Application of Internet of Things (IoT) in Boosting Irrigation Efficiency for Sustainable Agriculture

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Abstract: This paper presents the design, implementation, and evaluation of an Internet of Things (IoT)-based irrigation system aimed at improving water use efficiency in Indian agriculture. The system employs an ESP32 microcontroller integrated with soil moisture, temperature, humidity, and pH sensors, connected to a water pump and cloud storage via Google Sheets. SMS alerts are sent to farmers for real-time decision support. Field testing revealed up to 40% water savings, 10–15% yield improvements, and a return on investment within 2 years. A survey of 1100 farmers validated adoption potential, with 85.6% recommending IoT irrigation. Statistical analysis (Chi-square, t-test, regression) confirmed that adoption was independent of demographics and valued for multiple benefits. This study contributes to sustainable agriculture and aligns with national initiatives such as PMKSY and the Digital Agriculture Mission.

Keywords: *IoT, Smart Irrigation, ESP32, Agriculture 4.0, Sustainable Farming, PMKSY, Digital Agriculture*

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I. INTRODUCTION

Water scarcity and inefficient irrigation practices remain critical challenges in Indian agriculture. Traditional flood irrigation methods waste up to 40–60% of water, threatening both productivity and sustainability. IoT-based smart irrigation offers a solution by integrating real-time monitoring, automated irrigation, and cloud-based analytics. National programs like Pradhan Mantri Krishi Sinchai Yojana (PMKSY) and the Digital Agriculture Mission 2021–25 highlight the importance of digital technology adoption in farming. This research aims to design and validate a low-cost IoT irrigation system that conserves water, improves yields, and ensures farmer adoption.

II. LITERATURE REVIEW

Existing studies demonstrate IoT applications in agriculture using wireless sensor networks, ZigBee, RFID, and GSM modules. While these systems improve monitoring, adoption barriers include high cost, complexity, and limited rural connectivity.

Indian initiatives such as ICAR's smart farming trials and the SWAMP project have shown promise but remain limited in reach. Thus, there is a need for affordable, scalable, farmer-friendly IoT systems.

III. METHODOLOGY

The IoT irrigation system was developed using an ESP32 microcontroller, interfaced with soil moisture, temperature, humidity, and pH sensors. A water pump was automated based on soil moisture thresholds. Data was transmitted via Wi-Fi to Google Sheets and SMS alerts were sent through GSM. Two algorithms were designed for irrigation decision-making and data logging with SMS notifications.

- *Algorithm 1*:
  IoT-based Irrigation Decision-Making

- *Input*:
  Soil Moisture, Temp, Humidity, Threshold Output: Pump Status (ON/OFF)

- *Begin*
  Read Soil Moisture, Temp, Humidity If Soil Moisture < Threshold then
  Pump = ON Send SMS Alert
  Else
  Pump = OFF End If
  Log data to Cloud End

- *Algorithm 2:*
  Data Logging and SMS Alerting Input: Sensor Data

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- *Output*
  Cloud Record, SMS Alert

