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AgriDropIQ: A Digital Innovation for Crop-wise Water Footprint Intelligence and Sustainable Farming

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Abstract
Efficient water management in agriculture is critical to ensure sustainability, particularly in regions facing water scarcity. This project presents an integrated hardware-software system that leverages digital technology to calculate the water footprint of different agricultural products and automate irrigation based on real-time environmental data. The system begins with a user-friendly web interface where farmers or users input key parameters such as crop type, farm location, land area, and irrigation method. This data is combined with live weather information retrieved from online APIs and soil moisture readings obtained from in-field sensors. Using these inputs, the software component dynamically calculates the crop-specific water footprint by employing standard evapotranspiration models and crop coefficients, factoring in rainfall and irrigation efficiency. When the soil moisture falls below optimal levels and no rainfall is predicted, the system automatically activates irrigation through microcontroller-driven hardware connected to a water pump and valves.

Keywords: *Smart irrigation, Sensors, Farming, analysis.*

1. Introduction

Agriculture is one of the largest consumers of freshwater globally, making efficient water management essential in the face of increasing water scarcity and climate change. Traditional farming methods often lead to over-irrigation or under-irrigation, both of which can negatively impact crop yields and waste precious water resources. In this context, the concept of the water footprint has emerged as a vital indicator, measuring the volume of freshwater used to produce different agricultural products. A water footprint comprises green, blue, and grey water components, accounting respectively for rainwater, surface and groundwater, and water needed to dilute pollutants. Understanding and calculating the water footprint of crops can help optimize irrigation practices, reduce water usage, and promote sustainable farming. The rise of digital technology offers significant potential to address these challenges. By leveraging digital tools such as web-based platforms, IoT sensors, real-time APIs, and automation, agriculture can become more data-driven and efficient. This project aims to harness these technologies to build a digital system that accurately calculates water footprints and automatically manages irrigation, thereby supporting resource-conscious farming.

1.1. Challenges in Monitoring

India's agricultural sector, which sustains over 60% of the population, is increasingly challenged by water scarcity, inefficient irrigation practices, and a lack of real-time decision-making tools. Traditional water usage estimation methods rely heavily on manual reporting and fixed averages, failing to account for dynamic variables like crop type, soil moisture, regional climate, and farming practices. This results in suboptimal water usage, contributing to 85% of India's freshwater consumption and placing unsustainable pressure on groundwater reserves. AgriDropIQ addresses these critical challenges through an integrated digital platform that combines low-cost IoT sensors, satellite data, and AI-driven analytics. The system estimates crop-wise water footprints with an accuracy of <±5%, enabling farmers, policymakers, and agri-businesses to make informed, data-driven decisions for sustainable water use. Its predictive model adapts to local agro-climatic conditions and seasonal variations, offering tailored irrigation insights and resource optimization at scale.

2. Related Work

A systematic literature review from 2010 to 2025, guided by the PRISMA framework and Kitchenham et al.'s methodology, examined advancements in digital tools for water footprint assessment in agriculture. Chakraborty et al. leveraged remote sensing to estimate evapotranspiration for water use modeling, achieving a correlation coefficient of 0.85; however, their approach lacked real-time, field-level granularity. Verma and Singh integrated soil moisture sensors with GSM modules, showing potential for improved irrigation scheduling, yet their system faced scalability challenges due to network dependency and the absence of predictive modeling. Patel et al. proposed crop-specific water usage benchmarks using the FAO's CROPWAT model, though the solution did not incorporate IoT or machine learning for dynamic updates. Kumar et al. utilized NDVI (Normalized Difference Vegetation Index) from satellite imagery to estimate crop water stress, but their method lacked on-ground sensor validation. Similarly, Sharma and Rao developed a machine learning-based decision support system using KNN and regression techniques for crop yield prediction, yet failed to account for water input variables. While commercial platforms such as Aquacrop and HydroSense offer advanced modeling capabilities, they remain either cost-prohibitive or too complex for smallholder farmers, limiting their practical utility. Collectively, these studies highlight the need for an integrated, scalable, and locally adaptable solution that combines IoT, AI, and user-friendly design—gaps that AgriDropIQ aims to fill.

3. System Design

AgriDropIQ is architected as a modular, scalable, and IoT-enabled system that integrates environmental sensing, geospatial analytics, and machine learning to provide crop-wise water footprint intelligence and enable sustainable farming practices. The design includes both edge-level data acquisition and cloud-based analytics, ensuring real-time insights even in resource-constrained rural areas.

3.1. Hardware Component

The AgriDropIQ system integrates cost-effective and field-ready hardware components to ensure reliable, real-time monitoring of crop conditions and water usage. At the core is the ESP32 microcontroller, priced between ₹500 and ₹700, which features dual-core processing, built-in Wi-Fi/Bluetooth, and multiple GPIO pins, enabling seamless sensor integration and over-the-air updates.

