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## **Leveraging IoT and Machine Learning for Climate Resilient Agriculture: A Predictive Platform for Real-Time Data Analysis and Decision Support**

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### **KeyWords**

Variability, prediction, accuracy, IoT

### **ABSTRACT**

This paper presents an IoT-based web platform designed to generate predictive analyses on the impacts of climate change in agriculture. By leveraging Internet of Things (IoT) technology, the platform collects real-time data from various agricultural sensors, including soil moisture, temperature, humidity, and atmospheric conditions. The integration of machine learning algorithms allows for the analysis of this data alongside historical climate trends to generate accurate forecasts of potential agricultural risks related to climate variability. The user-friendly interface provides farmers, researchers, and policymakers with actionable insights through visual dashboards and alerts, facilitating informed decision-making for crop management and resource allocation. Through case studies and surveys conducted across diverse agricultural regions, the platform demonstrates significant improvements in yield optimization and resilience strategies against climate-related challenges. Furthermore, the machine learning showed significant improvement in climatic variability prediction accuracy.

### **1.0 Introduction**

This study focuses on the need to tackle agricultural challenges caused by unpredictable climate conditions. With climate change affecting crop yields and food security, this research intends to develop a web-based platform leveraging on IoT and machine learning for predictive analysis on weather conditions using climate change data. Adopting some powerful algorithms, historical climate data and real-time data, this platform aims to give farmers timely insights to help them make smart decisions.

Agriculture which is of utmost importance for nourishing the world's population, driving economic growth and preserving the environment. Agriculture can be practiced on a broad range of scales and methods, from modest subsistence farms to massive commercial operations. Agriculture has changed over time in response to developments in technology and methods, greatly influencing the growth of human communities and economies.

Climate change poses significant challenges to agriculture by altering temperature and precipitation patterns, leading to more frequent and intense heat waves, droughts, and floods. These changes can reduce crop production, hinder growing seasons, and increase pest and disease prevalence. Heat stress and fluctuations in proper grazing sites pose issues for livestock and water shortage has an influence on irrigation. The cumulative impact

on global food security is becoming increasingly concerning. Efforts to address these difficulties include developing resilient crop varieties, sustainable farming techniques, and adaptive strategies to ensure agriculture's long-term sustainability in the face of climate change. Although the negative impacts of climate change on agriculture are predominant, there are a few positive effects such as extended growing seasons and increased carbon dioxide levels stimulating crop growth (Malhi et al., 2021). Therefore, it is important to fully understand climate change and how best to tackle it.

Climate change and agriculture are strongly correlated; it is clear that the rapid speed of climate change will have major implications on agricultural ecosystems and productivity. As a result, it is important that we prepare for the upcoming difficulties in order to resist the effects of climate change and ensure food security not only for humans but also for other living beings (Arora, 2019).

The problem of food shortage has been greatly associated with the adverse effect of climate change on agricultural products. As such, various issues bothering on climate change brings about serious concerns to crop production and food security, making the agriculture sector more vulnerable. Temperature shifts, precipitation patterns, and extreme weather events have grown more common and severe, altering traditional farming techniques and worsening agricultural vulnerability. Farmers worldwide are dealing with the negative consequences of climate change, such as crop failures, water scarcity, and increased insect and disease challenges. Several attempts has been made by various authors to address the various challenges enumerated and has failed to bring optimal solutions to the problems.

Nidumolu et al., (2020) offered solutions aimed to help farmers make educated decisions in the face of climatic variability using social network analysis to identify central information hubs for better dissemination. This approach was not well utilized because of the inconsistency in information gathering techniques deployed for the system.

Furthermore, Gowri et al., (2024) developed a system that proposes using big data to create an application that predicts environmental changes and helps farmers adopt climate-smart agriculture. The system didn't give optimal solution because of the sole use of statistical analysis for predicting global economic implications of climate change.

## 2.0 Related Works

The relationship between the fields of agriculture and climate research has received a lot of attention in recent years, due to the significant impact that climate unpredictability has on agricultural systems all over the world. . Some of the related works include:

1. **Application of Predictive Analytics in Agriculture:** This research explores the implementation of predictive analysis in agriculture to increase productivity and meet customer demand. It studies how modern technology has facilitated the use of advanced agricultural equipment and procedures. It focuses on the significance of predictive analytics in agricultural businesses, focusing its importance in task assessment, matching consumer requests, and enhancing farmer performance. The study's goal is to provide practical proof on the influence of predictive analytics on organizations productivity and earnings in the global market (Gupta and Malik, 2022).
2. **Indicators of Climate Change in Agricultural Systems:** This research evaluates the effects of climate change on several areas of the agricultural sector, highlighting the growing vulnerability of agricultural systems to shifting weather patterns. It indicates the significance of creating indicators that evaluate the effects of climate change on various crop and livestock systems. The study brings together a set of indicators to assess agricultural responses to climate change in both the short and long term. It shows a vari-

ety of factors, including heat stress on animals, soil erosion, changes in soil carbon levels, economic responses, and agricultural output (Hatfield et al., 2020).

