Towards Sustainable Water Management: Leveraging Soil Moisture Sensors for Smart Irrigation in the GCC

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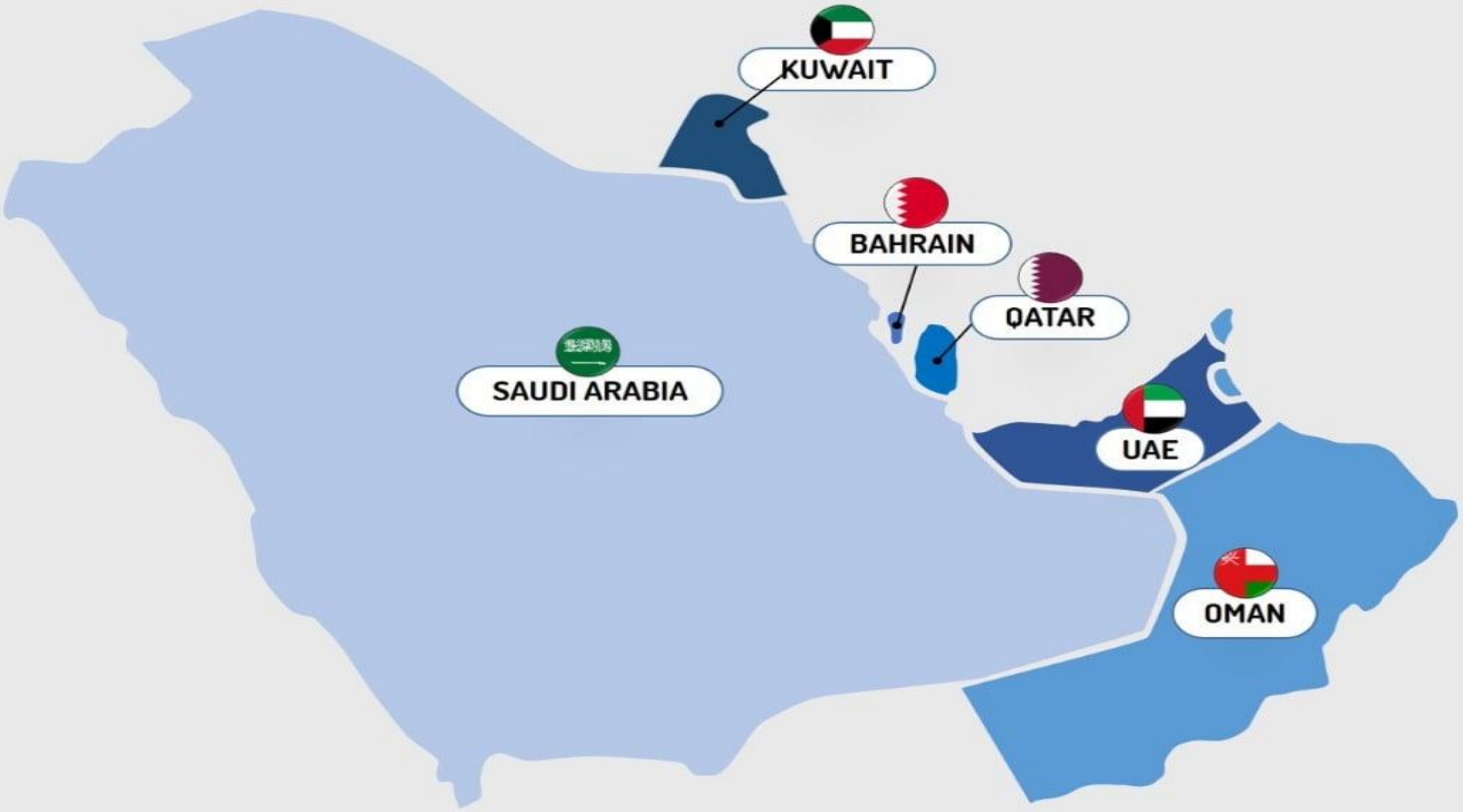
Overview

- Introduction and Objectives
- Smart Irrigation Scheduling and Soil Moisture Sensors
- Methodology
- R&D Efforts
- Challenges and Considerations
- Gaps and Opportunities
- Results and Discussion

