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RESEARCH ARTICLE

PHENOMENON OF SOIL CHARACTERISTIC DIGGING: ENHANCING THE CLUSTERING SCHEMES AND SORTING WITH KNN-ALGORITHM FOR SOIL PARAMETER CALCULATION AT KGI CAMPUS

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Abstract

Artificial Intelligence augments the domain of precision agriculture by fostering sustainability, enhancing resource allocation, and increasing productivity levels. Methodologies such as machine learning, computer vision, and the Internet of Things (IoT) facilitate the optimization of crop management practices, the identification of plant diseases, and the judicious utilization of resources, thereby responding to the imperative for efficient agricultural practices in the context of escalating global population dynamics and pressing environmental challenges. This study at KGI Campus describes the recent technological development in agriculture as abbreviating NG-AIA: next generation agriculture incorporated with AI. This study describes the different algorithms in AI/ML for agricultural development particularly for soil parameter setting and calculating as it defines the growth of any country's economy.

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Introduction:-

Soil is of paramount significance in the domain of agriculture, which in turn is essential for the advancement of a nation. Soil characteristic digging is an art of defining and designing the different soil parameters for more efficient and productive agriculture. Consequently, the analysis of soil parameters is crucial for the enhancement of agricultural productivity. The present investigation concerning soil parameters at the KGI Campus, utilizing Internet of Things (IoT) technology and designing different AI/ML algorithms represents an innovative methodology for environmental monitoring, agricultural planning, and land sustainability (Dey, 2025). The condition of the soil is shaped by numerous factors, including moisture, temperature, pH balance, nutrient content, and compaction, all of which later affect the growth of plants, retention of water in soil, and the activity of microorganisms. Traditional soil analysis methodologies typically involve manual sampling, which is labor-intensive, time-consuming, and often fails to capture real-time soil variability (Moharana et al., 2024). This research employs IoT sensors for the real-time monitoring of soil health, thereby facilitating efficient campus land management and promoting sustainable agricultural practices. Sensors can be systematically deployed throughout the campus to create an integrated system that transmits data regarding soil moisture, temperature, nutrient concentrations, and pH levels to a central platform, where it can be accessed remotely and visualized through dashboards or mobile applications, enabling data-driven

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decision-making by campus researchers, agricultural planners, and environmental managers. Moreover, IoT-enabled soil monitoring has the potential to detect issues before they manifest, such as nutrient deficiencies and excessive moisture levels that could adversely affect plant health or contribute to erosion and other environmental challenges associated with soil quality. This study is designed to have create and develop innovative AI/ML algorithms that can achieve the objectives of innovation and sustainability regarding smarter soil identification within KGI Campus by motivating students and professors to find frontiers in the management of resources and environmental science (Sahoo et al., 2024 & Sahoo et al., 2025). This study aims to cater to the regional soil analysis based on different AI/ML algorithms for data sorting and clustering.

Literature Survey:

Article	Key Contribution	Key Algorithms	Limitation
K Spandana et al. (2023)	IoT device utilizes various sensors, including soil moisture, pH value, and NPK level sensors, to collect data on soil parameters.	IoT sensor used.	It doesn't support high-end sensors and works only with desktop computer traditional programs. ➤ AI/ML algorithm missing
R. Reshma et al. (2021)	Tracks critical soil parameters like moisture, temperature, pH, humidity, NPK level.	Moisture ,Temperature pH,humidity,NPK level Calculation by IoT sensor.	The systems limitations like sensor accuracy, Internet dependency, high costs, power consumption, and data overload. ➤ AI/ML algorithm missing
Abhijit Pathak et al. (2019)	The various parameters such as temperature, turbidity, pH value, Moisture has been collected by using Internet of Things (IoT) platform.	Temperature, Turbidity pH value, Moisture sensor used.	High setup costs challenge effectiveness, sensor reliability, internet dependence, regional adaptation needs, and algorithm accuracy. ➤ AI/ML algorithm missing.
Kuangmin et al., 2018	The paper discusses the limitations of conventional methods in determining soil constitutive model parameters, particularly the influence of artificial experience. It highlights the need for improved efficiency in acquiring multiple constitutive model parameters simultaneously. The use of a fitness function to relate calculation data and test data is emphasized as a key innovation.	Temperature, Turbidity pH value, Moisture sensor used.	The systems limitations like sensor accuracy, Internet dependency, high costs, power consumption, and data overload. ➤ Major AI/ML algorithm missing.
Dey et al., 2025	Tracks soil parameters like moisture, temperature, pH, humidity, NPK level.	Moisture, Temperature pH, NPK level calculation based on IoT sensor.	The systems limitations like sensor accuracy and Internet dependency. ➤ Major AI/ML algorithm missing.