3. **The importance of climate for agriculture:** This paper explores the significant influence of climate on agriculture, distinguishing between long-term climate patterns and short-term weather conditions. It emphasizes the pivotal role of climate in determining suitable crops for cultivation and shaping land use practices. The study discusses various elements, including phenology, which helps predict agricultural outcomes based on seasonal growth patterns. It highlights the importance of modern technologies, such as sensors and satellite technology, in providing accurate weather forecasts for agricultural planning (365Academy, 2022).
4. **Reshaping Agriculture in a Changing Climate with Insights from Predictive Analytics:** This study focuses on the use of predictive analytics in agriculture, especially in the face of climate change issues. It discusses how predictive models use climatic data, soil health, and crop performance to advise farmers on the best planting schedules, crop varieties, and yield estimates. In addition, the study covers future difficulties such as data quality and accessibility, as well as the significance of incorporating predictive analytics into agriculture to effectively solve the climate catastrophe. It stresses stakeholder engagement in order to fully utilize the potential of predictive analytics for agriculture's long-term sustainability (Shrutiand Gosain, 2023).
5. **Predicting climate factors based on big data analytics based agricultural disaster management:** This study addresses the influence of climate change on agricultural disasters and presents a Data Handling Model employing Big Data Analytics (DHM-BDA) to efficiently address these concerns. It stresses the importance of big data analytics in monitoring, mitigating, and recovering from agricultural disasters caused by climate conditions. The simulation results show that DHM-BDA outperforms existing systems in terms of prediction accuracy, decision-making, data management, production efficiency, and risk reduction (Jaber et al., 2022).
6. **Weather-Based Crop Prediction Using Big Data Analytics** This study proposes using big data to create an application that predicts environmental changes and helps farmers adopt climate-smart agriculture. It aims to solve climatic variability challenges, strengthen farmer resilience, and boost productivity. The study additionally explores the use of statistical analysis for predicting global economic implications of climate change. It proposes an automated prediction technique based on the Hadoop architecture for effective weather data processing and forecasting (Gowri et al., 2024)
7. **Linking climate forecasts to rural livelihoods:** The study proposes three essential techniques to assist farmers predict climatic changes effectively: 1) Using social network analysis to identify central information hubs for better dissemination, 2) conducting value chain analysis to understand how different stakeholders can use seasonal climate forecasts, and 3) using decision analysis tools to convert climate forecast data into actionable strategies. These solutions aim to help farmers make educated decisions in the face of climatic variability (Nidumolu et al., 2020).
8. **Climate adaptation pathways for agriculture: Insights from a participatory process** by Cradock-Henry et al. (2020) focuses on climate change's impact on agriculture in Hawke's Bay, New Zealand. Using a pathways approach, stakeholders identify values, assess climate change impacts, and evaluate adaptation options. Comparative case studies inform decision-making, leading to the development of a regional adaptation pathway. The study highlights the complexity of interacting drivers and emphasizes the importance of considering trade-offs in adaptation strategies, aiming to empower stakeholders and inform policy-making.

- 9. Decision support systems for agriculture 4.0: Survey and challenges:** This paper explores challenges in implementing agricultural decision support systems for Agriculture 4.0, with a focus on addressing climate change impacts. Through a systematic review, several support systems are analyzed, covering areas such as agricultural planning, water management, and climate adaptation. The findings identify key challenges and suggest future research directions to enhance decision support systems in mitigating climate change effects in agriculture (Zhai et al., 2020).

### 3.0 Materials and methods

This framework outlines the systematic approach for developing the predictive platform while ensuring that it effectively utilizes IoT and machine learning to enhance climate-resilient agriculture.

- 1) IoT Sensors: Soil moisture sensors, temperature and humidity sensors were deployed including weather stations
- 2) Network configuration: Wi-Fi and cellular networks for data transmission
- 3) Data collection frequency: sensors collect data at regular intervals ( every 20 minutes)
- 4) Use of an API to receive real-time data from IoT devices
- 5) Cloud azure storage (Azure)
- 6) Use of regression models
- 7) Object oriented analysis and design methodology (OOADM)

The new application for predicting climate change in agriculture is primarily dependent on real time data. With a user-centric approach, the platform focuses on simplicity and accessibility for farmers. The fundamental feature of this design is an intuitive interface that is simple without compromising functionality.

