INTEGRATED SMART WATER-FOCUSED IRRIGATION SYSTEM USING IOT AND AI/ML

Project ID: 25-26J-520

Project Proposal Report

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DECLARATION

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We declare that this is our own work, and this proposal does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Name	Student ID	Signature
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Table 1: Declaration Table

The supervisor/s should certify the proposal report with the following declaration.

The above candidates are carrying out research for the undergraduate Dissertation under my supervision.

.... 27/08/2025

Signature of the supervisor **Date**

ABSTRACT

Water scarcity and inefficient irrigation remain major challenges for Sri Lanka's agriculture, where a significant portion of cultivated land depends on reservoir-fed water systems. Traditional irrigation practices, based on farmer intuition or fixed schedules, often result in water wastage, crop stress, and reduced productivity. This project proposes an Integrated Smart Water-Focused Irrigation System that utilizes Internet of Things (IoT) sensors and Machine Learning (ML) models to optimize irrigation scheduling. The system integrates soil moisture, climate, and reservoir-level data with predictive ML algorithms to dynamically calculate crop-specific water requirements. Automated actuators, controlled by a microcontroller-based logic system, ensure precise irrigation while allowing farmers override through a mobile and web dashboard. The expected outcomes include reduced water consumption, improved crop yields, and enhanced decision support for farmers and irrigation authorities. Designed for scalability, affordability, and sustainability through solar-powered IoT nodes, the proposed solution demonstrates strong commercialization potential as a localized, low-cost approach suitable for Sri Lanka and other agrarian economies facing similar water management challenges.

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LIST OF ABBREVIATION

Abbreviation	Description
IoT	Internet of Things
ML	Machine Learning
AI	Artificial Intelligence
WSN	Wireless Sensor Network
API	Application Programming Interface
MQTT	Message Queuing Telemetry Transport
NB-IoT	Narrowband Internet of Things
LoRaWAN	Long Range Wide Area Network
LTE	Long Term Evolution (4G)
Kc	Crop Coefficient
ANN	Artificial Neural Network
LSTM	Long Short-Term Memory (Recurrent Neural Network model)
ARIMA	AutoRegressive Integrated Moving Average
USV	Unmanned Surface Vehicle
GUI	Graphical User Interface
UI/UX	User Interface / User Experience
SQL	Structured Query Language
NoSQL	Non-relational Database Query Language
GIS	Geographic Information System
DoA	Department of Agriculture (Sri Lanka)
MA	Mahaweli Authority (Sri Lanka)
FAO	Food and Agriculture Organization
ADB	Asian Development Bank
IWMI	International Water Management Institute

1 INTRODUCTION

1.1 Background and Literature Survey

Agriculture in Sri Lanka relies heavily on irrigation, with more than 70% of cultivated land depending on water sourced from reservoirs, tanks, and canal networks [1]. Traditional irrigation scheduling methods are largely manual, guided by farmer intuition or fixed timetables. This often leads to water overuse, under-irrigation, and reduced crop yields. Climate change–induced rainfall variability further complicates irrigation management, creating frequent dry spells and occasional floods [2].

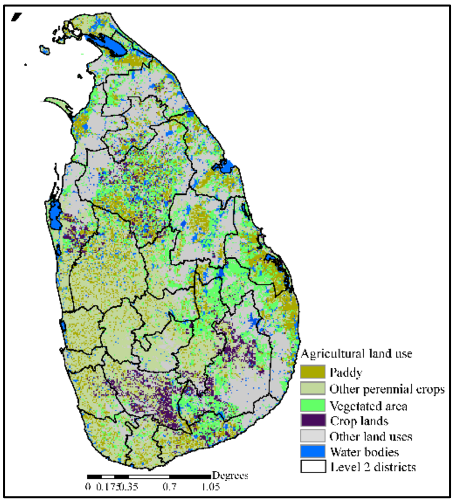

Figure 1.1:Agricultural Land Use Map

Recent advances in the **Internet of Things (IoT)** and **Machine Learning (ML)** provide new opportunities to modernize irrigation systems. IoT sensors such as soil moisture probes, humidity sensors, and flow meters enable the continuous monitoring of field conditions. These real-time datasets can then be analyzed using ML algorithms, including regression models, decision trees, and ensemble methods, to dynamically estimate irrigation requirements [3] [4]. Studies have demonstrated that sensor-driven irrigation systems can significantly reduce water consumption while improving crop health.