✓ *Begin*
Collect sensor data Transmit via ESP32 Wi-Fi Store in Google Sheets

If irrigation triggered, then Send SMS to farmer

End If End

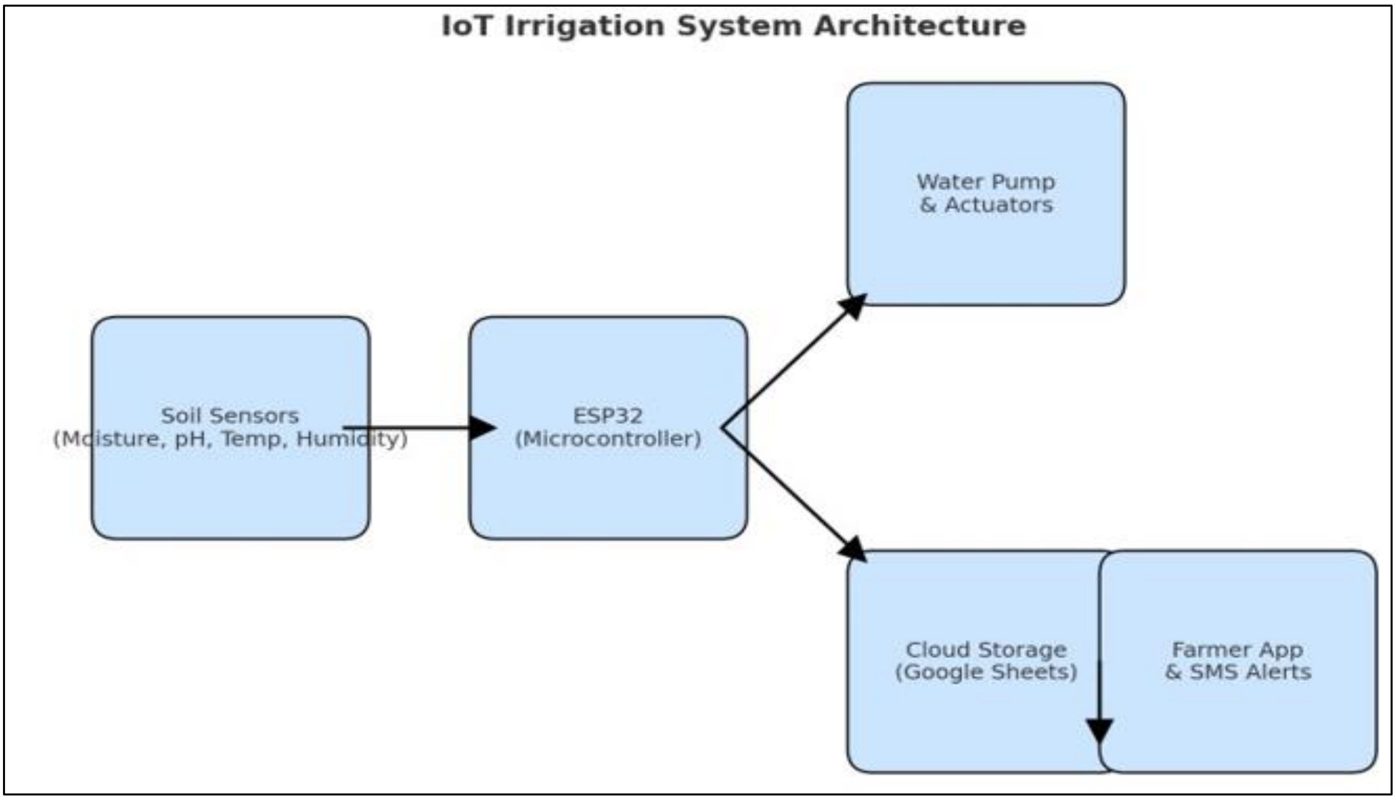