### 3.1 Algorithm

**Step 1:** Identify the problems and solutions for target users.

**Step 2:** Collect real time data from the location via IoT sensors.

**Step 3:** Design a proposed user interface for the system,

**Step 4:** Implement the proposed design into an active system.

**Step 5:** Integrate the system with an existing weather API (API already contains historical data)

**Step 6:** User testing and deployment

#### 3.1.1 Step 1: Data Preparation

1. Dataset Selection: Choose relevant datasets, such as: Weather data, e.g., Global Weather Data for Plant Growth including Soil properties and agricultural yield datasets.
2. Data Cleaning: Handle missing values, remove duplicates, and preprocess categorical variables.
3. Feature Engineering: Create features relevant to weather patterns (temperature, rainfall) and soil conditions (pH, moisture).

#### 3.1.2 Step 2: Model Selection

Random Forest Regression: Effective for predictive tasks with complex interactions.

Gradient Boosting Machines (e.g., XGBoost, LightGBM): Good for handling large datasets with different types of variables.

#### 3.1.3 Step 3: Model Training and Testing

1. Train-Test Split: Divide the dataset into training and testing sets (e.g., 80-20 split).
2. Hyperparameter Tuning: Use techniques such as Grid Search or Random Search for optimizing model parameters.

### 3.1.4 System Architecture



Fig 1 Track Field Outdoor Monitoring devices

IoT Device sensors

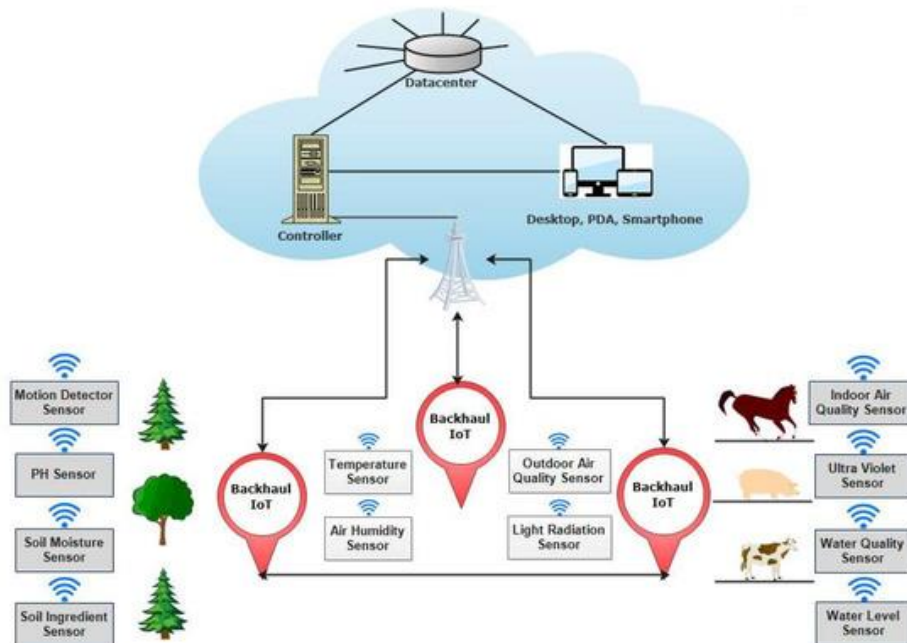


Fig 2 IoT based system architecture

The IoT sensor nodes collect real time data (soil moisture, temperature, humidity, and atmospheric conditions) as shown in figure 2, from the location then transmit to IoT backhaul devices which communicates with the machine learning model for analysis and prediction. Depending on the operation purpose and installation location, IoT sensor nodes can be installed as RFDs (reduced-function devices), which only communicate with FFDs (full-function devices).