Bayram et al.,2025	Soil analysis with machine learning approach predicts different parameters of soil for better soil productivity.	Used different algorithms of ML for clustering and data analysis.	Comparative analysis missing and Major algorithm comparison for different soil samples like multi-regional and multi seasonal is missing.
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Table 1: Key Literature Survey

The above literature survey suggests that a systematic approach in regional soil parameter analysis is missing and for better productivity and efficient NG-AIA (next generation agriculture incorporated with AI) the multi regional data analysis is required (Dey et al., 2024). This paper caters to the study of different soil parameter and their clustering on the basis of specific data.

Research Gap in Existing Studies:

Enhanced agricultural productivity can be attained with diminished requirements for water, fertilizer, and fuel. Concurrently, an increased number of crops may be cultivated within reduced spatial confines, thereby lessening the financial burdens on farmers. The utilization of big data analytics facilitates the examination of factors such as climatic conditions and soil fertility, consequently refining agricultural processes. At this juncture, machine learning (ML) methodologies assume a pivotal role in the analysis and forecasting of data. Therefore, advancements extending from digital innovations to autonomous systems are being integrated into the realm of smart agriculture by the help of different innovative AI/ML algorithms.

- As an illustration, Reddy et al. (2019) established a crop recommendation framework that incorporates machine learning algorithms in the Ramtek area of India. But there is huge gap in finding out proper ML algorithm efficiency in enhancing productivity.
- Garanayak et al. (2021) conducted an analysis of climatic and edaphic data utilizing machine learning regression techniques to enhance soil fertility in the Andhra Pradesh region. But some specific data set is used to carry out the regression techniques which again has huge research gap in analysing the soil fertility considering multiple parameters like pH value, moisture level and sand percentage etc.
- Paudel et al. (2022) introduced regional machine learning models for the prognostication of crop yields across multiple spatial dimensions. Patel and Patel (2023) sought to augment crop yield and optimize resource utilization through machine learning methodologies in Gujarat.
- Bhargavi and Jagannathan (2024) leveraged meteorological, soil, and locational data to forecast crop yields in the Maharashtra and Karnataka regions. These all are recent developments in soil parameter calculations and soil productivity enhancement through ML algorithms. But there is a huge research gap in calculating the efficiency of these algorithms and their practical implementations.
- Dey et al. (2024 & 2025), performed soil parameter calculations in different climate and temperature level in Odisha KGI campus via IOT sensor but there is a huge gap in evaluating some specific algorithm based soil data clustering and evaluation in Odisha region incorporating AI/ML algorithms.
- This study caters to analyze the different AI/ML algorithm like random forest (RF), k-Mean clustering, and decision tree algorithms for soil parameter calculation and finding out the best one amongst them. This study has enormous data set for evaluating suitable parameters for suitable or intelligent agriculture. Therefore, assessment is vital for critical and sustainable agriculture.
- Soil fertility exhibits regional variability, necessitating the selection of crops in accordance with these differences. Established studies have scrutinized the factors that determine soil fertility in various nations. Nonetheless, there is a scarcity of research that meticulously classifies soil characteristics in Odisha via machine learning algorithms. A detailed examination of soil analysis data from Odisha at KGI campus, along with their classification through machine learning techniques, is an essential research priority.

Research Methodology and Subsequent Process Flow:

This research utilized soil analysis data from Dey et al., 2025 from Odisha KGI campus. The soil's physical and chemical elements (e.g., soil pH, moisture levels, overall salinity, sand, clay, sodium, potassium, phosphorous value, saturation, and various other factors) were taken into account. Initially, the K-means clustering method was utilized to categorize soils, facilitating significant differentiation and assessment of fertility levels. Subsequently, these clusters served as labels for training supervised machine learning models. The goal was to anticipate the group of a

randomly chosen soil sample. The results are anticipated to assist farmers of odisha region with soil management techniques and aid in upcoming research. In this context, this research seeks to offer advantages like precise crop choices for farmers, promoting sustainable farming methods, averting soil degradation, lowering expenses, choosing correct soil factors with required percentage through optimal land utilization, and diminishing environmental effects. The entire research methodology has been designed through the following flowchart.