In Sri Lanka, early experiments in wireless sensor network–based smart irrigation systems have shown promising results. For instance, Mallikarathne et al. (2024) deployed IoT-enabled soil and climate sensors to automate irrigation, achieving measurable water savings compared to traditional practices [5]. Similarly, global research indicates that data-driven irrigation management can improve water-use efficiency by 30–50%, depending on crop type and soil conditions [6].

Despite these successes, large-scale adoption in Sri Lanka remains limited, primarily due to the lack of **integrated platforms** that combine IoT sensing, predictive ML models, and automated actuation [7]. This project proposes an IoT-enabled **Smart Water Management** system that addresses these shortcomings by integrating soil moisture, weather, and reservoir data with machine learning–based irrigation scheduling and automatic actuator control.

1.2 Research Gap

While pilot projects in Sri Lanka have explored IoT-based irrigation automation, most existing systems operate on **rule-based thresholds** (e.g., irrigate if soil moisture < 30%) [5]. Such approaches fail to account for crop-specific water requirements, seasonal variability, and upstream reservoir conditions. Moreover, there is limited integration of **real-time data analytics** and **ML-driven decision-making** in current implementations [3] [8].

Another gap lies in the lack of **seamless field-to-dam integration**. Farmers typically irrigate fields independently, without synchronization with reservoir discharge schedules. This disjointed practice contributes to inefficient water use and resource mismanagement [7].

Therefore, there is a clear need for a **modular IoT-ML framework** that dynamically calculates irrigation demand, synchronizes it with available reservoir resources, and automates irrigation at the field level.

1.3 Research Problem

The central problem addressed in this study is:

"How can IoT and ML-driven smart water management systems be designed to optimize irrigation scheduling, reduce water wastage, and improve crop productivity in Sri Lanka's reservoir-fed agricultural ecosystems?"

Traditional irrigation management is reactive, labor-intensive, and prone to inefficiencies. Without data-driven decision-making, farmers risk **over-irrigation**, leading to water scarcity, or **under-irrigation**, resulting in crop stress [2] [4]. By leveraging IoT sensors for real-time data collection and ML models for adaptive decision-making, this research aims to **bridge the gap** between available water resources and actual crop requirements, thereby ensuring sustainable and efficient irrigation practices.

2 OBJECTIVES

2.1 Main Objectives

To design and develop an **IoT-enabled, ML-driven Smart Water Management System** that optimizes irrigation scheduling by integrating real-time soil, weather, and reservoir data, thereby reducing water wastage and improving crop productivity in Sri Lanka's reservoir-fed agricultural ecosystems [1] [5].

2.2 Specific Objectives

1. **Sensor Integration and Deployment**
    - Identify appropriate IoT sensors (soil moisture, temperature, humidity, reservoir level) and deploy them in pilot agricultural fields.
    - Ensure proper calibration with Sri Lankan soil and crop conditions, as guided by the Department of Agriculture [2] [3].
2. **Data Communication Infrastructure**
    - Establish wireless communication channels (e.g., LoRaWAN, NB-IoT, 4G LTE) between field sensors, edge gateways, and cloud platforms [4].
    - Implement secure data transmission using MQTT/TLS protocols to ensure reliability.
3. **Control Logic and Automation**
    - Develop a microcontroller-based actuator system for valves and pumps to automate irrigation.
    - Enable manual override functionality for farmers through a mobile or web interface [6].
4. **Machine Learning Model Development**
    - Collect training data from pilot fields, including soil moisture patterns, weather conditions, and reservoir levels.

- Train ML models (e.g., online regression, decision trees, random forest) to dynamically estimate irrigation requirements [5] [7].

5. **Decision Support Dashboard**
    - Implement a real-time monitoring dashboard accessible via mobile and web applications.
    - Provide features for irrigation status visualization, water usage analytics, and system alerts [8].
6. **System Testing and Evaluation**
    - Conduct controlled experiments comparing ML-driven irrigation with traditional farmer-led scheduling.
    - Measure **water savings, crop yield improvement, and system responsiveness** under variable conditions [6] [9].
7. **Sustainability and Scalability**
    - Explore energy-efficient solutions such as solar-powered IoT nodes.
    - Design the system architecture to be modular, allowing future integration with larger dam and reservoir operations [7] [10].