Fig 1 Iot Irrigation System Architecture

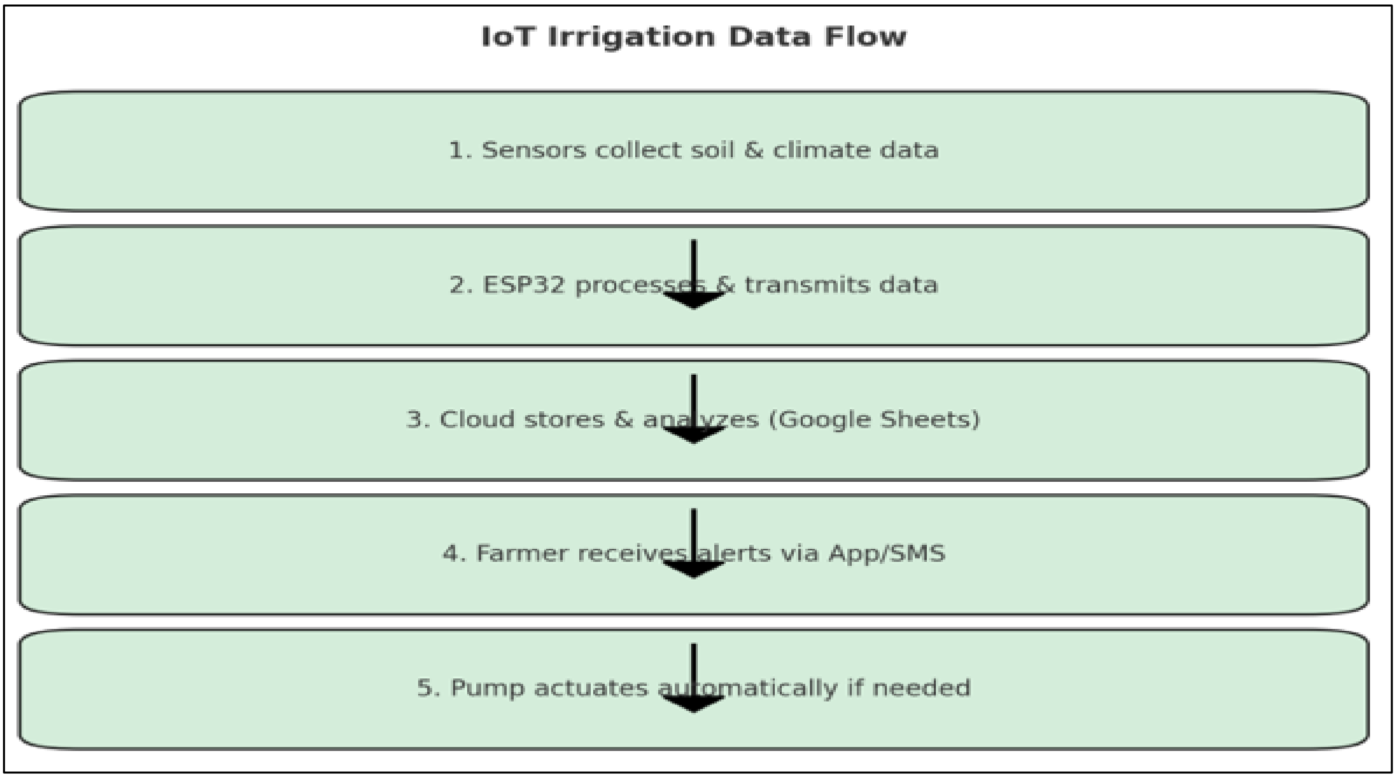

Fig 2 Iot Irrigation Data Flow

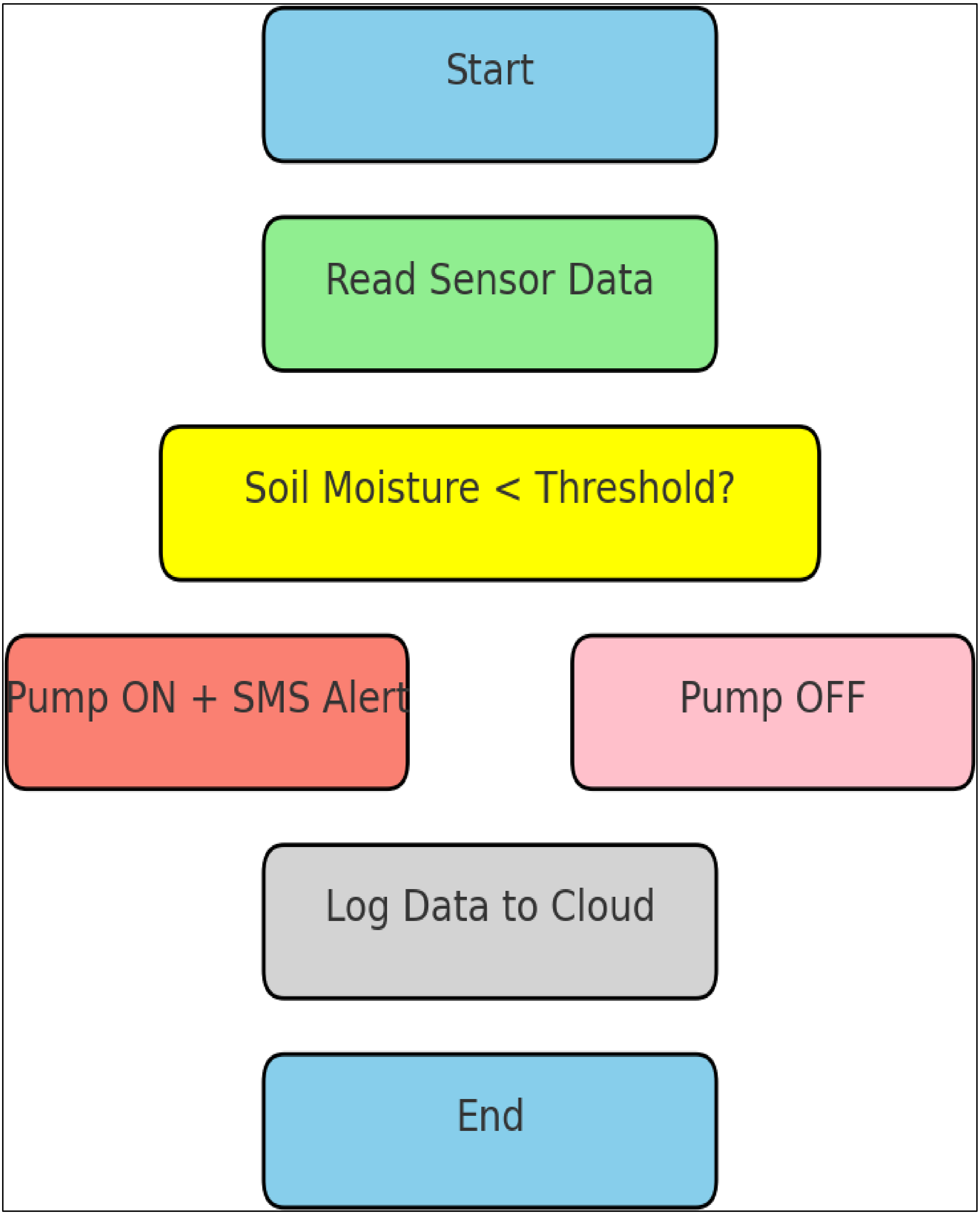

