# Identification of Technical Practices for Climate-Smart Agriculture (CSA) in Indonesia: A Case Study in the Sukabumi Regency, West Java

## Output 2 – Identify Technologies to Support the Identification of Water Content and Soil Chemistry on Agricultural Land

### Design of the Macro System Framework

D2.4.1

United Nations Environment Programme (UNEP)

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# 1 Introduction

Soil moisture and chemical monitoring systems are essential for implementing Climate-Smart Agriculture (CSA), which aims to enhance productivity, resilience, and mitigation in the agricultural sector. One of the key factors for improving crop production is soil moisture management (Yuan et al., 2022). By using high-resolution soil moisture data, farmers can optimize irrigation and water use efficiency (Zhang et al., 2022). Soil moisture sensors enable farmers to adjust the amount and frequency of water supply to their crops, ensuring optimal hydration for growth and yield. They also help to identify and address soil moisture variability and stress, which can affect crop performance and quality.

The monitoring systems increase agricultural resilience to climate change impacts. Climate change poses significant challenges to agriculture, such as droughts, floods, and erratic rainfall patterns. Continuous soil moisture monitoring allows farmers to anticipate and adapt to these conditions. For example, farmers can adopt soil conservation practices, such as mulching or minimum tillage, to retain soil moisture and reduce evaporation when the soil moisture data indicates dryness. They can also select and plant crops that are more tolerant to soil moisture stress or salinity (Sholihah et al., 2022). Research shows that these monitoring systems can effectively assess soil conditions and improve irrigation practices, leading to higher crop yield and water savings.

Soil moisture monitoring is invaluable for irrigation scheduling and can significantly enhance irrigation efficiency (Chappell et al., 2013). Efficient irrigation based on accurate soil moisture data reduces water consumption and energy use. This results in lower carbon emissions associated with water pumping and distribution. Furthermore, soil moisture sensors prevent over-irrigation, which is a major source of nitrous oxide emissions, a powerful GHG. Over-irrigation causes waterlogging and nutrient leaching in the soil, which can trigger GHG emissions such as methane and nitrous oxide. By using soil moisture sensors, farmers can avoid these problems and maintain soil health and fertility.

This report introduces a macrosystem framework for soil moisture and chemistry data acquisition technology. The framework is designed to help smart and sustainable agriculture by providing a deep understanding of soil conditions.

The soil condition in sukabumi region is an important factor for smart and sustainable agriculture. The soil is derived from volcanic rocks and has a tropical climate with high rainfall variability, generally acidic, low in base saturation and cation exchange capacity, and high in aluminum saturation. The soil can provide a good medium for crop growth but it also requires proper management to improve its fertility and reduce its degradation. Some of the management practices that can be applied are adding organic matter, fertilizing, and liming the soil according to the soil characteristics and crop needs (Damayani et al., 2019; Subardja, 2007). By using the proposed framework for soil moisture and chemistry data acquisition technology, farmers in sukabumi region can monitor their soil conditions more accurately and efficiently, and optimize their agricultural practices accordingly.

The framework utilises modern and innovative technology to obtain and manage soil moisture and chemistry data. The primary technology used in the framework is on-site implanted sensors. These sensors are designed with a capacitive approach and can produce valuable information about soil moisture, temperature, and soil electrical

conductivity. This information not only covers moisture conditions but also provides a general overview of soil nutrients.

The framework also considers the use of Unmanned Aerial Vehicles (UAVs) for periodic monitoring. UAVs provide the ability to monitor soil and crop conditions from the air, allowing for problem identification before they have detrimental impacts on crops. Additionally, remote sensing data is also considered for data acquisition with a lower temporal resolution but covering the entire management area.

With this approach, the framework aims to present a way to monitor and manage soil conditions, contributing to the goals of smart and sustainable agriculture effectively and efficiently.

# 2 Basic Approach

In the rapidly digitizing world, the implementation of robust and efficient systems in various sectors becomes important. A proven technology aiding such implementation is SCADA, an acronym for Supervisory Control and Data Acquisition. The design approach to the macro system framework being explored in this document is based on this powerful system.