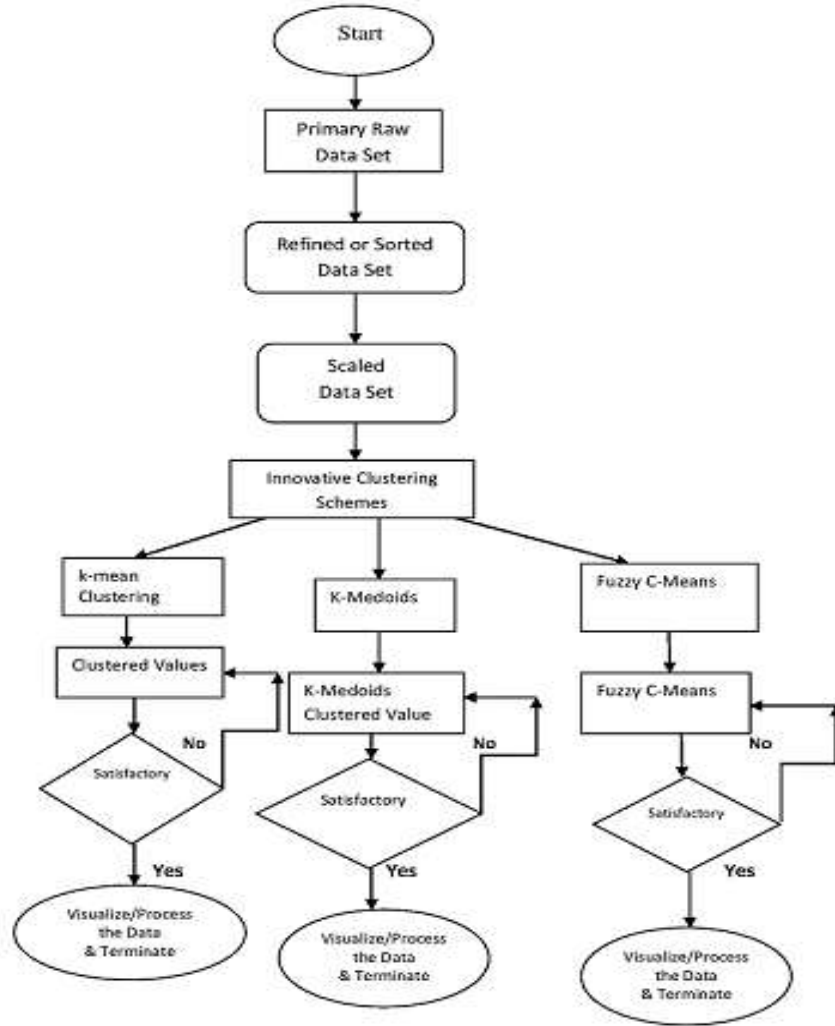


Figure 1: Flow Chart for Innovative Clustering Schemes used in Soil Analysis at KGI campus.

Figure 1 describes about the innovative clustering schemes used in soil analysis at KGI campus with mainly three proposed methodologies, k-mean clustering, k-medoids and fuzzy C-means. The k-mean clustering is used for clear boundaries of data's whereas fuzzy C-mean schemes are used for unclear boundaries of data's. But k-medoids clustered scheme is used here based on physico-chemical properties or spatial distribution. Each phase has opportunity to get refined data with the process of feedback and proceed for next level. Figure 2 explains the soil characteristic digging workflow which designs the system a robust one for soil clustering by the help of supervised, unsupervised and reinforced machine learning schemes. The soil characterization is passed through a dedicated three stage route for future decision making.