3 METHODOLOGY

3.1 System Overview

The proposed **Smart Water Management System** integrates IoT sensors, edge/cloud computing, and machine learning models to automate irrigation decisions. Real-time field data including soil moisture, temperature, humidity, and reservoir water levels is collected through IoT devices and transmitted via low-power wireless protocols (e.g., LoRaWAN, NB-IoT) to a central gateway.

This data is processed by an ML-driven decision-making engine hosted on cloud or edge servers, which dynamically determines irrigation requirements for different crop types and soil conditions [1]. The system then triggers actuators (valves or pumps) to release precise amounts of water to the fields.

A web/mobile dashboard allows farmers to monitor field conditions, view irrigation schedules, and override automated decisions if required. The overall design reduces manual intervention, enhances water-use efficiency, and synchronizes local irrigation with upstream reservoir conditions [5] [6].

3.1.1 System Overview Diagram (Overall)

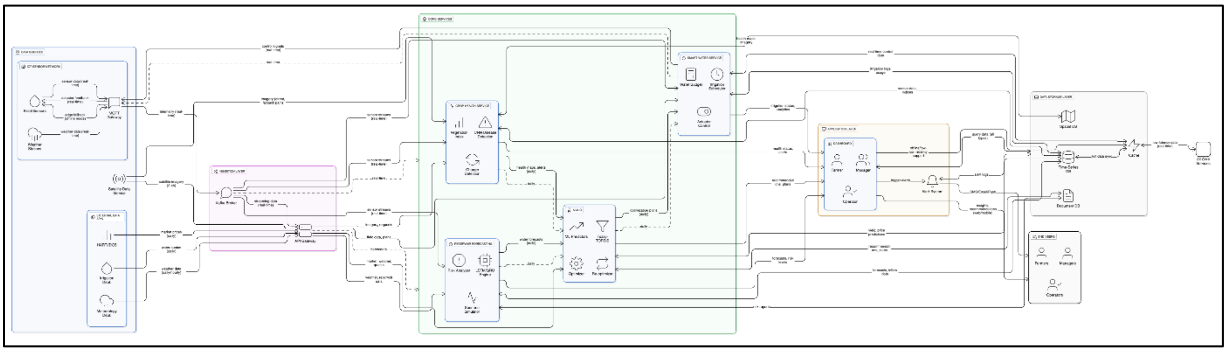

Figure 3.1: Full System Overview Diagram

3.1.2 Approach and Workplan

The methodology follows a modular, iterative approach:

1. **Requirements Gathering and Field Study**
    - Identify crop types, soil categories, and water needs specific to Sri Lankan dry-zone agriculture.
    - Consult with agrarian officers and the Department of Agriculture for irrigation best practices.
2. **Sensor Network Deployment**
    - Install soil moisture probes, temperature/humidity sensors, and reservoir-level monitors.
    - Use wireless protocols (LoRaWAN/NB-IoT) for communication between sensors and gateways.
3. **Data Collection and Processing**
    - Collect continuous real-time sensor data
    - Preprocess the data to remove noise, normalize readings, and handle missing values.
4. **Machine Learning Model Development**
    - Train models such as online regression, decision trees, and random forest on collected datasets.
    - Optimize model performance based on water savings, crop yield improvement, and response latency [5][8].
5. **Automation and Actuation**
    - Connect microcontroller-based actuators (valves, pumps) to irrigation pipelines.
    - Integrate control logic with ML outputs to automate water release.

- Allow manual overrides through dashboard interfaces [6].

6. **System Integration and Dashboard Development**

    - Develop a farmer-friendly dashboard (web and mobile) with real-time visualization, alerts, and analytics.

    - Provide bilingual support (Sinhala/Tamil + English) for accessibility.

7. **Testing and Evaluation**

    - Compare ML-based irrigation with traditional farmer-led scheduling in pilot fields.

    - Evaluate performance metrics: water usage reduction, crop health improvement, system response time [9].

3.1.3 Data and Instruments

- **Sensors:** Soil moisture probes, DHT11/DHT22 humidity and temperature sensors, ultrasonic or float-based reservoir water-level sensors.
- **Actuators:** Solenoid valves and submersible pumps controlled via microcontrollers (Arduino/ESP32).
- **Communication:** LoRaWAN/NB-IoT gateways for low-power, long-range connectivity [4].
- **Processing:** Edge computing nodes (Raspberry Pi) for initial data aggregation; cloud servers for ML training and decision logic.
- **Software & Tools:**
    - Python (scikit-learn, TensorFlow) for ML model development.
    - Node-RED/MQTT for IoT communication orchestration.
    - Web/mobile app frameworks (React, Flutter) for dashboard development.