SCADA, essentially, is a computer-based system for gathering and analysing real time data. It enables monitoring, control, and alarm of plants or regional operating systems from a central location. SCADA is a type of application utilised in various industries such as power generation, oil and gas refining, agriculture, etc. SCADA can be used as a basis for the development of a macro system framework of field implanted soil moisture and chemical sensors.

The utilisation of SCADA based system can improve efficiency and effectiveness by offering the ability to monitor and control processes from a centralized location. It plays a vital role in understanding the status of a system, making necessary adjustments in real-time, enhancing productivity, saving time, and reducing costs.

A SCADA system typically consists of the following component (Figure 2.1):

1 **Sensors and Control Relays:**

- Installed in the field where data is collected and measured.

2 **Remote Terminal Units (RTUs) or Programmable Logic Controllers (PLCs):**

- Interfaces for sensor and relay signals that connect to the SCADA network.

3 **Communications Network:**

- The path by which data is transmitted between the central host and sensors and control relays.

4 **Central Host:**

- Often referred to as a Master Station, this is the hub where operators interface with the SCADA system.

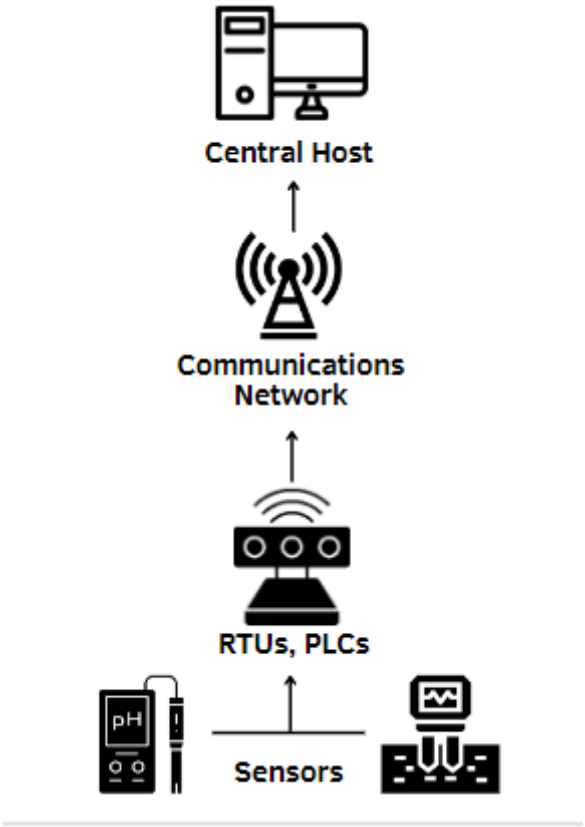


Figure 2.1 Typical SCADA System

In the following sections, a more detailed exploration of how these components play a role in the macro system framework for soil moisture and chemistry data acquisition technology is provided.

Essentially, SCADA is a system that collects data from various sensors in the field, processes that data, and uses the information obtained to control operations in the field automatically or semi-automatically. Considering the on-site implanted soil moisture sensor technology, the following are the important components that must be prepared in preparing the SCADA macro system framework:

- **Soil Moisture Sensor**:
  - It is the main component in the system. This sensor will be planted in the field and continuously measure soil moisture. This data will then be transmitted to the Remote Terminal Unit (RTU).
- **Remote Terminal Unit (RTU):**
  - The RTU collects data from sensors and sends it to the SCADA system. It can also send signals back to the devices in the field based on instructions from the SCADA system.
- **Data collection point in the field:**
  - The sensor will be connected to the RTU, which is responsible for collecting data from the sensor and sending it to the central SCADA system through the communication network.
- **Communication System**:

- This refers to the network that will be used to send data from the RTU to the SCADA system and vice versa. The RTU will use this communication system to send data to the central SCADA system and receive instructions from the central SCADA system. This communication system can be a wired or wireless network, depending on the environment and needs. This could involve cellular networks, wireless networks (such as Wi-Fi or LoRa), or wired connections, depending on distance and conditions on the ground.