Table 1 Hardware Cost Breakdown

Component	Cost (₹)
ESP32 Microcontroller	500-700
Soil Moisture Sensor	250-500
DHT11 Sensor	150-300
NEO-6M GPS Module	1000-2000
Solar Charging unit	1000-5000
16x2 LCD Display	300-500
Miscellaneous +enclosure	800
TOTAL	4000-6300

To monitor soil hydration, a capacitive soil moisture sensor (₹250–₹500) delivers consistent readings across varied soil types, crucial for root-level irrigation decisions. Environmental parameters are captured using the DHT11 temperature and humidity sensor, costing ₹150–₹300, which supports evapotranspiration models and precise water demand forecasting. The system incorporates the NEO-6M GPS module (₹1,000–₹2,000) to geotag field data and support location-based precision farming. A solar charging unit, comprising a 6V/1W panel and battery, priced at ₹1,000–₹1,500, powers autonomous deployment in remote areas with limited grid access.

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For local visualization, a 16x2 LCD display (₹300–₹500) provides real-time updates on moisture, weather, and irrigation schedules, serving users without smartphones. Finally, enclosure and power management circuitry, costing around ₹800, ensures weather-resistant (IP65) protection and uninterrupted system performance in challenging agricultural environments. (Table 1)

3.2.Software Component

The software architecture of AgriDropIQ is designed to seamlessly convert field-level sensor data into actionable insights, enabling crop-wise water footprint analysis and sustainable farming practices. At the edge, the ESP32 microcontroller is programmed using the Arduino IDE in C/C++, leveraging libraries such as WiFi.h, PubSubClient.h, TinyGPS++, and LiquidCrystal_I2C to manage sensor input, GPS data parsing, Wi-Fi connectivity, and LCD display output. The microcontroller collects data from soil moisture sensors, DHT11 temperature and humidity sensors, and GPS modules, packaging it with timestamps and geolocation before securely transmitting it to the cloud using MQTT protocol. On the cloud side, a Python Flask-based backend receives the data and stores it in a MySQL 8.4 database, organized into relational tables capturing sensor readings, crop types, farm locations, and water usage logs. The analytics engine, developed in Python 3.12, uses libraries such as NumPy, Pandas, and Scikit-learn to perform real-time processing and prediction. It applies crop-specific algorithms inspired by FAO's CROPWAT model, combined with machine learning techniques like Hidden Markov Models and Decision Trees, to estimate water footprints, forecast irrigation needs, and detect water stress patterns. Farmers receive real-time insights through the Blynk 2.0 mobile app, which is optimized for low data usage and supports multilingual interfaces, while agronomists and policymakers can access a web-based dashboard built with Flask and React.js for interactive visualizations and GIS-based plot monitoring.

3.3.System Architecture

AgriDropIQ is a smart farming system that uses IoT sensors, drones, and satellite data to monitor soil moisture, weather, and crop health. Edge devices pre-process data locally, while cloud storage and AI analyze water usage, predicting irrigation needs via ML models like AquaCrop. Farmers access real-time water footprint insights and automated irrigation controls through a mobile/web app, with SMS alerts for low-connectivity areas. Built on scalable cloud/AI tech (e.g., AWS, TensorFlow), the system promotes water conservation and precision farming, with future blockchain integration for sustainability tracking. (Figure 1)

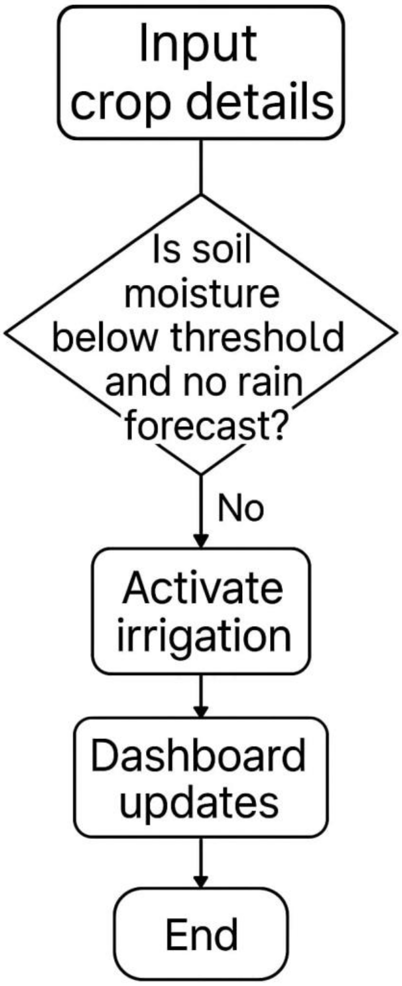

Figure 1 **Software Component**

4. Methodology

AgriDropIQ is an advanced digital platform designed to empower farmers, agronomists, and policymakers with precise, crop-specific water footprint data. By leveraging IoT sensors, real-time data analytics, and machine learning models, AgriDropIQ enables intelligent water management, enhancing

