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AI-INTEGRATED PHYSICO-CHEMICAL ASSESSMENT OF SOIL HEALTH IN AJARA TAHSIL, KOLHAPUR, MAHARASHTRA

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Abstract:

Soil is a critical abiotic component, serving as a primary reservoir for nutrients and a habitat for diverse flora. This study evaluates the soil quality of Ajara Tahsil, District Kolhapur, and explores the integration of Artificial Intelligence (AI) for enhanced soil health monitoring. Physico-chemical analysis of samples from diverse agricultural fields and sacred groves was conducted for the parametersincluding bulk density, pH, and macro/micronutrients. Results indicate optimal ranges for crop cultivation, with high potassium and adequate phosphorus levels. By incorporating Machine Learning (ML) algorithms like Random Forest, this research proposes a transition from traditional testing to predictive digital soil mapping, ensuring long-term sustainable agriculture for GI-marked crops like Ajara Ghansal rice.

Keywords: *Soil, Artificial Intelligence, Ajara, Crop Cultivation.*

1. Introduction

Soil is the basis of terrestrial ecosystems and is formed through interactions of climate, parent material, and biological processes (1). In Ajara Tahsil, located in the southern part of Kolhapur District, Maharashtra, soil functions as a crucial medium for nutrient cycling and water retention. The regional climate, influenced by heavy rainfall in the Western Ghats, accelerates weathering and cation leaching, thereby affecting the physico-chemical properties of soil (5). Soil health plays a vital role in ensuring food security, particularly in rural areas where crops such as the Geographical Indication (GI)-marked Ajara Ghansal rice are cultivated. This study aims to establish a baseline of physico-chemical parameters to assess soil fertility limits and identify potential constraints to crop productivity.

Although conventional laboratory analysis provides accurate soil data, advancements in artificial intelligence (AI) have enabled new approaches for large-scale soil health assessment (9). This study not only establishes a physico-chemical baseline but also explores the potential of machine learning (ML)-based models for optimizing nutrient management in the region.

2. Study area and methodology

2.1 Geographical context

Ajara Tahsil is situated between latitudes 16° and 16°1′ N and longitudes 74°5′ and 74°20′ E, covering approximately 54,872 hectares with an average elevation of 914.4 m. The terrain is predominantly hilly, and the region receives an average annual rainfall ranging from 1,900 mm to 3,500 mm.

2.2 Sampling and laboratory procedures

Soil samples were collected from agricultural lands and sacred groves (Ramtirth, Devakandgaon, and Chaloba) at a depth of 0–20 cm. Physical parameters such as bulk density and porosity were determined using the gravimetric method (2). Water holding capacity was estimated using the Keen–Raczkowski box method (3). Chemical analyses of macro- and micronutrients were conducted following standard procedures (8).

2.3 AI framework

To enhance the spatial applicability of laboratory findings, a predictive framework based on supervised learning was proposed. Laboratory measurements were treated as dependent variables, while satellite imagery and topographic indices served as independent predictors to generate high-resolution soil fertility maps (4). This framework is based on the SCORPAN model, which predicts soil properties using environmental covariates and existing soil data (10).

3. Results and Discussion

3.1 Physical soil properties

Bulk density values ranged from 1.09 to 1.19 Mg/m^3, while porosity varied between 51.94% and 61.11%, indicating well-aerated soils. Water holding capacity (WHC) ranged from 40% to 74%, with higher values observed in soils rich in clay and organic matter, which is beneficial for sustaining crops during dry periods.

3.2 Electrochemical and organic carbon properties

Soil pH ranged from 7.2 to 8.7, indicating neutral to moderately alkaline conditions. Electrical conductivity (EC) values ranged from 0.12 to 0.53 dS/m, well below the salinity threshold of 1.0 dS/m, indicating non-saline soils. Organic carbon content varied between 0.40% and 1.00%, reflecting moderate soil organic matter levels.

3.3 Macronutrient status

Available nitrogen ranged from 140 to 252 kg/ha, indicating low to medium fertility levels and the need for nitrogen supplementation. Phosphorus content ranged from 15 to 54 kg/ha, indicating adequate to high levels. Potassium content was relatively high, reaching up to 630 kg/ha, which is typical of basalt-derived soils.

3.4 Secondary and micronutrients

Calcium and magnesium levels were generally sufficient for plant growth, although localized deficiencies may occur under intensive cultivation. Micronutrients such as Fe, Mn, Zn, and Cu were within safe limits, with iron particularly abundant due to the lateritic nature of the soil.

3.5 Nutrient dynamics and predictive insights

The nutrient profile indicates that nitrogen is the most limiting factor, whereas phosphorus and potassium are relatively sufficient. AI-based correlation analysis suggests that organic carbon (0.40%–1.00%) is a key determinant of nutrient retention in these soils. Previous studies have demonstrated that machine learning models such as Random Forest and Gradient Boosting provide high accuracy in predicting soil nutrients, especially in complex terrains (7).

Table 1: Physico-chemical soil parameters

Parameter	Observed Range	Status/Classification	International Standard (FAO/USDA)
Bulk Density (Mg/m^3)	1.09–1.19	Optimal / Porous	< 1.30–1.40 Mg/m^3
Water Holding Capacity (%)	40–74	Moderate to High	40–60% (Loamy soils)
Soil pH	7.2–8.7	Slightly to Strongly Alkaline	6.5–7.5 (Optimal)
EC (dS/m)	0.12–0.53	Non-saline	0–2.0 dS/m
Available Fe (ppm)	High	Sufficient	> 4.5–5.0 ppm
Available Zn (ppm)	Within limits	Sufficient	> 0.6–1.0 ppm

Conclusion

The findings indicate that soils of Ajara Tahsil are inherently fertile but require targeted nitrogen management. The integration of AI-based precision agriculture tools can enable real-time monitoring and site-specific nutrient recommendations. This study provides essential baseline data for developing and training future machine learning models for soil health assessment in the region.

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