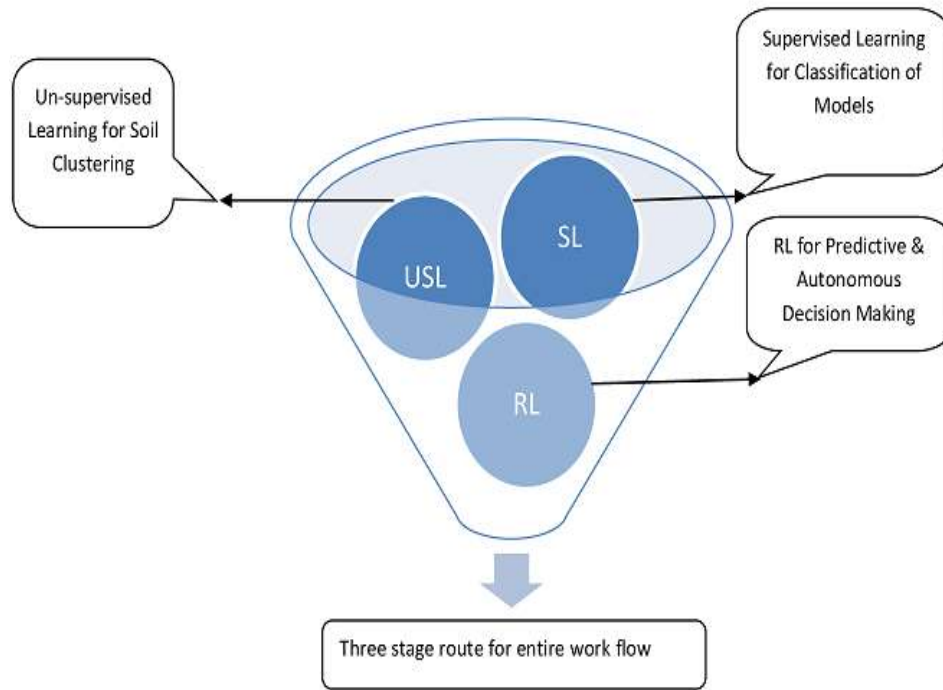


Figure 2: Soil Characteristic Digging Workflow

Figure 3 studies about the innovative AI/ML algorithm used in the process of data splitting, grouping and sorting. Data splitting, sorting and grouping is again made via training and testing. In training phase different algorithms like random forest, logical regression, decision trees, and kNN is used to evaluate a proper training model while in testing phase model performance is evaluated based on benchmarking. The data set here is used from the previous project at the KGI campus (Dey et al., 2025).The data set includes physical and chemical properties of soil samples collected from various locations of KGI campus and it’s in and around locations. Parameters like saturation with water, pH percentage in water saturated soil, total salt percentage, sand percentage, clay percentage and NPK values etc. The proportions and descriptive statistics are listed in a table below after averaging out from the random values.This study has five soil samples like KGI soil sample1, KGI soil sample2, KGI soil sample3, KGI soil sample4, KGI soil sample 5.Sample 6 is calculated as the average of all samples from KGI 1, KGI 2....to KGI 5. Finally after all the process of training and testing, the soil quality categorization is done ranging from Quality 1 to Quality N.

Parameter	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Saturation with water (%)	83.294	86.456	82.334	84.394	84.284	84.152
pH in water saturated soil	7.62	7.73	7.34	7.69	7.61	7.598
Total salt (%)	0.031	0.029	0.034	0.028	0.031	0.0306
Sand (%)	30.814	31.35	30.754	31.24	31.025	31.036
Clay (%)	44.45	46.35	43.55	45.25	45.35	44.99
N	11	12	11	11	11	11
P	12.55	12.75	12.05	12.70	12.70	12.55
K	41.75	42.65	40.55	42.75	42.75	42.09

Table 1: Different Soil Sample at KGI campus.

KGI Soil Sample Characteristics	Average Value
Saturation with water (%)	84.152
pH in water saturated soil	7.598
Total salt (%)	0.0306
Sand (%)	31.036
Clay (%)	44.99
N	11
P	12.55
K	42.09

Table 2: Soil Sample Average Values at KGI.

Table 1 and Table 2 provides the different soil samples at KGI campus with five samples as sample 1, sample 2, sample 3, sample 4 and sample 5. An average value is calculated after accumulating every samples together. The average pH value is 7.598 which is mildly alkaline. Total percentage of salt content is low at about 0.0306%. The sand and clay proportions are 31.036% and 44.99% respectively. The value of N, P and K is averaged out to be at the lower side (Dey et al., 2023). So, these soil statistics show that the soils at KGI campus have a heterogeneous physical and chemical structure and their diversity will make a right decision to incorporate the machine learning schemes here.