3.1.4 Anticipated Results and Evaluation

The system is expected to:

- Reduce irrigation water usage by compared to manual scheduling [6][9].
- Improve crop yield by ensuring timely, crop-specific irrigation [3].
- Provide farmers with actionable insights and flexibility via dashboards.
- Demonstrate scalability for integration with reservoir management systems.

Evaluation Metrics:

- **Water Savings (%):** Difference in total water used vs. traditional methods.
- **Crop Health Indicators:** Yield per hectare, plant stress index.
- **System Responsiveness:** Time taken for data-to-actuation loop.
- **Farmer Usability:** Feedback surveys on dashboard effectiveness.

3.1.5 System Overview Diagram (Individual)

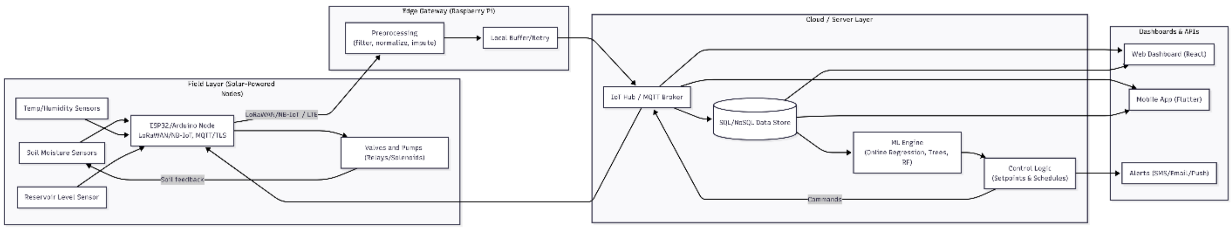

Figure 3.2: System Overview of the Smart Water Management

3.2 Requirement Analysis

3.2.1 Functional Requirements

The Smart Water Management system must support the following functional capabilities:

1. **Real-Time Data Collection** - Gather soil moisture, temperature, humidity, and reservoir water level readings continuously from IoT sensors [1][3].
2. **Data Transmission** – Transfer collected data securely to edge/cloud servers via LoRaWAN, NB-IoT, or 4G LTE protocols [4].

3. **Data Preprocessing** – Handle missing values, normalize datasets, and filter noise before analysis [7].
4. **Machine Learning–Driven Irrigation Scheduling** – Use trained ML models (e.g., online regression, random forest) to calculate irrigation needs dynamically [5][8].
5. **Automated Actuation** – Control irrigation pumps and valves based on ML model outputs, with minimal manual intervention [6].
6. **Manual Override** – Allow farmers to override automated schedules using a web/mobile interface when necessary.
7. **Dashboard Monitoring** – Provide real-time dashboards to visualize soil conditions, water usage, and irrigation schedules [9].
8. **Alerts & Notifications** – Send SMS/email/mobile alerts when critical thresholds (e.g., drought stress, reservoir depletion) are detected [2].
9. **Data Logging & Reporting** – Maintain historical records of water usage, crop irrigation cycles, and system performance.

3.2.2 Non-functional Requirements

- **Performance** - The system should process data-to-decision within ≤5 seconds to ensure real-time responsiveness.
- **Scalability** - Architecture must support scaling from a single farm to a large multi-reservoir irrigation network [7].
- **Reliability** - Ensure high uptime of IoT devices and communication links.
- **Security** - Protect data in transit using MQTT/TLS encryption and enforce secure device authentication [4].
- **Energy Efficiency** - IoT nodes should run on low power, with optional solar support for sustainability.
- **Maintainability** - Use modular architecture so individual components (sensors, ML models, dashboard) can be upgraded independently.

- **Usability** - The dashboard interface must be farmer-friendly, multilingual (Sinhala/Tamil + English), and mobile-optimized [6].
- **Affordability** - The solution should minimize deployment and operational costs for farmer adoption.

3.2.3 User Requirements

The following user requirements were identified based on insights from existing research studies, government reports, and related IoT-based irrigation projects, rather than primary user surveys:

- Farmers require a simple and intuitive dashboard to monitor real-time soil conditions, water usage, and crop health, enabling them to make informed irrigation decisions.
- Reservoir operators need analytical tools and summary reports that help synchronize field-level irrigation schedules with upstream reservoir water releases, ensuring coordinated water management [1].
- Agricultural officers require access to historical and comparative datasets to provide data-driven recommendations and policy guidance for efficient irrigation practices.
- All users require mobile application support for real-time access, even in rural areas with limited connectivity, ensuring inclusivity and usability.

