Qatar Delves into the Earth:

AI Unveils the Secrets of Soil, Water, and Plants for Environmental Sustainability

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Introduction

Qatar faces significant environmental and agricultural challenges due to its harsh climatic conditions, including high temperatures and scarce rainfall. These factors contribute to water scarcity, soil salinity, and hinder sustainable agricultural production-challenges that are critical to the nation's food security. In response, Qatar has embraced a forward-thinking vision for sustainable development, launching a multidisciplinary and collaborative research project involving academia and government.

This initiative is led by a team from Qatar University under the supervision of Dr. Noora Al-Qahtani. The team comprises graduates and undergraduate students from the Colleges of Arts and Sciences and Engineering, along with high school students participating in training programs. The project is in collaboration with the Ministry of Municipality's Agricultural Affairs Department and Agricultural Research Administration.

The project employs Artificial Intelligence (AI) and the Internet of Things (IoT) to monitor soil, water, and plant health through a network of sensors that collect real-time data on soil moisture, pH, nutrients, water quality parameters, and plant characteristics. This data is processed to provide actionable insights enabling farmers and experts working in the agriculture sector to make informed decisions about irrigation, fertilization, and resource management. This approach boosts crop productivity, minimizes resource consumption, and promotes sustainable agricultural practices aligned with Qatar National Vision 2030.

Data Collection and AI Analysis

Figure 1 shows the entire system, showcasing how the system starts by collecting data from soil, water, and plant sensors, including key parameters such as soil moisture, pH, temperature, and nutrient levels, as well as water quality parameters like turbidity, dissolved oxygen (DO), and salinity. Data is transmitted via an ESP32 microcontroller using the MQTT (Message Queuing Telemetry Transport) protocol through Azure IoT Hub, either via Wi-Fi or LoRa (Long Range) for areas with limited connectivity. Upon reaching the cloud, the

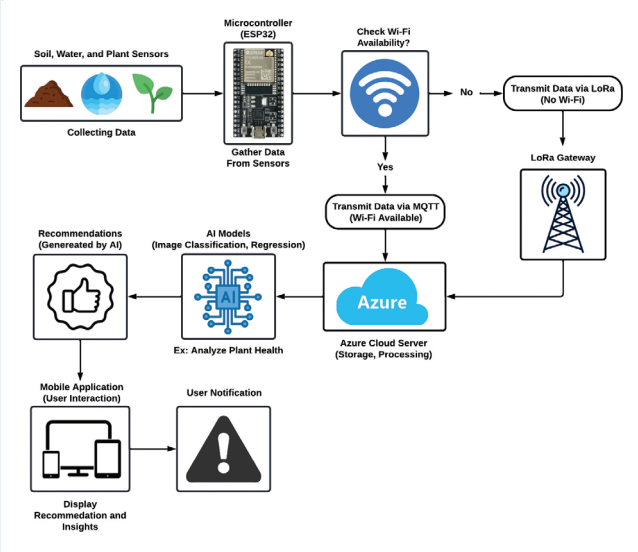

Figure 1: System Architecture and Workflow.

data becomes stored in an Azure SQL database for structured data and analyzed using Azure Time Series Insights for temporal trends. Advanced AI techniques are applied:

- **Regression Models** predict irrigation needs based on weather and environmental changes.
- **Convolutional Neural Networks (CNN)** analyze plant images to detect diseases or nutrient deficiencies using Azure Custom Vision.
- **Integration with Geographic Information Systems (GIS)** ensures location-specific recommendations, enhancing resource efficiency and sustainable agricultural performance.

Real - Time Alerts and Recommendations

A key feature of the system is its ability to provide instant notifications/alerts and recommendations. Automated actions, such as triggering irrigation when soil moisture drops below thresholds, are activated based on real-time data analysis. Notifications about nutrient management are sent directly to users. Users can access these insights via an interactive interface displaying data through graphs and dashboards. Figure 2 illustrates the initial design of the mobile app, showcasing features including real-time soil, water, and plant health indicators, as well as user instructions for optimal usage. Recommendations are supported by cloud-based storage, enabling access via mobile devices for comprehensive long-term monitoring. These features empower farmers and experts to make informed decisions, optimize resource use, and reduce manual interventions.

