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AI-Based Smart Agricultural Assistance for Reducing Water Consumption and Chemical Fertilizer Usage

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ABSTRACT: Agriculture is one of the largest consumers of freshwater resources and chemical fertilizers, leading to serious environmental challenges such as water scarcity, soil degradation, and groundwater pollution. Artificial Intelligence (AI)-based machine learning algorithms analyze historical and real-time data to accurately predict crop water requirements and nutrient needs, enabling precise and timely resource management. The AI-driven system provides farmers with an automated decision-support platform, reducing manual effort and enhancing productivity, sustainability, and overall efficiency in agricultural practices. By implementing the AI-based smart agricultural assistance system, it is realistic to expect 25–40% water savings in the future, depending on crop type, soil, and irrigation efficiency.

KEYWORDS: Artificial Intelligence, Predictive Analytics, Resource Optimization, Machine Learning Algorithm.

I. INTRODUCTION

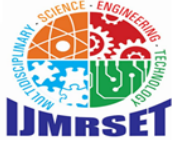
Agriculture is a fundamental pillar of global food security, yet it remains one of the largest consumers of freshwater resources and chemical fertilizers. Leading to inefficient water use and excessive fertilizer application. These practices not only increase production costs for farmers but also cause severe environmental problems such as soil degradation, groundwater contamination, and ecosystem imbalance. AI-based smart agricultural assistance systems integrate advanced machine learning algorithms with real-time data collected from field sensors, weather stations, and satellite imagery. By continuously analyzing soil moisture, nutrient levels, crop growth patterns, and climatic conditions, these systems can accurately estimate crop-specific water and fertilizer requirements. AI-based smart agricultural assistance systems represent a promising approach toward achieving sustainable agriculture, economic efficiency, and environmental protection. Their implementation has the potential to revolutionize modern farming practices by reducing water consumption and chemical fertilizer usage while ensuring long-term agricultural resilience.

II. DATA SOURCE

The data sources used in this study consist of both real-time and historical agricultural data obtained from multiple reliable platforms. Soil parameters such as moisture content, nutrient levels, and temperature are collected through field observations and monitoring systems. Weather-related data including rainfall, humidity, and climatic variations are gathered from meteorological records. Crop growth, yield history, and fertilizer application data are sourced from agricultural databases and farm records. These data sources support accurate AI-based analysis for efficient water and fertilizer optimization

1. Efficient Water Management

- Freshwater resources are rapidly depleting due to population growth and climate change.
- Agriculture consumes nearly 70% of global freshwater resources. Smart agricultural systems help optimize irrigation by analyzing soil moisture, weather forecasts, and crop water requirements.



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2. Reduction in Chemical Fertilizer Usage

- Excessive use of chemical fertilizers degrades soil quality and pollutes water bodies. Smart systems analyze soil nutrient levels and crop growth stages to recommend precise fertilizer application. This not only reduces input costs for farmers but also promotes sustainable farming by maintaining soil health and minimizing environmental pollution.

3. Climate-Resilient Farming

- Climate change has increased the frequency of droughts, floods, and extreme weather events. Smart agricultural assistance systems use historical and real-time climate data to predict weather patterns and assess risks. Early warnings and adaptive recommendations help farmers take preventive measures, reducing crop losses and improving resilience against climate uncertainties.

4. Improved Crop Productivity and Quality

- By continuously monitoring crop health and environmental conditions, smart systems enable early detection of diseases, pests, and nutrient deficiencies. Timely intervention improves crop productivity, quality, and consistency. Higher yields directly contribute to improved farmer income and national food security.

5. Decision Support for Farmers

- Many farmers lack access to expert agricultural guidance. Smart assistance systems act as virtual advisors by providing personalized recommendations through mobile applications or digital platforms. These systems reduce dependency on manual expertise and help farmers make informed decisions based on scientific data.

6. Cost Reduction and Economic Sustainability

- Optimized use of resources such as water, fertilizers, and energy reduces operational costs. Automation minimizes labour dependency and human error. As a result, farmers can achieve higher profitability with lower investment, making agriculture economically sustainable.

III. ROLE OF AI

Artificial Intelligence (AI) plays a pivotal role in transforming traditional agriculture into a smart, data-driven, and sustainable system. By enabling machines to analyze data, learn from patterns, and make intelligent decisions, AI significantly enhances agricultural efficiency, productivity, and resource optimization. In smart agricultural assistance systems, AI acts as the core intelligence that converts raw sensor data into meaningful insights and actionable recommendations for farmers.