GCC MEMBER STATES



Introduction and Objectives

- Water scarcity challenges in the GCC due to arid climate and limited fresh water resources
- Need for efficient water management, primarily in agriculture
- Soil moisture sensors
  - enable continues monitoring of soil moisture levels
  - Provide valuable insights into water dynamics crucial for crop health
- Growing adoption of soil moisture sensors in GCC for smart irrigation scheduling

- **Objective:** Explore role of soil moisture sensors based irrigation scheduling in the GCC region towards efficient water management

Smart Irrigation Scheduling System

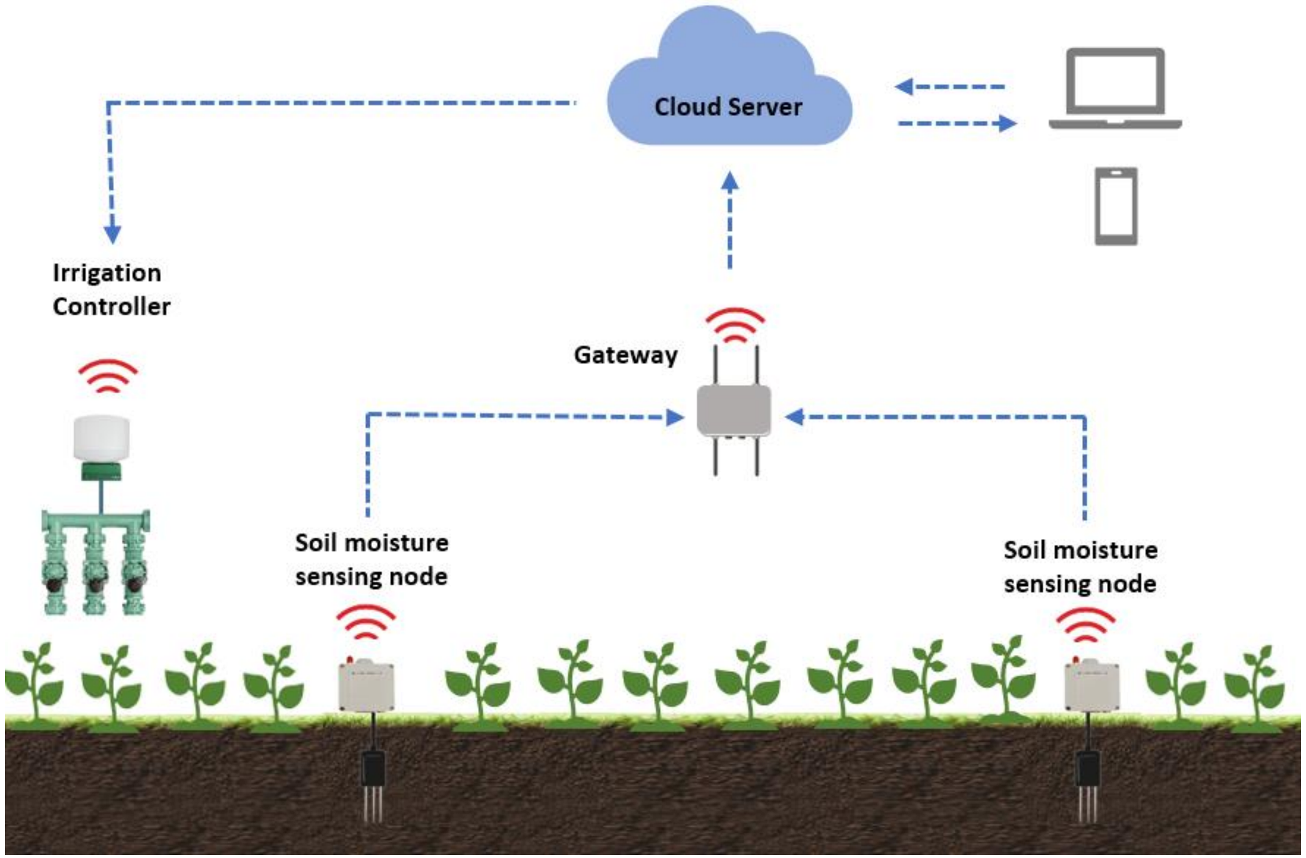


Figure 1. A smart irrigation scheduling system.