- **Central SCADA System**:
  - This system receives data from the RTU, processes that data, and displays relevant information to the user. It can also send instructions back to the RTU based on the data received. This system is the 'brain' of operation. The system receives data from the RTU, processes that data, and displays relevant information on the user interface. The central SCADA system will also send instructions back to the RTU based on the data received.
- **User Interface (HMI):**
  - This interface allows users to interact with the SCADA system, monitor data from sensors, and provide instructions to the system. This user interface connects with the central SCADA system. It allows users to view data, control operations, and interact with the system.
- **System Data Historian**:
  - This component stores historical data from sensors and system operations. This data can be used for trend analysis, research, and system improvement. This Data Historian System is connected to the central SCADA system and is tasked with storing historical data from operations.
- **Alarm Management System:**
  - This system keeps an eye on data from sensors and creates an alarm if there are abnormal conditions. This Alarm Management System is also connected with the central SCADA system. This system will create an alarm if there are abnormal conditions.
- **Actuators and Control Devices:**
  - Based on the data received and analysis performed, the SCADA system can give commands to actuators and other control devices in the field. For example, if soil moisture drops below a threshold, the SCADA system could instruct the irrigation system to water the field. These actuators and control devices will be connected with RTUs. Based on instructions from the central SCADA system, the RTU will control these actuators and control devices to execute actions in the field.
- **Integration with Other Systems:**
  - For maximum benefit, SCADA systems can be integrated with other systems, such as geographic information systems (GIS) for mapping soil moisture data, or farm management systems for planning and decision making. The central SCADA system can be integrated with other systems such as geographic information systems (GIS) or farm management systems, to provide better understanding and more effective decision making.

All these components are connected in a circuit that forms the structure of the SCADA framework. However, this configuration can differ depending on the specific needs of the system and available technology.

Basic configuration of SCADA is depicted in Figure 2.2, and Figure 2.3 shows the generic SCADA architecture for the layer structure comprising of supervisory, communication, local control and field. In this case the system design must consider the optimum operational conditions which include sensor and actuator devices (after the irrigation system is integrated), local controllers, modes of communication on the ground and internet communication, and machine or computer supervisory. It will also be related to power supply, security, human resources and software.