Fig 3 Flowchart for Iot-Based Irrigation Decision-Making

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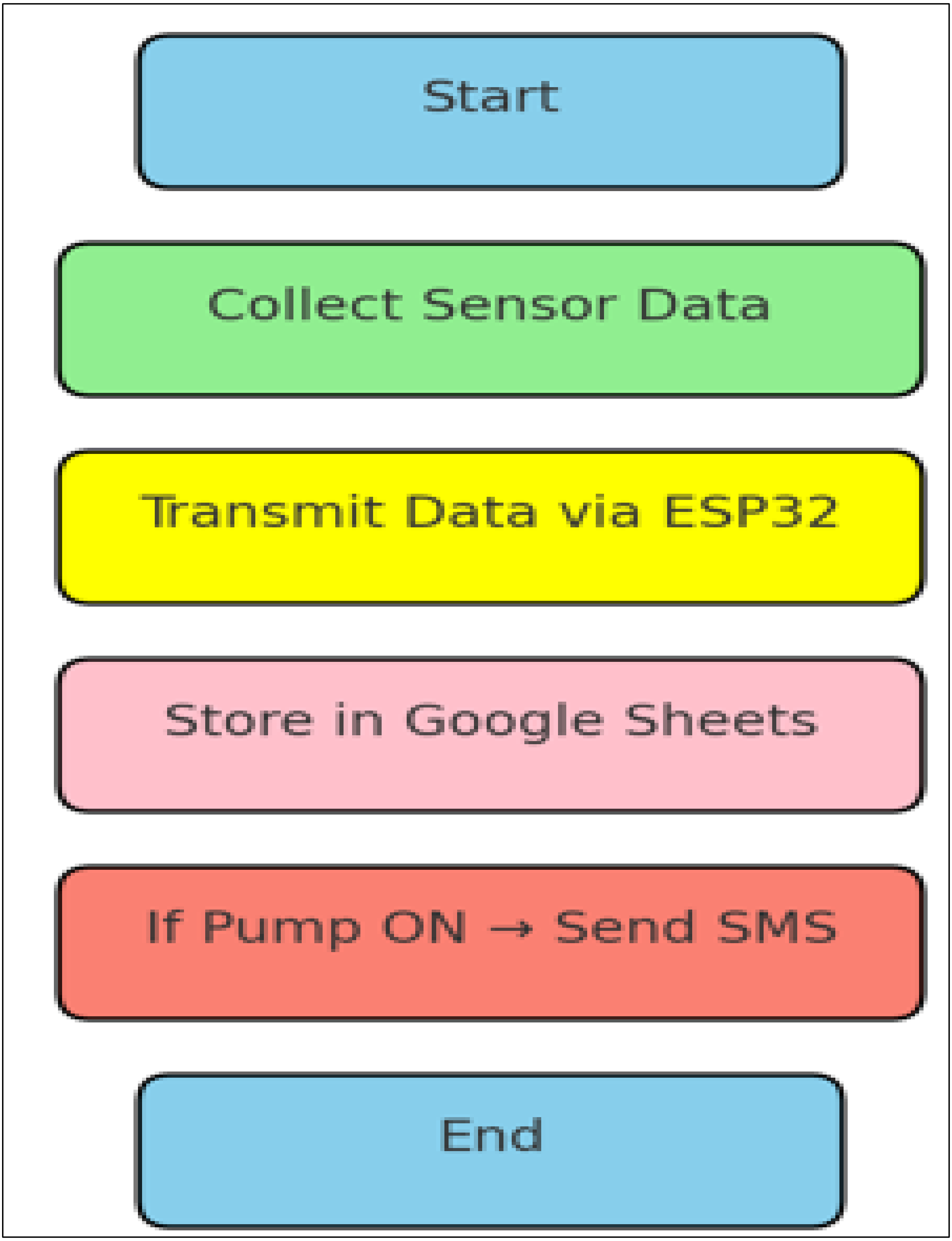