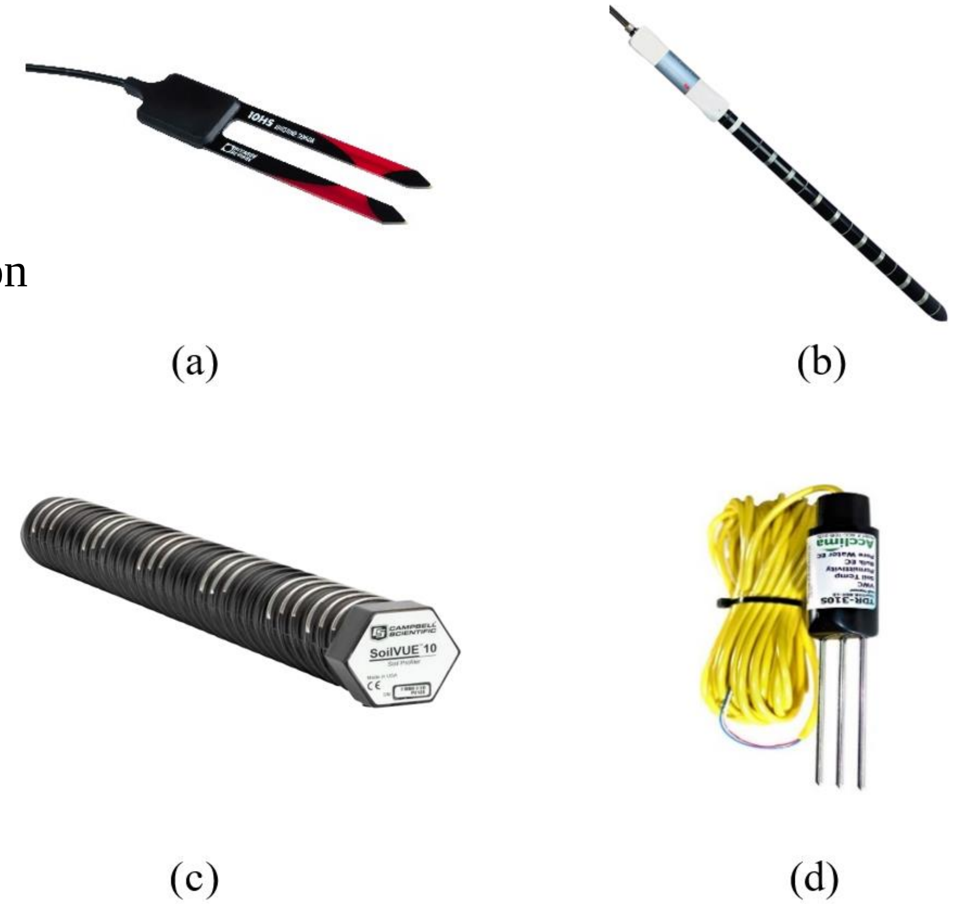
Soil Moisture Sensors

Volumetric Soil Moisture Sensors

- Generally, crops experience stress when soil water depletion reaches 30-50% of the available water holding capacity (AWC), termed as Management Allowable Depletion (MAD).
- Irrigation should commence when the percentage of soil water depletion aligns with or nears the MAD threshold