Significance for Qatar

This project represents a strategic step in supporting national efforts toward environmental sustainability in Qatar. With soil and water quality serving as the foundation for agricultural development and resource sustainability, the project provides precise and comprehensive data on the characteristics of these vital resources. This enables stakeholders to guide policies and investments toward enhancing food security and improving water-use efficiency, in alignment with Qatar's National Vision 2030. Additionally, the project modernizes the agricultural sector by equipping it with advanced technology and fosters collaboration between academic institutions and government entities, helping to identify Qatar's environmental needs and align them with the latest scientific advancements. Coordination has already taken place with the Ministry of Municipality and Environment to ensure the project's results are aligned with national plans.

Empowering students

The project also includes active student participation, offering hands-on training in the latest artificial intelligence and environmental technologies. Involving both undergraduate and high school students, participants gain field experience through data collection and sample analysis using advanced tools. This experience encourages students to engage in scientific research and develop effective problem-solving skills, enhancing

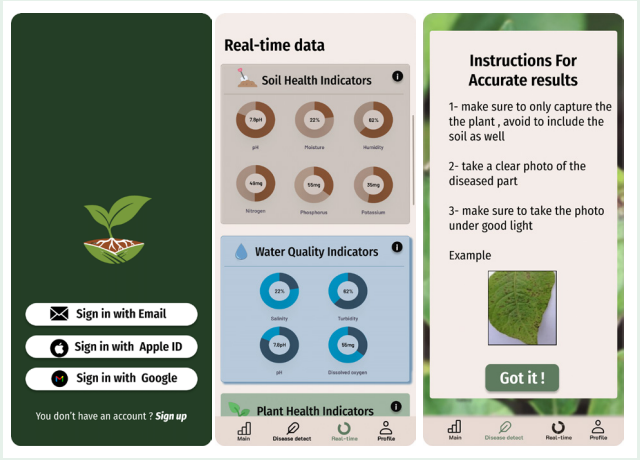

Figure 2: Initial Program Design.

their abilities to tackle environmental challenges with modern technological solutions. Through this involvement, students interact with experts and decision-makers, which hones their leadership and research skills and deepens their understanding of Qatar's environmental challenges and ways to actively address them.

Challenges and Solutions

The project faces challenges such as managing and accurately analyzing large datasets. Addressing these challenges involves advanced AI tools and intensive training for students and researchers. Partnerships with international institutions specializing in environmental data analysis and internal training programs have been established to overcome these obstacles.

Expected Outcomes

The project is anticipated to deliver innovative results, enhancing Qatar's capacity to address environmental challenges. Interactive maps of soil distribution and water quality will aid in agricultural planning, pollution mitigation, and sustainability. These outputs will directly contribute to efficient policymaking, supporting a green economy and bolstering water and food security.

Agricultural Sector Benefits

Agriculture stands to benefit significantly from this project. Precise soil and water analyses will enable farmers to optimize resource use, reduce reliance on chemical fertilizers and pesticides, and sustainably increase productivity. Additionally, water quality data will inform better resource management strategies, ensuring sustainable utilization of these critical inputs. This research initiative, led by Qatar University in collaboration with the Ministry of Municipality, sets a benchmark for employing AI in soil and water analysis to achieve sustainable development. Through academic and field collaboration, it bridges scientific innovation with Qatar's strategic needs, offering groundbreaking environmental solutions. With the expected outcomes, this project will have a long-term impact on key sectors like agriculture and water resource management, supporting Qatar's vision of comprehensive environmental and economic sustainability.

During the research team visit to Hayat Water Factory to observe the process of adding materials to the water.