AI/ML Schemes for Soil Analysis Model Building:

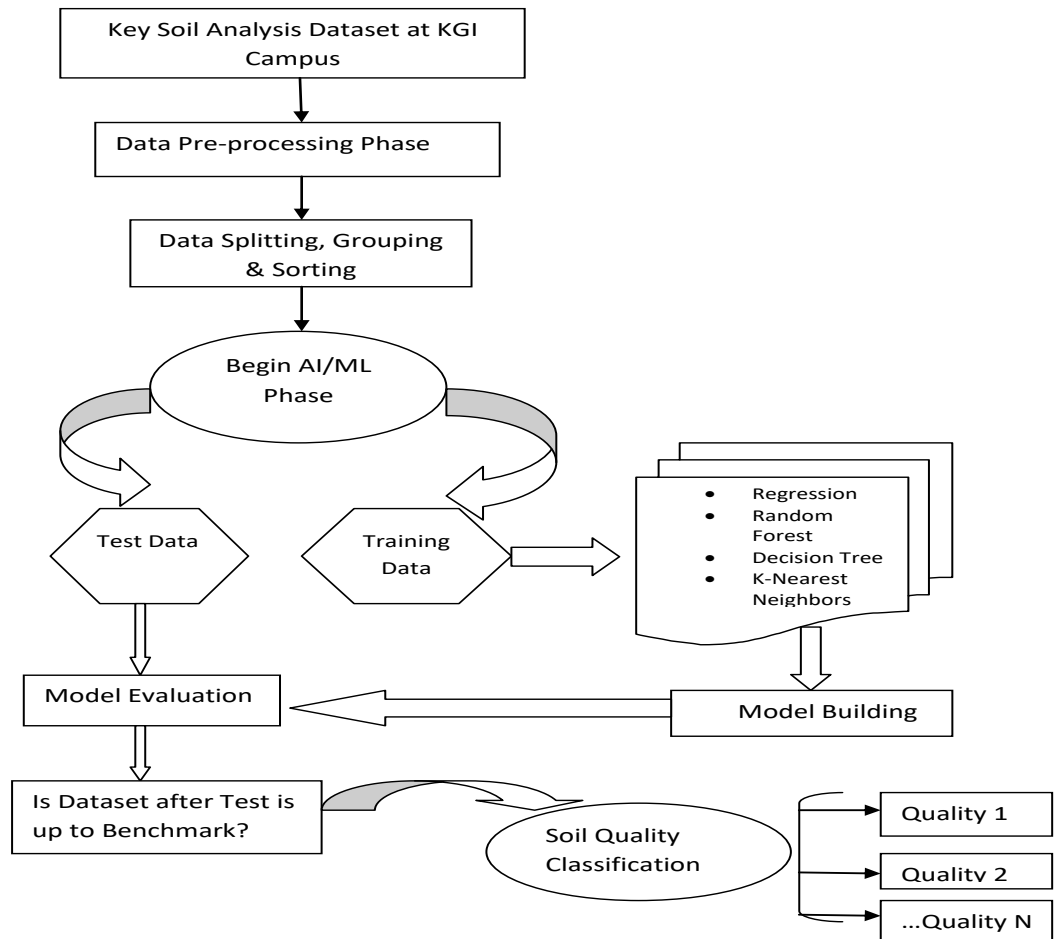


Figure 3: Model Evaluation Process incorporating Innovative AI/ML schemes.

As per figure 3, a soil characteristic analysis model has been proposed incorporating different AI/ML schemes. Algorithms like regression, random forest, decision tree and k-nearest neighbors are the building blocks of this model which are helpful in model training and evaluation. Subsequent soil quality classification is deployed as per the evaluation is done which tests the benchmark and defines the quality from quality 1 to quality N. Data clustering is done through the methods like k-means clustering, logistic regression algorithm and decision tree algorithm. The most important advantages of decision tree are its interpretability but they are very sensitive to noise and susceptible to over fitting. Decision trees are generally combined with random forests to provide effective accuracy and higher rate of generalization. Decision tree is the stand out algorithm which has been incorporated as valuable ML algorithm for the effective uses in healthcare, agriculture and environmental studies. Figure 4 shows the soil analysis arrangement procedure in KGI campus.