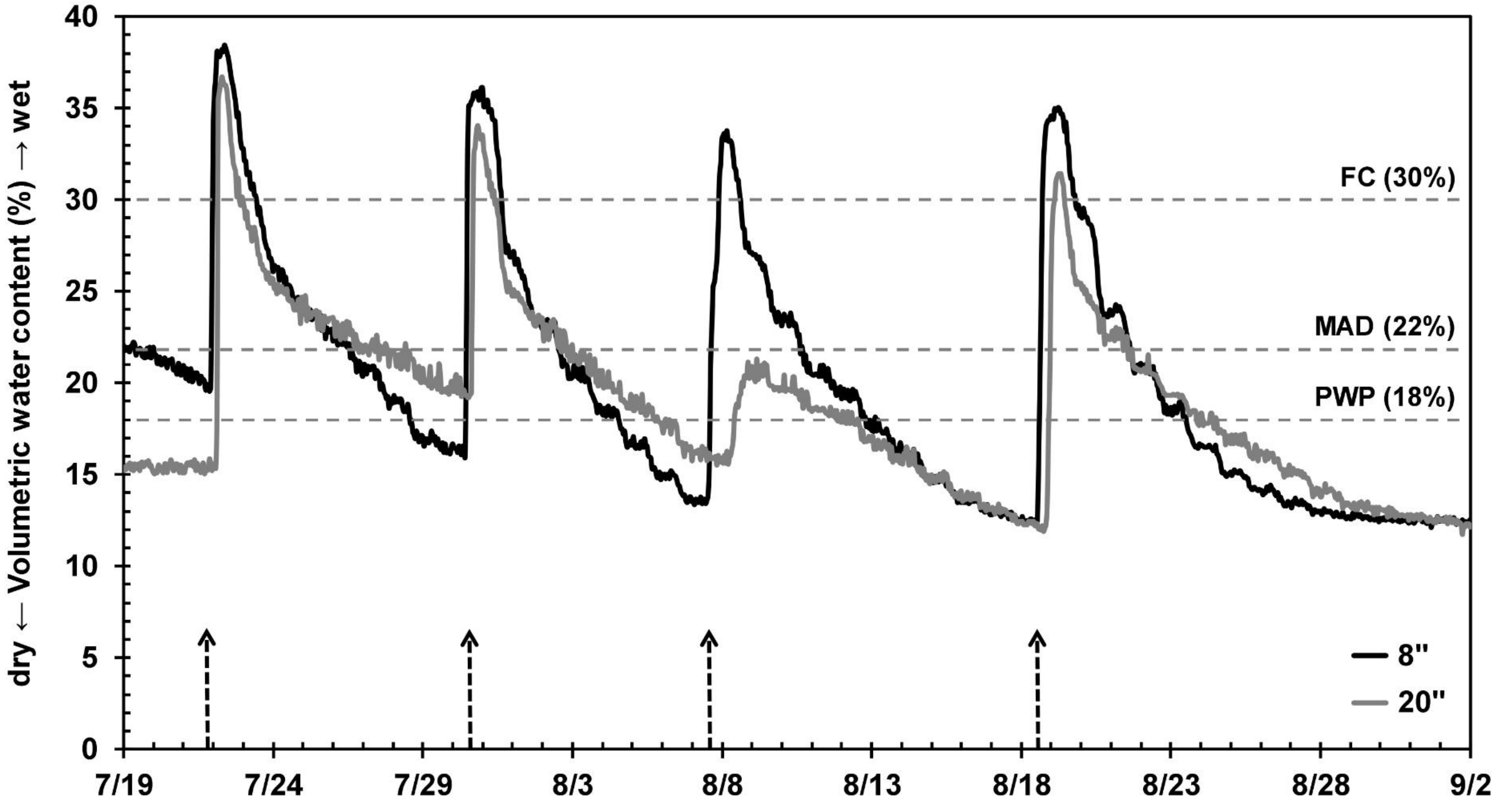
$$\% \, Soil\ Water\ Depletion =$$

$$= \left[1 - \left(\frac{Sensor\ VWC(\%) - PWP(\%)}{FC(\%) - PWP(\%)}\right)\right] * 100$$



VWC sensors: a) a capacitance sensor (b) a multi depth capacitance sensor, (c) a SoilVue 10TDR soil moisture and temperature profile sensor, (d) a TDR sensor [9].

Managing Irrigation based on VWC data



- Hourly VWC fluctuations at 8 and 20 inches below soil surface over a 45-day period.

Soil Moisture Sensors

Matric Potential Sensors

Soil water tension represents the energy needed by plant roots to draw water from soil particles.

As soil water diminishes, tension within the soil increases.