1. Data-Driven Decision Making

- Modern agriculture generates vast amounts of data from soil sensors, weather stations, satellite imagery, and farm equipment. AI algorithms process this large-scale data to identify patterns and trends that are not easily detectable through manual observation. Based on these insights, AI supports informed decision-making related to irrigation scheduling, fertilizer application, crop selection, and harvesting time.

2. Precision Irrigation Management

- One of the most critical applications of AI in agriculture is efficient water management. AI models analyze soil moisture levels, crop water requirements, weather forecasts, and historical irrigation data to determine optimal watering schedules. This ensures that crops receive the required amount of water at the right time, reducing water wastage and preventing over-irrigation or under-irrigation. As a result, AI-driven irrigation systems contribute to significant water conservation.

3. Optimized Fertilizer and Nutrient Management

- Excessive use of chemical fertilizers leads to soil degradation and environmental pollution. AI-based systems evaluate soil nutrient content, crop growth stages, and yield goals to recommend precise fertilizer dosages. This targeted approach improves nutrient absorption, maintains soil health, reduces input costs, and minimizes the negative environmental impact of fertilizers.



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4. Crop Health Monitoring and Disease Detection

- AI techniques such as computer vision and machine learning enable early detection of crop diseases, pests, and nutrient deficiencies. By analyzing images captured from drones or cameras, AI systems can identify symptoms of stress or infection at an early stage. Early detection allows timely intervention, reducing crop loss and improving overall yield quality.

5. Yield Prediction and Crop Planning

- AI models use historical crop data, climate conditions, and soil characteristics to predict crop yield accurately. These predictions help farmers plan crop rotation, market supply, and storage requirements. Yield forecasting also assists policymakers and agricultural planners in ensuring food security and supply chain stability.

6. Climate Adaptation and Risk Management

- Climate change has introduced uncertainty into agricultural practices. AI helps farmers adapt to changing climatic conditions by analyzing long-term weather patterns and predicting extreme events such as droughts or floods. AI-driven early warning systems enable farmers to take preventive measures, thereby reducing risks and improving resilience against climate variability.

7. Automation and Reduced Human Effort

- AI-powered automation reduces dependency on manual labor by controlling irrigation systems, fertilizer dispensers, and agricultural machinery. Automated decision support systems minimize human error, improve operational efficiency, and save time, allowing farmers to focus on strategic farm management activities.



Fig.1. Automation and Human Effort

8. Farmer Support and Advisory Services

- AI-based smart agricultural assistance systems function as virtual advisors, providing farmers with personalized recommendations through mobile or web applications. These systems bridge the gap between farmers and agricultural experts by delivering scientific guidance in a simple and accessible manner, even in remote rural areas.

IV. AI-BASED SMART AGRICULTURAL ASSISTANCE SYSTEM ARCHITECTURE

The AI-based smart agricultural assistance system is designed as a multi-layered architecture that integrates sensing devices, data communication, intelligent processing, and user interaction modules. The architecture ensures real-time monitoring, accurate analysis, and efficient decision support for optimized water and fertilizer management.

1. Data Acquisition Layer

- This is the foundational layer of the system responsible for collecting real-time field data. It consists of IoT-based sensors deployed across agricultural land to measure critical environmental and soil parameters such as:
 - Soil moisture content



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- Soil nutrient levels (NPK)
- Temperature and humidity
- Light intensity
- Rainfall and weather conditions

These sensors continuously monitor field conditions and generate raw data essential for intelligent analysis.

2. Communication Layer

The collected sensor data is transmitted to the central processing system through reliable communication technologies such as Wi-Fi, LoRa, GSM, or cellular networks. This layer ensures secure and uninterrupted data transfer from the field to cloud or edge computing platforms.

3. Data Processing and Storage Layer

In this layer, raw sensor data is cleaned, filtered, and stored in cloud databases or local servers. Data preprocessing techniques such as normalization, noise removal, and missing-value handling are applied to ensure data quality. Historical agricultural data and weather records are also integrated to enhance prediction accuracy.