Figure 4(a, b, c): Systematic Arrangements of Soil Characteristic Analysis

Results and Discussion:-

A systematic arrangement of five different soil samples and subsequent average value calculation after optimization shows that the average pH value is 7.598 which is mildly alkaline. Total percentage of salt content is low at about 0.0306%. The sand and clay proportions are 31.036% and 44.99% respectively. The value of N, P and K is averaged out to be at the lower side. So, these soil statistics show that the soils at KGI campus have a heterogeneous physical and chemical structure and their diversity will make a right decision to incorporate the machine learning schemes. For fertility and effective soil, the incorporation of different ML schemes will give optimized value of these characteristics to choose right soil for quality assurance. The values are plotted as per graph shows where sample 6 of each plot shows the average value of that soil parameter.

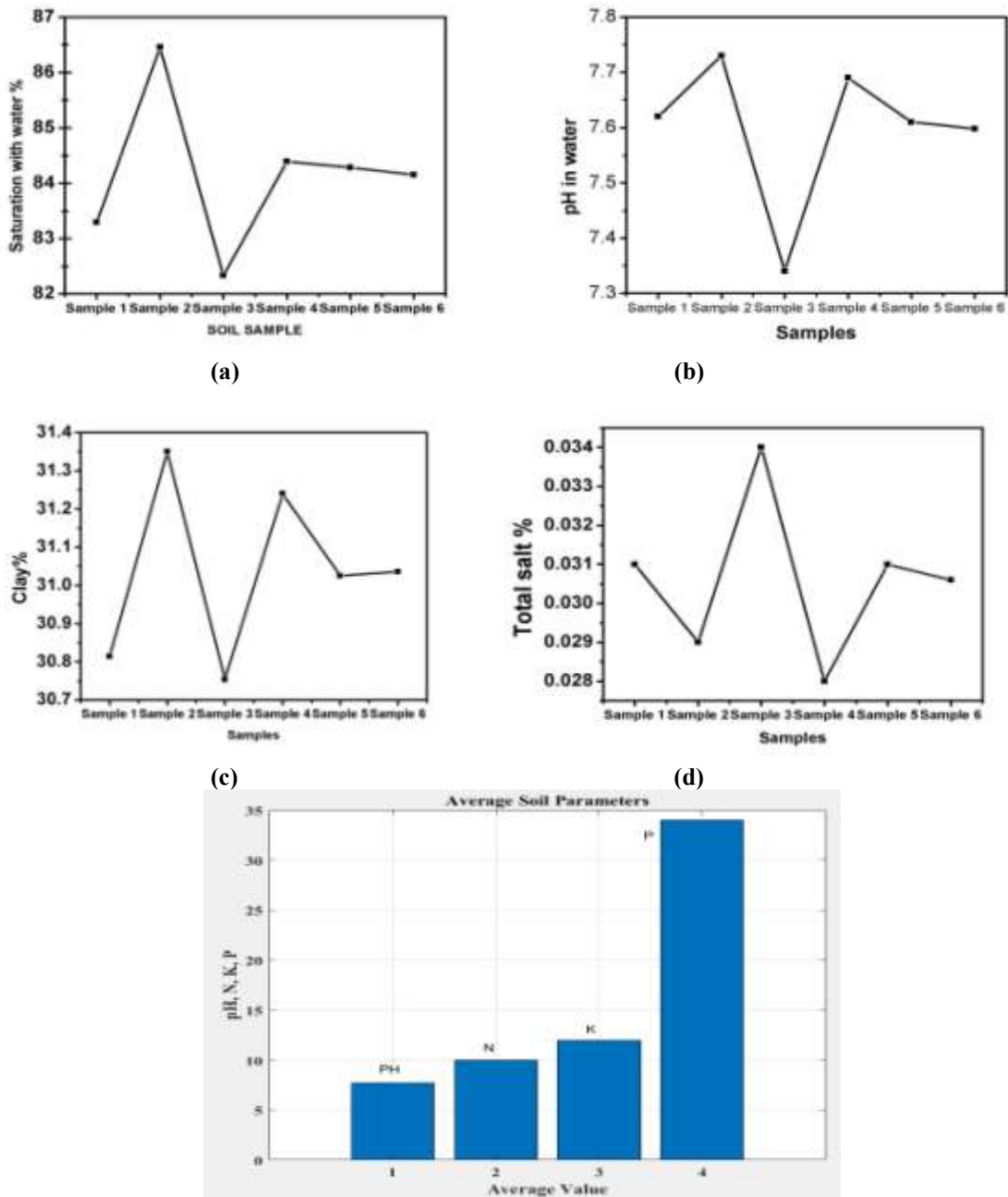


Figure 5 (a, b, c, d, and e): Soil Parameter Values with Respect to Different KGI Samples.

Soil Fertility ML Workflow at KGI Campus:

Data Collection & Preprocessing:-

- Gather soil parameters: pH, salinity, sand/clay %, NPK values, organic matter, moisture.
- Clean data: handle missing values, normalize ranges (e.g., scale pH between 0–14).
- Feature engineering: derive indices like fertility score, water retention index.

Exploratory Data Analysis (EDA):-

- Visualize distributions (histograms for pH, salinity).
- Correlation analysis (e.g., NPK vs fertility).

- Cluster soils into groups (heterogeneous patches).

Model Selection:-

- **Classification Models:**
 - Decision Trees / Random Forests → classify soils into fertility categories (low, medium, high).
- **Regression Models:**
 - Linear Regression / Gradient Boosting → predict crop yield or nutrient availability.
- **Clustering:**
 - K-means / Hierarchical clustering → group soils with similar properties.
- **Optimization:**
 - Genetic Algorithms / Bayesian Optimization → suggest best soil-crop-fertilizer combinations.

Training & Validation:-

- Split dataset (train/test).
- Use cross-validation for robustness.
- Evaluate with metrics: accuracy (classification), RMSE (regression).

Deployment:-

- Build a decision-support dashboard for campus soil management.
- Input: soil sample data.
- Output: fertility score, crop recommendation, fertilizer plan.

Continuous Improvement:-

- Retrain models with new soil samples each season.