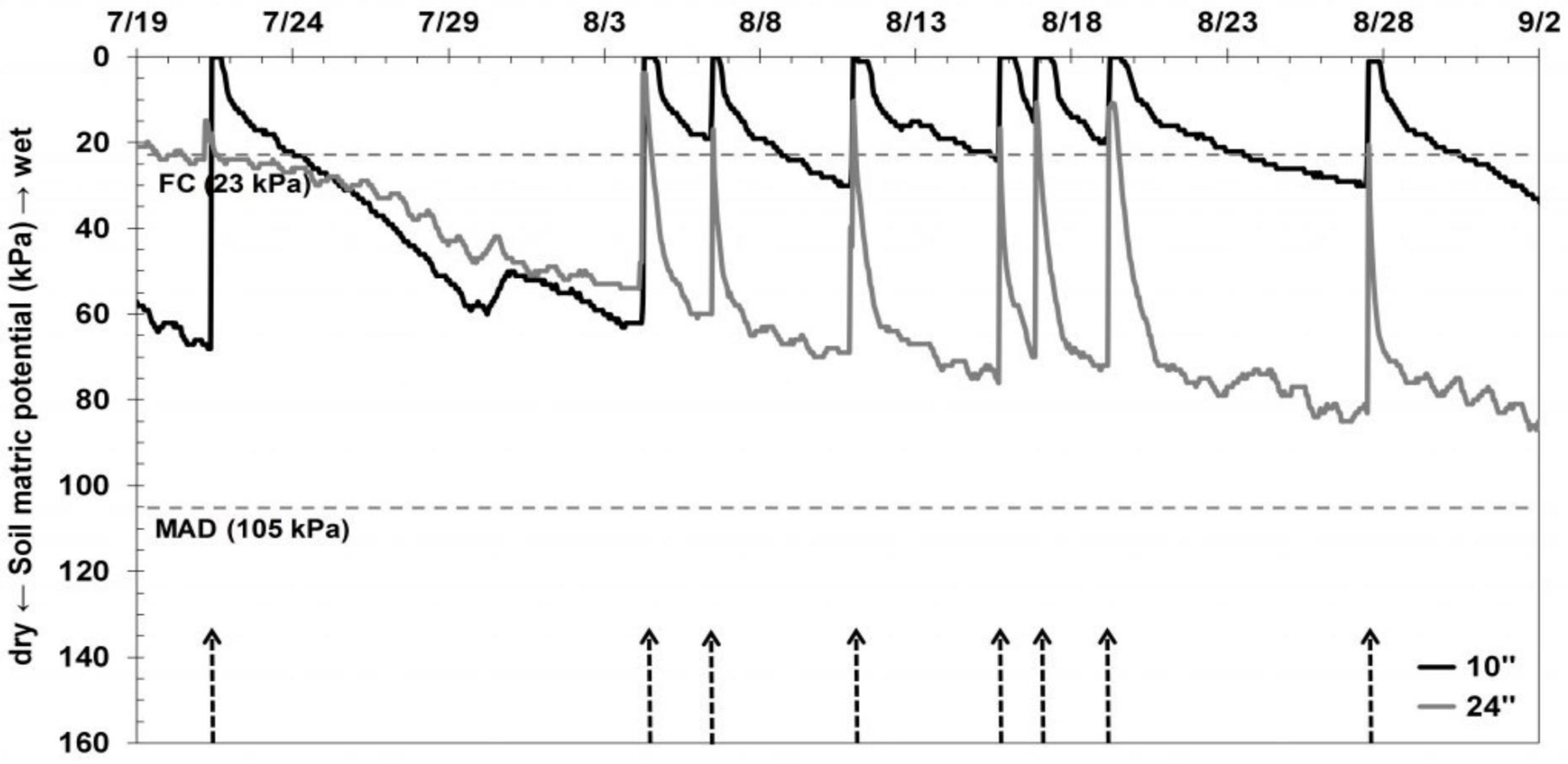
(a)

(b)

a) Tensiometer with vacuum gauge and b) water mark granular matrix electrical resistance sensor

[Understanding Soil Water Content and Thresholds for Irrigation Management | Oklahoma State University (okstate.edu)]

Managing Irrigation based on SMP data



- Hourly SMP fluctuations at 10 and 24 inches below the soil surface over a 45-day period.

Table I. Summary list of commercially available soil moisture sensors.