3.2.4 System Requirements

Hardware Requirements

- **Sensors:** Soil moisture sensors, DHT11/DHT22 humidity and temperature probes, ultrasonic water-level sensors.
- **Actuators:** Solenoid valves, irrigation pumps, relay switches.
- **Processing Devices:** Arduino/ESP32 microcontrollers, Raspberry Pi edge gateway.
- **Network Infrastructure:** LoRaWAN/NB-IoT gateway, 4G LTE backup.

- **Power:** Solar panels with battery backup for field devices [4].

Software Requirements

- **IoT Middleware:** Node-RED / MQTT broker for device communication.
- **ML Development:** Python with scikit-learn, TensorFlow.
- **Database:** Cloud-hosted SQL/NoSQL (e.g., Firebase, MySQL).
- **Dashboard:** React (web), Flutter (mobile).
- **Cloud Platform:** Microsoft Azure IoT Hub / AWS IoT Core for device management and data storage.

3.3 Work Breakdown Structure

Module	**Tasks**
Module 1 - Requirements & Research	• Task 1.1: Conduct literature review on IoT-ML irrigation systems. • Task 1.2: Gather requirements from farmers, reservoir authorities, and agricultural officers. • Task 1.3: Define scope, objectives, and success criteria for the smart irrigation system.
Module 2 - Sensor Network Deployment	• Task 2.1: Select appropriate IoT sensors (soil moisture, humidity, temperature, reservoir water level) • Task 2.2: Calibrate sensors for Sri Lankan agro-climatic conditions [2][5]. • Task 2.3: Deploy sensors in pilot agricultural fields • Task 2.4: Configure wireless communication (LoRaWAN/NB-IoT)

Module 3 - Data Collection & Preprocessing	• Task 3.1: Collect real-time sensor data at 10–30 min intervals • Task 3.2: Implement preprocessing pipeline (missing value handling, normalization, filtering) • Task 3.3: Store processed data in cloud database (e.g., MySQL, Firebase)
Module 4 - Machine Learning Model Development	• Task 4.1: Define model inputs (soil moisture, weather forecast, reservoir level) • Task 4.2: Train models (online regression, decision trees, random forest) • Task 4.3: Evaluate models against performance metrics (water saving, yield improvement) • Task 4.4: Optimize models for real-time predictions
Module 5 - Actuation & Control Logic	• Task 5.1: Design microcontroller-based actuator system (Arduino/ESP32) • Task 5.2: Connect pumps and solenoid valves to irrigation lines • Task 5.3: Implement actuation control algorithm integrating ML outputs • Task 5.4: Test automated vs. manual irrigation response
Module 6 - Dashboard Development	• Task 6.1: Develop web dashboard (React) for real-time monitoring • Task 6.2: Develop mobile app (Flutter) for farmer accessibility • Task 6.3: Implement features: data visualization, manual overrides, alerts/notifications

Module 7 - System Integration & Testing	• Task 7.1: Integrate sensors, ML models, actuators, and dashboard into unified workflow • Task 7.2: Conduct controlled experiments comparing smart irrigation vs. farmer-led scheduling [8] • Task 7.3: Measure key metrics (water saved, crop health, response latency) • Task 7.4: Collect farmer/operator feedback for system refinement
Module 8 - Documentation & Reporting	• Task 8.1: Maintain experiment logs and datasets • Task 8.2: Document system design, algorithms, and evaluation results • Task 8.3: Prepare final proposal report, thesis, and presentation slides

Table 3.1: Work Breakdown

4 BUDGET AND BUDGET JUSTIFICATION

Item	Description	Estimated Cost (LKR)
Soil Moisture Sensors (x3)	Measures soil water content in pilot plots	9,000
Temperature & Humidity Sensors (DHT22 x2)	Monitors environmental conditions	4,000
Ultrasonic/Float Water Level Sensor (x1)	Measures reservoir or tank level	3,500
Microcontrollers (ESP32/Arduino x2)	Controls sensors and actuators	8,000
Solenoid Valves (x2)	Automates irrigation water flow	7,000
Relay Modules & Pump Controller	Controls irrigation pumps	4,500
Solar Power Unit (Panel + Battery)	Provides renewable power for field nodes	15,000
LoRa/NB-IoT Modules	Wireless data transmission from field sensors	10,000
Raspberry Pi / Edge Gateway	Local data processing and control unit	18,000
Cloud Storage / IoT Platform (AWS/Azure/Firebase)	For data storage and ML model deployment	5,000
Prototype Field Setup and Calibration	Installation and field testing	7,000
Transportation and Miscellaneous	Visits to test sites	6,000
Total Estimated Budget		**LKR 97,000**