- Incorporate external data (weather, crop performance).
- Feedback loop: compare predicted vs actual yields.

Example Use Case:-

- Input: Soil sample with pH 7.6, clay 45%, NPK low.
- ML Output: Fertility = “Moderate,” Recommended crop = “Legumes,” Suggested intervention = “Organic compost + phosphorus fertilizer.”

Future Research:

The prospective advancements in Artificial Intelligence (AI) and Machine Learning (ML) hold the potential to render soil analysis both precise and universally attainable, whilst ensuring sustainability. The following delineates several pathways for future exploration.

Hybrid Methodologies of AI Frameworks: The integration of conventional soil science with AI methodologies, which entails the utilization of hybrid models that amalgamate the intrinsic physical characteristics of soils with predictive analytics derived from AI, significantly augments the precision and flexibility of the model. For instance, physics-informed neural networks, grounded in the foundational principles of both soil and environmental sciences, may yield enhanced predictive capabilities concerning the behavior of soils across varying environmental conditions.

Edge AI: Edge AI denotes the computational processes conducted on devices, including sensors, as opposed to utilizing cloud-based servers. This technology possesses the capacity to deliver instantaneous soil assessments while minimizing both latency and energy consumption. Given its ability to lessen reliance on continuous internet connectivity, it proves to be exceedingly advantageous for regions characterized by remote or limited connectivity.

Variegated Dataset Integration: Combining various datasets, including remote sensing, soil sensors, and GIS data, to provide a comprehensive view of soil characteristics.

Conclusion:-

The different soil parameter analysis at KGI campus shows that the average pH value is 7.598 which is mildly alkaline. Total percentage of salt content is low at about 0.0306%. The sand and clay proportions are 31.036% and

44.99% respectively. The value of N, P and K is averaged out to be at the lower side. So, these soil statistics show that the soils at KGI campus have a heterogeneous physical and chemical structure and their diversity will make a right decision to incorporate the machine learning schemes. For fertility and effective soil, the incorporation of different ML schemes will give optimized value of these characteristics to choose right soil for quality assurance.

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