Types	Commercial sensors	Advantages	Disadvantages	Cost
Capacitance or frequency domain sensors	• Spectrum SMEC300, SM100 • Sentek Enviroscan, Diviner 2000 • METER 5TE, 5TN	• Rapid response time • Lower cost compared to TDR • Remote accessibility • Suitable for high saline soils • High accuracy with site calibration	• Small sensing area • Preferential site/soil-specific calibration • Affected by soil conditions: salinity, clay content, temperature, bulk density	• $250-400 per sensor
TDR	• Acclima true TDR 315, 315L,310 S • Spectrum Field Scout TDR; • CS 655, 650	• Very accurate • Remote access of data available • Soil/site calibration usually not required.	• Expensive technology • Very small area of influence	• $250-400 per sensor
Tensiometers	• Irrometer tensiometers	• Inexpensive • Available in various lengths • Unaffected by salinity	• Limited operative range for fine-textured soils • Requires frequent maintenance • Slow response time to soil water changes • Manual readings and data collection • Not suitable for cold temperatures	• $80 per sensor • $150 - $170 for transducer
Granular matrix sensors	• Irrometer watermark sensors	• Good accuracy in medium to fine soils • Remote data logging and retrieval • Large soil tension range • Inexpensive • Continuous measurement at the same location	• Sensitive to temperature and salinity • Less accurate in sandy soils • Relatively slow response time • Requires calibration for each soil type	• $40-60 per sensor.

Methodology

- Successful R&D initiatives implemented soil moisture sensors for irrigation scheduling in the GCC region
- Methodology relied on major contributions from ***scholarly literature***
  - Pilot search conducted using specific keywords: soil moisture sensors, smart irrigation, irrigation scheduling, and country name
  - Internet research performed using Google Scholar, MDPI, Elsevier, and IEEE Xplore
- Results compiled manually for literature search, review, and analysis

R&D Efforts

- **Smart Irrigation in the Kingdom of Saudi Arabia**

- KSA's irrigation sector faces challenges like **limited water resources, high salinity, and inefficient practices**.
- Consequences include ***reduced yields and abandoned lands***.
- Soil moisture sensors offer efficient irrigation solutions.
- Studies highlight their critical role in implementing smart irrigation scheduling.

R&D Efforts

- **Smart Irrigation in the Kingdom of Saudi Arabia**

Initiative	Description	Outcome
High-Tech Soil Moisture Sensor by KAUST [20] [20] (n.d.). High-tech soil sensor designed to help farmers conserve precious water. New Atlas. Retrieved January 29, 2024, from https://newatlas.com/science/mof-soil-moisture-sensor/	Developed a soil moisture sensor using metal-organic framework (MOF), exhibiting excellent water capture capabilities. Field tests planned for further evaluation.	Promising performance with plans for field testing.
Low-Cost Capacitive Soil Moisture Sensor [21] Okasha, A. M., Ibrahim, H. G., Elmetwalli, A. H., Khedher, K. M., Yaseen, Z. M., & Elsayed, S. (2021). Designing Low-Cost Capacitive-Based soil moisture sensor and smart monitoring unit operated by solar cells for greenhouse irrigation management. Sensors, 21(16), 5387. https://doi.org/10.3390/s21165387	Designed and calibrated a low-cost capacitive soil moisture sensor for use in controlled greenhouses, demonstrating reliable performance in clay soils.	Reliable performance in clay soils, with future research focusing on applicability to diverse soil types and automation using deep learning.
IoT-Based Automated Wastewater Irrigation System [22] Habib, S. J., Alyahya, S., Islam, M., Alnajim, A. M., Alabdulatif, A., & Alabdulatif, A. (2022). Design and Implementation: An IoT-Framework-Based Automated wastewater irrigation system. Electronics, 12(1), 28. https://doi.org/10.3390/electronics12010028	Proposed an IoT-based system for real-time monitoring of soil and atmospheric conditions, facilitating efficient wastewater irrigation.	Enables real-time monitoring, facilitating efficient wastewater irrigation.