4. Artificial Intelligence and Analytics Layer

This is the core intelligence layer of the system. Machine learning and AI algorithms analyze real-time and historical data to generate insights and predictions. Key functions include:

- Crop water requirement estimation
- Fertilizer recommendation based on soil nutrient analysis
- Crop growth stage identification
- Yield prediction
- Disease and stress detection
- AI models continuously learn from new data, improving system accuracy over time.

5. Decision Support and Automation Layer

Based on AI analysis, this layer generates actionable recommendations and automated control signals. It supports:

- Smart irrigation scheduling
- Automated fertilizer dispensing
- Alerts and notifications for abnormal conditions
- Automation minimizes human intervention and ensures precise resource application.

6. User Interface Layer

The final layer provides interaction between the system and farmers through mobile applications or web dashboards. Farmers receive real-time updates, recommendations, alerts, and visual analytics in a user-friendly format, enabling informed decision-making.

The methodology defines the step-by-step operational workflow of the proposed system, from data collection to intelligent decision making.

Step 1: Sensor Deployment and Data Collection

- IoT sensors are installed across the agricultural field at appropriate locations. These sensors continuously collect soil and environmental data required for crop monitoring and resource optimization.

Step 2: Data Transmission

- The collected data is transmitted in real time to the cloud or central server through wireless communication protocols. Secure transmission ensures data integrity and reliability.

Step 3: Data Preprocessing

- Raw data is processed to remove noise, handle missing values, and standardize inputs. This step improves the accuracy and efficiency of AI models.



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Step 4: Feature Extraction and Dataset Formation

- Relevant features such as soil moisture trends, temperature variations, nutrient levels, and weather patterns are extracted. These features form the input dataset for machine learning models.

Step 5: AI Model Training and Prediction

- Machine learning algorithms such as regression models, decision trees, or neural networks are trained using historical agricultural data. The trained models predict:
 - Optimal irrigation schedules
 - Required fertilizer quantity and timing
 - Crop stress and disease risks
 - Expected crop yield

Step 6: Decision Support Generation

- Based on AI predictions, the system generates personalized recommendations for farmers. These decisions are tailored according to crop type, soil condition, and climatic factors

Step 7: Automated Actuation

- The system triggers automated irrigation and fertilizer application systems where available. This ensures precise and timely execution of AI-based decisions.

Step 8: Monitoring and Feedback

- The system continuously monitors field conditions after actuation. Feedback data is used to update AI models, enabling adaptive learning and continuous system improvement.

Role of Artificial Intelligence in Smart Agricultural Assistance Systems

V. ROLE OF ARTIFICIAL INTELLIGENCE IN SMART AGRICULTURAL ASSISTANCE SYSTEMS

Artificial Intelligence (AI) plays a vital role in modernizing agriculture by enabling intelligent decision-making, automation, and efficient resource management. In smart agricultural assistance systems, AI serves as the core component that transforms raw agricultural data into meaningful insights, helping farmers improve productivity, sustainability, and profitability.

1. Intelligent Data Analysis

- Agricultural environments generate large volumes of data from soil sensors, weather stations, and crop monitoring devices. AI algorithms analyze this data to identify hidden patterns and trends that cannot be detected through traditional methods. This analysis supports accurate decision-making for irrigation, fertilization, and crop management.

2. Precision Irrigation Management

- AI evaluates soil moisture levels, crop water requirements, and weather forecasts to determine optimal irrigation schedules. By supplying water only when and where it is needed, AI reduces water wastage, prevents over-irrigation, and improves crop health.

3. Optimized Fertilizer Usage

- AI-based systems assess soil nutrient levels and crop growth stages to recommend precise fertilizer quantities. This minimizes excessive chemical usage, maintains soil fertility, lowers input costs, and reduces environmental pollution



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4. Crop Health Monitoring and Disease Detection

- Using machine learning and image analysis techniques, AI enables early detection of crop diseases, pests, and nutrient deficiencies. Early identification allows timely corrective actions, reducing crop loss and improving yield quality

5. Yield Prediction and Crop Planning

- AI models predict crop yield by analyzing historical agricultural data, soil conditions, and climatic factors. These predictions assist farmers in planning crop cycles, managing storage, and estimating market supply.

6. Climate Risk Management

- AI analyzes weather data and climate trends to forecast adverse conditions such as droughts or heavy rainfall. Early warnings help farmers take preventive measures, improving resilience against climate change.