Note: The above budget represents a rough estimation derived from similar IoT-based smart irrigation research studies and a preliminary cost analysis based on the functional requirements of this project.

5 COMMERCIALIZATION AND ENTREPRENEURSHIP POTENTIAL

The proposed Smart Water Management system is not only a research initiative but also has high commercialization potential in Sri Lanka and other agrarian economies. With agriculture contributing significantly to the national economy and water scarcity becoming a growing concern, there is a clear demand for cost-effective, technology-driven irrigation solutions [1][2].

5.1 Target Market

1. **Smallholder Farmers**
   - Majority of Sri Lankan farmers cultivate on plots less than 2 hectares.
   - Affordable IoT-based irrigation kits can help them reduce water usage. [3][5].
2. **Commercial Farms & Plantation Sector**
   - Large-scale paddy, and horticulture plantations require efficient irrigation monitoring and predictive analytics.
   - Adoption of the system would lead to significant operational savings and higher productivity [4].
3. **Government & Irrigation Authorities**
   - Integration with reservoir operations enables better water distribution and reduces conflicts between upstream and downstream users.
   - Aligns with **national water management strategies** and **climate resilience goals** [2][7].
4. **Agri-Tech Companies**
   - The solution can be offered as a **"Smart Irrigation-as-a-Service"** model.

5.2 Value Proposition

- **For Farmers:** Reduce manual labor, save water, and increase crop yields through optimized irrigation.
- **For Government:** Ensure sustainable reservoir-fed agriculture, prevent water conflicts, and support climate adaptation.
- **For Investors/Startups:** Opportunity to build a scalable agri-tech product that can be expanded regionally (India, Southeast Asia, Africa).

5.3 Business Model

1. **Product Sales:** Low-cost IoT irrigation kits (sensors, pump/valve controller, mobile dashboard).
2. **Subscription Model:** Farmers pay a small monthly fee for access to cloud analytics, ML-driven irrigation recommendations, and dashboard services.
3. **Public-Private Partnerships (PPP):** Collaborate with Ministry of Agriculture and Department of Irrigation to deploy at scale.
4. **Green Financing:** Potential funding via climate adaptation grants, World Bank projects, and agricultural cooperatives.

5.4 Competitive Advantage

- **Localized Design:** Tailored to Sri Lankan soil, crop, and reservoir conditions (unlike imported solutions).
- **Low Cost:** Uses open-source software and low-power IoT hardware to reduce expenses [5].
- **Scalability:** Designed to scale from **individual farms → reservoir-fed irrigation networks**.
- **Sustainability:** Energy-efficient with solar-powered IoT nodes.

5.5 Entrepreneurship Potential

This project can evolve into a **startup venture** focused on **AgriTech + Water Management**. Possible entrepreneurship pathways include:

- **Startup Incubation:** Partner with Sri Lankan university incubators or ICTA programs for commercialization support.
- **Pilot-to-Scale Model:** Begin with pilot deployments in one irrigation zone, then expand through government/NGO partnerships.
- **Export Potential:** Neighboring countries with similar challenges (India, Bangladesh, Myanmar) can adopt the system.

6 DESCRIPTION OF PERSONNEL AND FACILITIES

6.1 Personnel

- **Ms. Hansi De Silva** - Supervisor, Sri Lanka Institute of Information Technology (SLIIT)
- **Ms. Karthiga Rajendran** - Co-Supervisor, Sri Lanka Institute of Information Technology (SLIIT)
- **Mr. Thilanka Bandara** - External Supervisor, Renewable Energy Consultant
- **Mr. Hesara P.K.A.N. (IT22561398)** - Student Researcher, Smart Water Management Component

6.2 Facilities

- Sri Lanka Institute of Information Technology (SLIIT)
- Irrigation Department
- Udawalawe Dam Authority
- Udawalawa Agricultural Office

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8 TURNITIN REPORT