R&D Efforts

- **Water Management and Food Security in Qatar**

Initiative	Description	Outcome
RIWA Project [17] Saudi Arabia captivated by Dacom irrigation management system. Dutchwater Sector. Retrieved January 29, 2024, from https://www.dutchwatersector.com/news/saudi-arabia-captivated-by-dacom-irrigation-management-system	Monitored soil moisture across farms, resulting in significant water savings and yield improvements.	Water savings of 30-75% and yield improvements of 10-25%.
Study on ECH2O-5TE Sensors [18] Louki, I., & Al-Omran, A. (2022). Calibration of Soil Moisture Sensors (ECH2O-5TE) in Hot and Saline Soils with New Empirical Equation. Agronomy, 13(1), 51. https://doi.org/10.3390/agronomy13010051	Investigated factors influencing soil moisture measurements, proposing an empirical equation for correction.	Sensors performed well under specific conditions, with an empirical equation developed to correct for salinity, temperature, and soil texture.
Wireless Automated Irrigation System for Wheat [19] Atta, R., Boutraa, T., & Akhkha, A. (2011). Smart Irrigation System for Wheat in Saudi Arabia Using Wireless Sensors Network Technology	Presented a wireless system based on soil moisture sensors for wheat crops, achieving improved growth and water use efficiency.	Demonstrated enhanced plant growth, improved soil condition, and increased water use efficiency.

R&D Efforts

Water Management and Food Security in Qatar

- Qatar faces water scarcity and socio-economic challenges.
- Limited water and land hinder food crop cultivation.
- Reliance on imports makes Qatar vulnerable to market fluctuations.
- Qatar's National Food Security Strategy aims to enhance resilience.
- MME supports food production research.
- UDST and Qatar University focus on food security and sustainability.

R&D Efforts

- **Water Management and Food Security in the State of Qatar**

Initiative	Description	Outcome
QNRF & MME Joint Initiatives	Launched initiatives for sustainable smart irrigation practices under the Food Security Call. -funding sustainable smart irrigation practices for key crops under the under the 3rd Cycle of the Food Security Call [24] - UDST project "*Development of Smart Agricultural Technologies to Optimize Resource Allocation to Ensure Food Security*".	Integration of soil moisture sensors, data loggers, and AI-based crop water requirements for optimized water management.
Commercial Soil Moisture Settings [25] Rohan Tabish (2013). A fuzzy logic based irrigation system enhanced with wireless data logging applied to the state of Qatar. Computers and Electronics in Agriculture.	Various sensors deployed in commercial settings, demonstrating efficacy of smart irrigation for crops like cucumbers.	Effective irrigation systems showcased through comparative studies

R&D Efforts

Initiative	Description	Outcome
Centralized Smart Irrigation [26] Qatar turns to smart irrigation technology amid climate threat htttps://h2oglobalnews.com/qatar-turns-to-smart-irrigation-technology-amid-climate-threat/	Qatar investing in centralized systems for urban gardens, using real-time weather and soil moisture data for precise scheduling.	Contributing to water efficiency and environmental sustainability.
Smart Sustainable Greenhouse Model [27] Al-Naemi, S., & Al-Otoom, A. (2023). Smart sustainable greenhouses utilizing microcontroller and IOT in the GCC countries; energy requirements & economical analyses study for a concept model in the state of Qatar. Results in Engineering.	Innovative greenhouse powered by solar energy and soil moisture sensing, reflecting Qatar's commitment to sustainable agriculture.	Promoting sustainable practices through renewable energy and optimized water management.

R&D Efforts

Precision Irrigation Management in the United Arab Emirates

- UAE faces challenges from high temperatures, low rainfall, and limited freshwater.
- **Increasing demands from domestic, industrial, and agricultural sectors**.
- **Sharp decline in groundwater resources**.
- **Water scarcity hampers agriculture, landscaping, and green spaces**.
- Conventional irrigation methods are inefficient.
- Smart irrigation systems offer a promising solution.