7. Automation and Reduced Human Effort

- AI enables automation of irrigation systems, fertilizer application, and farm equipment. Automated operations reduce human effort, minimize errors, and increase operational efficiency

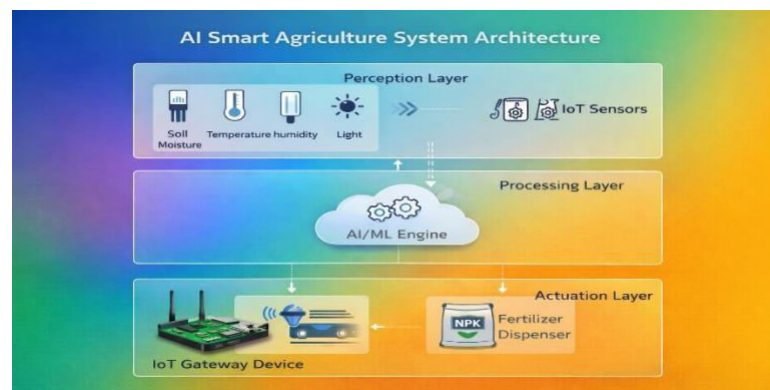


Fig.2. AI Smart Agriculture System Architecture

8. Decision Support and Farmer Advisory

AI-based systems act as virtual agricultural advisors by delivering real-time alerts and personalized recommendations through mobile or web platforms. This bridges the gap between farmers and expert knowledge.

VI. WATER AND FERTILIZER OPTIMIZATION STRATEGY

Efficient management of water and chemical fertilizers is essential for achieving sustainable agricultural productivity and environmental conservation. The proposed AI-based smart agricultural assistance system adopts an integrated optimization strategy that ensures precise application of water and nutrients based on real-time field conditions, crop requirements, and predictive analytics.

1. Data-Driven Resource Assessment

- The optimization strategy begins with continuous monitoring of soil moisture, nutrient levels (NPK), temperature, humidity, and weather conditions using IoT sensors. This real-time data provides an accurate assessment of the field's current status and forms the basis for intelligent decision-making.

2. Crop-Specific Requirement Analysis

- Different crops and growth stages require varying amounts of water and nutrients. The system maintains a crop knowledge base that stores crop-specific water and fertilizer requirements. AI algorithms analyze this information along with real-time sensor data to determine optimal input levels tailored to each crop and growth phase.



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3. Intelligent Irrigation Scheduling

- AI models predict soil moisture depletion and evapotranspiration rates by analyzing weather forecasts and historical irrigation data. Based on these predictions, the system schedules irrigation events only when required. This strategy prevents over-irrigation, reduces water loss due to evaporation and runoff, and ensures efficient utilization of available water resources.

4. Precision Fertilizer Recommendation

- Soil nutrient data is analyzed to identify deficiencies or excess nutrient levels. The AI-based system recommends precise fertilizer dosage, type, and application timing. By applying fertilizers only where and when needed, the system minimizes chemical wastage, improves nutrient uptake efficiency, and maintains soil fertility.

5. Integrated Water–Nutrient Management

- Water and fertilizer optimization are managed in a coordinated manner through fertigation techniques, where nutrients are delivered along with irrigation water. AI algorithms synchronize irrigation schedules with fertilizer application to ensure uniform nutrient distribution and maximum absorption by crops.

6. Automation and Control Mechanism

- The system supports automated control of irrigation valves and fertilizer dispensers. Based on AI-generated recommendations, actuators are triggered to apply the exact quantity of water and nutrients. Automation reduces human error and ensures consistent execution of optimization strategies.



fig.3. Automation and Mechanism

VII. CONCLUSION

This study concludes that the integration of Artificial Intelligence–based smart agricultural assistance systems plays a crucial role in promoting sustainable and resource-efficient farming practices improvement of optimization strategies over time. By analyzing historical and real-time agricultural data, the proposed system enables precise irrigation scheduling and optimized fertilizer application, significantly reducing unnecessary water usage and chemical input. The AI-driven decision support mechanism not only improves crop productivity but also minimizes environmental impacts such as soil degradation and groundwater pollution. Furthermore, the system supports farmers in making timely, data-driven decisions, reducing manual effort and operational costs. Overall, the adoption of AI-based agricultural assistance systems represents a promising and scalable solution for achieving sustainable agriculture, ensuring long-term food security, and conserving natural resources for future generations



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