## 4.0 Results

### 4.1 Performance Metric Calculation for the model parameters

#### 1) Weather Patterns Analysis:

**MAE:** 1.5 °C (prediction of temperature)

**RMSE:** 2.0 °C

**R<sup>2</sup>:** 0.85 (the model explains 85% of the variability in temperature)

#### 2) Soil Conditions and Crop Performance Metrics:

**MAPE:** 10% (for predicting crop yield)

**F1 Score:** 0.78 (for classifying high, medium, low yield)

**Confusion Matrix:**

**Predicted**

**High Medium Low**

High	30	5	2
Medium	3	25	8
Low	1	4	35

### 4.2 Control Centre/Main Menu

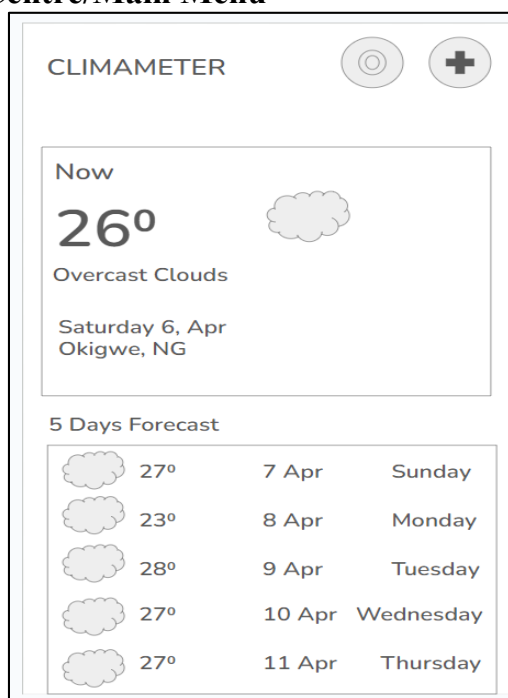


Fig. 3. Diagrammatic representation of the control center/main menu

### 4.3 Post Deployment Performance Evaluation

We followed a systematic approach to analyzing the performance of our predictive analysis platform for climate change in agriculture. This entails developing hypotheses, engaging survey participants, examining their feedback, and finally validating or disputing our initial ideas using analysis.

### 4.4 Findings and Discussions

The following information gives a qualitative analysis of survey results assessing perception, acceptance, and satisfaction with the system. This section of the attempts to validate the hypothesis proposed earlier.

1. **Hypothesis 1:** The establishment of a web-based platform will improve farmers' access to fast and accurate weather forecasts, allowing them to make more informed decisions about crop management and resource allocation.

**Findings:** The results obtained from the question "How strongly do you think farmers can make informed decisions based on the information provided?" show that 70.3% of respondents either "agree" or "strongly agree" that farmers can make informed decisions based on the provided information which therefore satisfies the hypothesis.

2. **Hypothesis 2:** The weather predictions generated by the system will closely align with actual weather conditions experienced.

**Findings:** The results obtained from the question "How accurate are the weather predictions generated by the system compared to actual weather conditions experienced?" indicate that over 80% of the respondents had positive views as regards the accuracy of the system's predictivity.

3. **Hypothesis 3:** Positive usability ratings correlate with increased user satisfaction and engagement with the system.

**Findings:** Based on survey responses to questions such as "How do you rate the usability of the system?" and "Is our feedback collection method effective?", the findings indicate that the majority of respondents (73.5%) rated the system's usability as either 'very easy' or 'easy,' indicating a high level of user-friendliness and effectiveness when navigating the platform. Furthermore, 80% of participants said that the feedback gathering approach was effective, indicating that the system successfully collects relevant user input. These findings suggest that the system's ability to provide weather predictions may be well aligned with real weather conditions, as proven by pleasant user experiences and the perceived usefulness of the feedback mechanism.

### 4.5 Analysis of Survey Data (Reliability, Descriptive etc. using SPSS)

Descriptive analysis including mean, median, mode etc is shown in table 1.

Table 1: Data analysis using Descriptive statistics

		Statistics				
		How accurate are the weather predictions generated by the system compared to actual weather conditions experienced ?	How do you rate the usability of the sytem ?	What improvements could be made to the web-based platform to better meet the needs of farmers and stakeholders in the agricultural community?	Is our feedback collection method effective ?	How strongly do you think farmers can make informed decisions based on the information provided ?
N	Valid	155	155	155	155	155
	Missing	0	0	0	0	0
Mean		1.90	2.08	3.24	1.20	2.21
Median		2.00	2.00	3.00	1.00	2.00
Mode		2	2	3	1	2
Std. Deviation		.913	1.016	1.339	.401	1.121
Range		4	4	4	1	4
Sum		294	322	502	186	342

## Conclusion

The platform uses sophisticated IoT device sensors and prediction algorithms to give farmers accurate and fast weather forecasts, allowing them to make more informed decisions and reduce the risks associated with climate variability. The user-friendly interface, strong data security measures, and feedback-driven development approach ensure the platform's accessibility, dependability, and continual progress. Its capacity to give accurate weather predictions, together with its user-friendly interface and strong data security safeguards, presents it as an important instrument for improving agricultural resilience and sustainability. Continued investment in research and development is required to improve the platform's capabilities and ensure its long-term success in assisting agricultural communities worldwide.

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