R&D Efforts

- **Precision Irrigation Management in the UAE**

Initiative	Description	Outcome
Smart Irrigation Management System [29] (n.d.). AI-Powered Solutions for Water Resources, Disaster Management, and Agriculture: Transforming Sustainability in the UAE. Retrieved January 29, 2024, from https://42abudhabi.ae/ai-powered-solutions-for-water-resources-disaster-management-and-agriculture-transforming-sustainability-in-the-uae/	Deployed in Abu Dhabi's Masdar City, utilizing AI algorithms to monitor and regulate irrigation based on weather forecasts, soil sensors, and plant requirements.	Reduces water consumption, promotes optimal plant growth, and contributes to sustainable water management practices.
Study on Smart Irrigation in Warsan Nursery [30,31] Alsulaimani, F. (2017). Testing and Evaluation of a Smart Irrigation System Towards Smart Landscaping in UAE. Journal of Applied Sciences Research.	Evaluation of potential water savings through smart irrigation compared to conventional systems used in Warsan Nursery, Dubai, UAE.	Smart Irrigation System (SIS) with smart soil moisture sensor reduced water consumption by 5.76% and improved vegetation health.
Evaluation of Wireless Capacitive Sensor [31] Shrouf, A., Alhammadi, M. S., Alkaabi, A., Alderai, M., Zaki, A. A., Hajeri, S., Alrashedi, M., Alketbi, A., & AlArran, A. (2017b). Evaluation the use of electronic wireless tensiometers in the irrigation of main crops in Abu Dhabi. Emirates Journal of Food and Agriculture, 1. https://doi.org/10.9755/ejfa.2016-12-1830	Assessment of a wireless capacitive sensor's effectiveness in irrigating greenhouse tomato and cucumber crops in Abu Dhabi.	Capacitive sensor provided accurate irrigation amounts, yielded best crop yields, and aided in devising suitable irrigation schedules for tomato and cucumber crops.

R&D Efforts

Smart Irrigation in the Sultanate of Oman

Study Description	Outcome
Design and Implementation of Automated Irrigation System in Oman's Batinah Region [32] Alahakoon, P., Jayasuriya, H. P. W., Zekri, S., Al-Busaidi, H., & Zaier, R. (2014). COMPARATIVE STUDY OF ET-BASED AND SOIL MOISTURE-BASED IRRIGATION FOR AL BATINAH REGION IN OMAN. Acta Horticulturae, 1054, 135–144. https://doi.org/10.17660/actahortic.2014.1054.15	Aimed to reduce water over-pumping while ensuring essential water requirements for plants. Theoretical analyses conducted to assess variations in irrigation requirements.
Introduction of Irrigation System Utilizing Wireless and GSM Technology [33] Mahadevan, V., Vikraman, B. P., Venusamy, K., Alshaqsi, A. S. S., AlBalushi, K. M., & Alharrasi, D. H. A. (2022). Design and construction of soil moisture content sensor for an automatic irrigation system. 2022 2nd International Conference on Intelligent Technologies (CONIT). https://doi.org/10.1109/conit55038.2022.9847794	System sends notifications when soil moisture levels are low, enhancing irrigation efficiency. Employs soil moisture sensor to determine watering needs.

Results and Discussion

- Advanced sensor technologies provide options for accuracy, depth measurement, and response time.
- Soil moisture sensors enable data-driven decision-making, optimizing irrigation schedules and enhancing crop yields.
- Smart irrigation, using sensors and IoT technologies, is increasingly adopted in the GCC region.
- Feasibility of smart irrigation scheduling systems explored, facilitating timely responses to soil conditions via mobile applications.

Challenges and Considerations

- **Cost Constraints:** Expenses strain resources, especially for small-scale farmers.
- **Data Interpretation:** Skilled interpretation of sensor data is crucial.
- **Calibration and Placement:** Accurate readings depend on proper sensor calibration.
- **Salinity and Soil Variability:** Sensor adjustments may be needed for varying soils.
- **Energy Availability:** Reliable power sources for sensors pose challenges.
- **Knowledge and Awareness:** Farmer education is crucial for sensor understanding.

Gaps and Opportunities

- Limited Focus on Smallholder Farming
- Geographic Coverage
- Crop Diversity
- Data Sharing and Collaboration
- Cost-Benefit Analysis
- Technology Accessibility
- Climate Change Adaptation
- Policy Integration
- Scalability

Conclusion

- Soil moisture sensors address GCC water challenges - Crucial for GCC agricultural sustainability
- Implemented successfully in Qatar, Saudi Arabia, UAE, and Oman
- Intelligent irrigation conserves water
- Challenges: calibration, cost, data interpretation
- Opportunities: smallholder focus, broader coverage, crop-specific strategies, data sharing, cost-benefit analysis, technology access, climate adaptation, policy integration, scalability

- With sustained research, innovation, and collaborative efforts, these sensors hold promise in playing a pivotal role in fostering sustainable and resilient agricultural practices in the region.

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