Fig 4 Flowchart for Data Logging and SMS Alerting

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IV. RESULTS AND DISCUSSION

Field testing demonstrated significant benefits: ~40% water savings compared to traditional irrigation, 10–15% yield improvement, and ROI within 2 years. Correlation analysis revealed relationships between soil moisture, temperature, humidity, and irrigation needs. Statistical validation confirmed adoption was independent of farmer education or landholding size. Survey findings showed 85.6% of 1100 farmers recommended IoT irrigation, citing water efficiency, SMS usefulness, and yield gains.

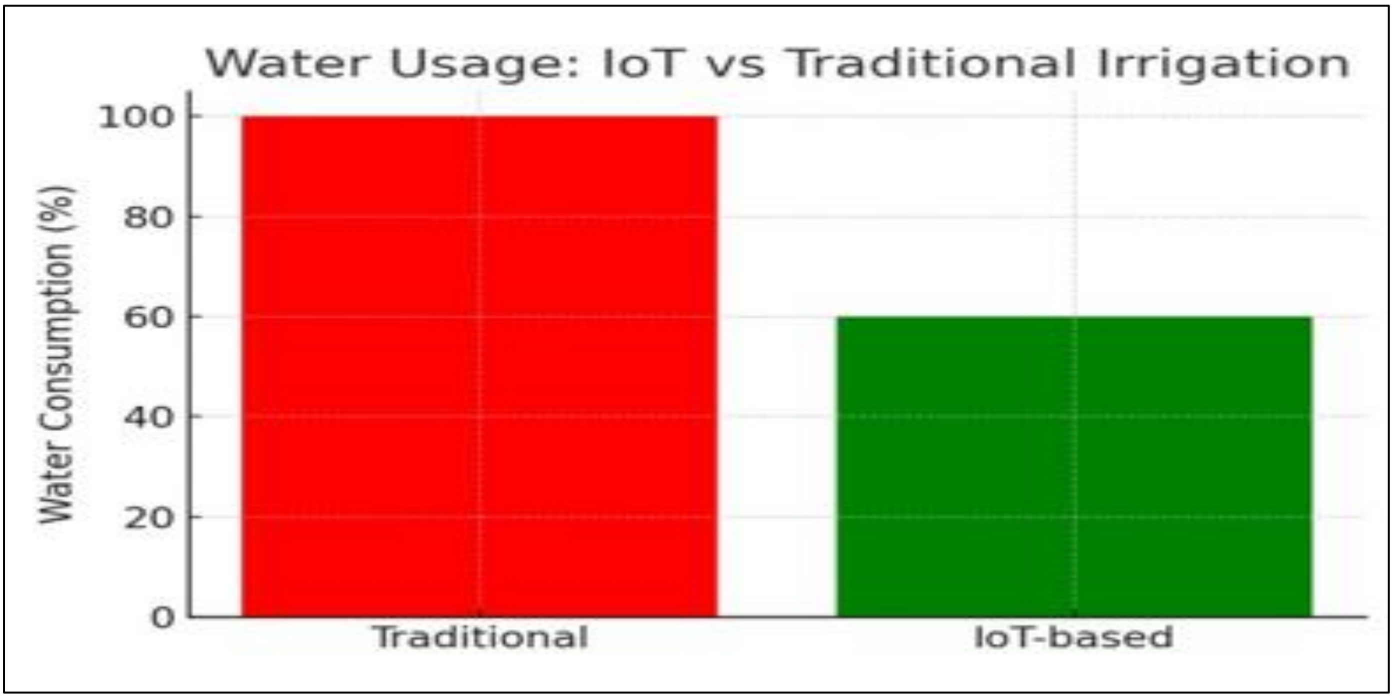

Fig 5 Water Usage Comparison

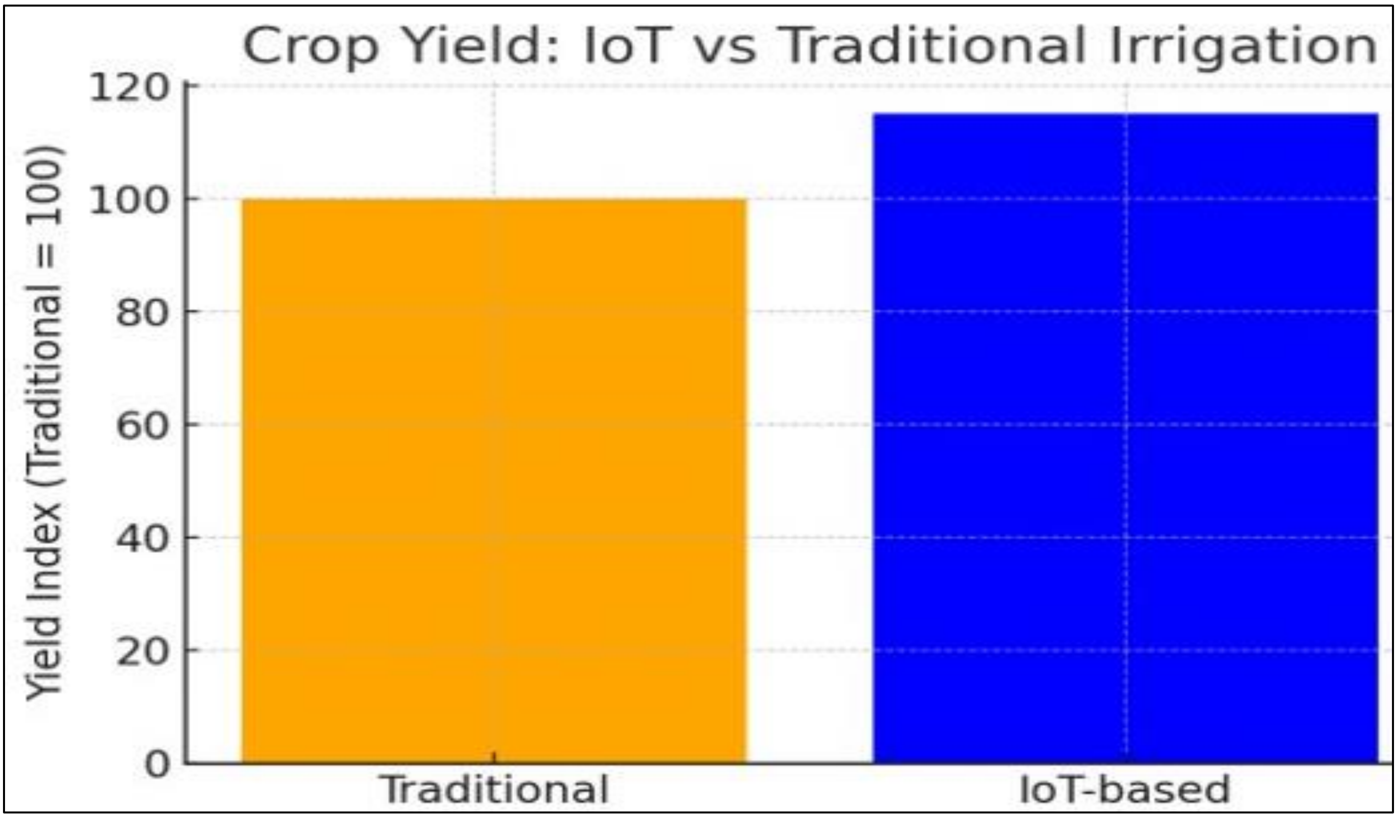

Fig 6 Yield Comparison

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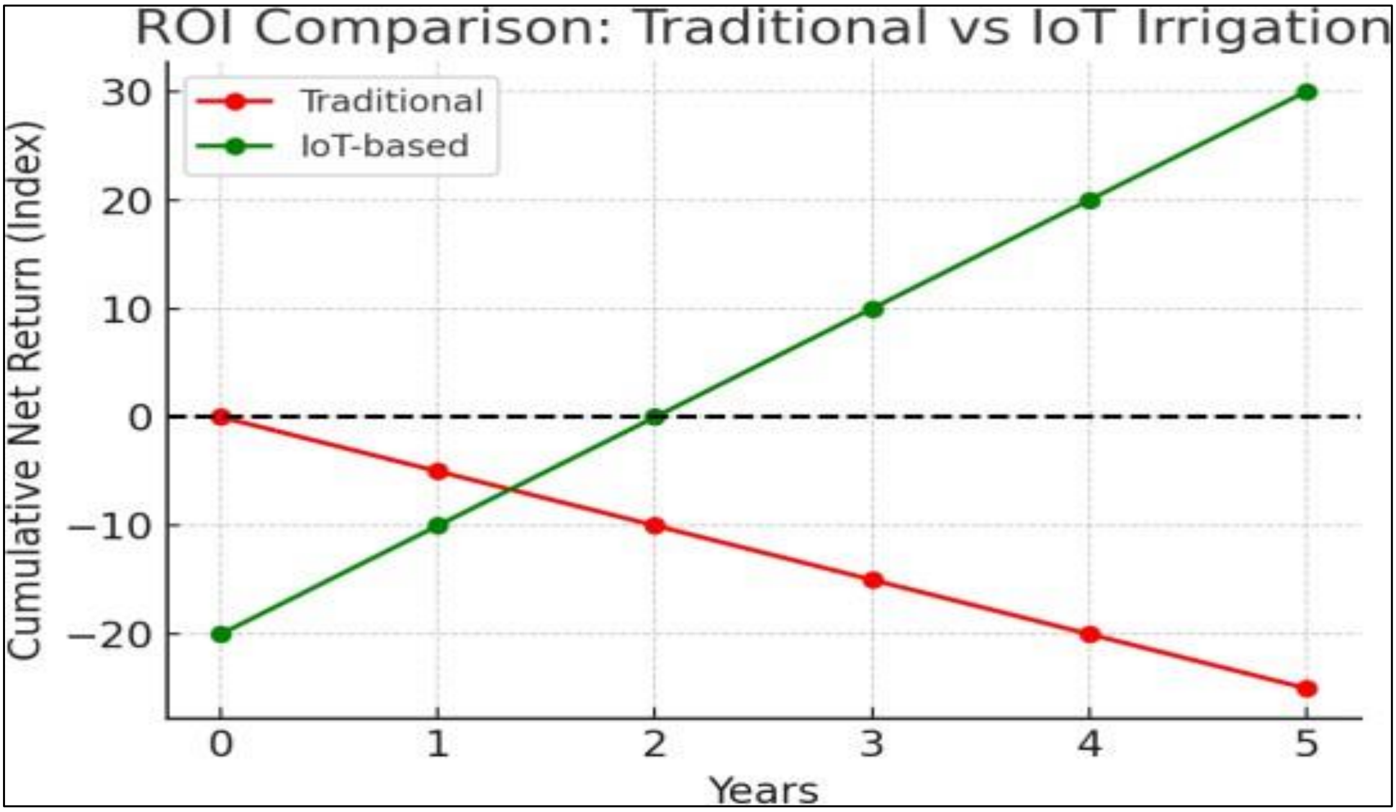

Fig 7 ROI Comparison

➢ *Statistical Analysis:*

- Chi-Square (Education vs Recommendation): $\chi^2 = 4.77$, $p = 0.189$ (NS)
- T-test (Water Saved % by Recommend Vs Not): $t = -0.045$, $p = 0.964$ (NS)
- Regression (Water Saved predictors): $R^2 = 0.003$ (weak)
- Cronbach's Alpha: $\alpha = 0.02$ (survey measures multidimensional aspects)

✓ *Interpretation:*

IoT adoption is universal, not limited by demographics, and valued for multiple dimensions beyond water saving.

V. CONCLUSION AND FUTURE WORK

This research demonstrates that IoT-based irrigation using ESP32 and sensors can significantly reduce water use, increase yield, and ensure profitability with ROI within two years. Adoption is validated through farmer surveys and statistical analysis. Future work includes integration of AI/ML for predictive irrigation, linkage with weather forecasts, and deployment at scale with government support under PMKSY.

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