this region could prove profitable or they can be grown here.

b) **Horticulture Promotion:** Expand strawberry and vegetable cultivation in Mahabaleshwar and Jaoli, promote pomegranate and grapes in Wai and Khandala where loamy, well drained soils exist. Cultivating these crops in this region could prove profitable or they can be grown here.

B. Soil Health and Nutrient Management

1. Targeted Amendments:

a) Apply lime in acidic pockets (western tehsils).

b) Use gypsum and organic manure in alkaline calcareous zones (eastern tehsils) to improve phosphorus availability.

c) Promote micronutrient (Zn, Fe, Mn) foliar sprays in high pH areas.

2. Soil Health Cards: Mandate and expand the use of GIS-integrated soil health cards with texture, depth and pH data for every farmer.

a) **Organic Matter Enhancement:** Encourage green manuring and compost application, especially in Very Shallow soils (34% of district) to improve water retention and reduce erosion.

C. Soil Conservation and Land Management

a) **Western Hilly Tehsils:** Implement terracing, contour bunding, and agroforestry on Very Shallow and Shallow soils to control erosion.

b) **Irrigation Planning:** Prioritize drip and sprinkler irrigation in Deep Clayey zones for water-use efficiency; promote watershed development in shallow eastern areas.

c) **Erosion Hotspots:** Identify and treat areas with Very Shallow, Clayey soils through vegetative barriers and check dams.

D. Agribusiness and Policy Recommendations

a) **Precision Input Supply:** Input companies and cooperatives should use GIS soil maps for targeted distribution of seeds, fertilizers and amendments.

b) **Crop Insurance and Risk Mapping:** Integrate soil depth and texture layers into insurance models to better assess risk in shallow soil zones.

c) **Value Chain Development:**

- Establish sugarcane processing and Jaggery units in Karad-Koregaon belt.
- Develop onion storage and export infrastructure in Satara and Koregaon.

- Promote strawberry and vegetable processing units in Mahabaleshwar.

d) Farmer Capacity Building: Conduct GIS-based training programs on precision agriculture and soil test based fertilizer application.

e) Government Interventions: Incorporate findings into District Agriculture Plan and Maharashtra State Soil Health Mission. Allocate funds for soil conservation in Very Shallow areas.

E. Technological and Research Recommendations

a) For dynamic monitoring, it is important to conduct studies by integrating real-time remote sensing (NDVI) and IoT soil sensors with existing GIS layers.

b) Soil maps should be periodically updated every 3 to 5 years.

c) Future studies should incorporate soil organic carbon, macronutrients, and the modelling of climate change impacts.

d) Mobile apps or web GIS portals should be promoted to provide tehsil wise soil and crop related advisories to farmers.

EXPECTED OUTCOMES:

Implementing these recommendations could increase crop productivity by 15 to 25% in suitable areas reduce input costs through precise application and enhance resilience against climate change and soil degradation.

Conclusion

This research relies on data regarding the types of soil, soil depth, and pH levels available in the area. The findings indicate that the crops cultivated in Satara district and the decisions regarding which crops to grow depend on soil type, depth, and pH. Furthermore research has been conducted on potential agriculture related businesses, all of which is based on the prevailing natural conditions of the region.

1. This GIS-based study in Satara district reveals significant spatial variations in soil texture, depth and pH, which strongly influence agricultural potential. The medium to deep alluvial clay and clay-loam soils in the central and eastern Tehsils possess high productivity potential, whereas the western regions require a conservation oriented approach.

2. These findings provide a robust scientific basis for decision making regarding precision agriculture targeted, input supply and crop insurance zoning and agribusiness investments. Adopting these GIS based recommendations can enhance district wide productivity, improve soil health and support sustainable development goals.

3. Future research should focus on high resolution village level mapping and the integration of climate change projections for long term planning.

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