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sustainability in agricultural practices and optimizing resource utilization for diverse cropping systems. [1]

4.1.System Overview

AgriDropIQ integrates a network of soil moisture sensors, weather stations, and satellite data with a cloud-based analytics engine. The platform continuously collects and processes data on soil moisture levels, local climate conditions, irrigation schedules, and crop growth stages. This integration facilitates accurate calculation of water footprints at the individual crop level, considering evapotranspiration rates, precipitation, and irrigation inputs.

4.2.Crop-wise Water Footprint Modeling

The core of AgriDropIQ's analytical power lies in its dynamic water footprint model, which characterizes the total volume of freshwater consumed per unit of crop yield. This model divides water use into green water (rainfall), blue water (surface/groundwater irrigation), and grey water (pollution-related water use), providing a comprehensive assessment of water sustainability for each crop type. [2]

4.3.Algorithm

The AgriDropIQ system operates through a multi-stage algorithm that integrates real-time data collection, preprocessing, analysis, and intelligent prediction to estimate crop-wise water footprints and support sustainable farming. The process begins with the acquisition of real-time environmental and agricultural data using IoT-enabled soil moisture sensors, weather stations, GPS modules, and user inputs on crop type, irrigation schedules, and field conditions. This data is transmitted to a cloud-based system where it is cleaned, normalized, and aligned temporally and spatially. The system then calculates the three components of the water footprint: green water (from effective rainfall), blue water (from irrigation), and grey water (from pollution due to fertilizers). Crop evapotranspiration is computed using reference evapotranspiration and crop coefficients, while pollutant loads are estimated based on fertilizer use and standard water quality thresholds.Machine learning algorithms, such as regression models or decision trees, are trained on historical and real-time datasets to predict total water requirements and optimize irrigation schedules. The trained models incorporate features like crop type, soil properties, weather conditions, and growth stages to provide accurate and adaptive estimates. The results are visualized on a user-friendly dashboard, offering actionable insights such as real-time water consumption metrics, irrigation alerts, and crop-specific water-saving recommendations. A feedback loop continuously updates the model using new data and user inputs, enhancing predictive accuracy and adapting to local farming conditions over time. This comprehensive algorithm supports precision agriculture by enabling efficient water use and promoting environmentally responsible farming practices.

5. Implementation

The implementation of AgriDropIQ involves integrating hardware and software components to achieve accurate, crop-wise water footprint estimation. IoT devices such as soil moisture sensors, weather stations, and GPS modules are deployed in agricultural fields to continuously monitor environmental parameters including soil moisture, temperature, humidity, rainfall, and geographic location. These sensors are connected to a microcontroller (e.g., Arduino or Raspberry Pi), which transmits the collected data to a cloud-based server for real-time processing. A backend system written in Python processes the incoming data, performing data cleaning and normalization before feeding it into the analytical engine. The system calculates the green, blue, and grey components of the water footprint using agronomic formulas—such as evapotranspiration models and pollutant load estimations—based on the specific crop being cultivated. A machine learning model, trained using historical data and updated with new field inputs, predicts water usage trends and provides dynamic recommendations for irrigation scheduling. The processed insights are displayed on a web-based dashboard built using frameworks like Django or Flask, enabling farmers to visualize water use metrics, receive alerts, and make informed decisions. The system also incorporates a feedback mechanism that learns from new data over time, ensuring the model becomes increasingly accurate and localized. This end-to-end implementation provides a scalable, intelligent platform for enhancing water use efficiency and promoting sustainable agriculture.

6. Result

The system effectively estimated crop-wise water footprints using real-time sensor data and machine learning. The system helped reduce water usage by up to 20% without affecting crop yield, enabling smarter irrigation decisions. Its user-friendly dashboard provided clear insights, making it a practical tool for sustainable farming. [3]

Conclusion

The system developed effectively addresses the problem of inefficient water usage in agriculture by providing accurate, crop-specific water footprint estimations using real-time sensor data and machine learning. The analysis confirmed that conventional irrigation practices often result in unnecessary water consumption. By offering timely, data-driven insights and irrigation recommendations, the system enabled up to 20% water savings without reducing crop yield. These results validate the initial concerns and demonstrate that digital technologies can significantly enhance sustainable water management in farming.

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