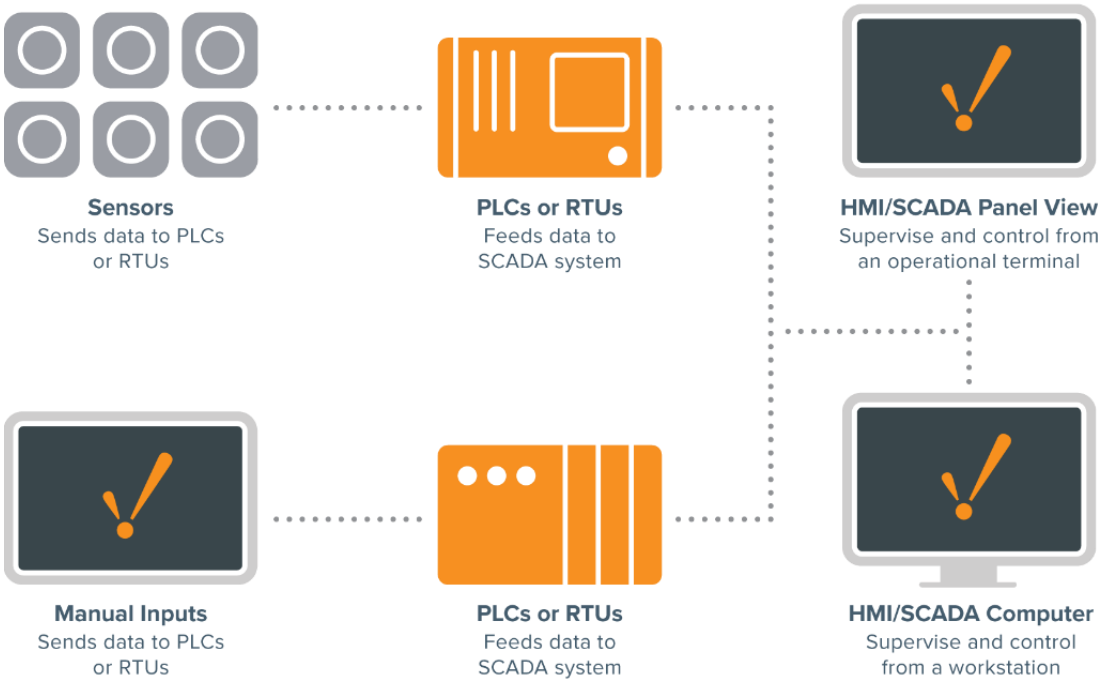


Figure 2.2 Basic SCADA Configuration (*What Is SCADA? Supervisory Control and Data Acquisition*, n.d.)

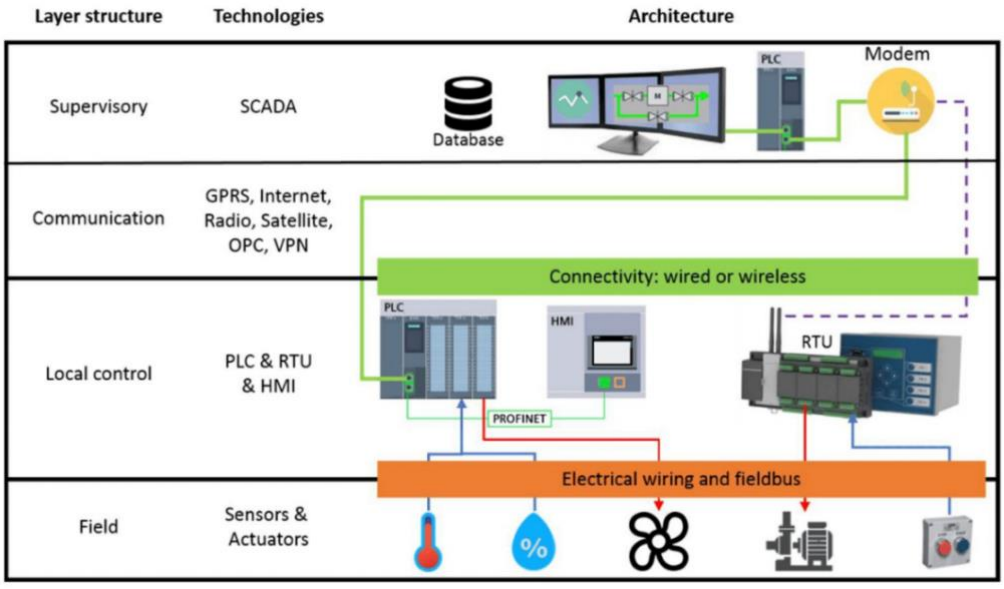


Figure 2.3 The generic SCADA architecture (Brad et al., 2021)

In irrigation field, there are numerous SCADA application such as irrigation scheduling (O'Shaughnessy et al., 2016), irrigation channels control (Figueiredo et al., 2013) and tricle irrigation (Molina et al., 2014). Automated irrigation systems with an architecture akin to SCADA are utilized in Indonesia. An example is found in Sukabumi district, where chili plant irrigation has been developed based on wireless and Internet of Things (IoT) technologies. Temperature and humidity sensors are employed to collect data, which is subsequently sent to a server via a WiFi communication system and can be accessed via a website (Hendrawati & Algifary, 2022).

In another instance, the IoT system has been harnessed for smart agriculture in Cisarua, West Bandung District. This system incorporates three types of sensors: air humidity, temperature, and soil moisture sensors. The sensors capture real-time conditions in the plant area, with the data relayed to a controller. The controller, upon detecting suboptimal conditions, activates an actuator to maintain the ideal plant environment. Furthermore, this data is transmitted to a server over the internet and showcased on the monitoring system (Putri et al., 2021).

In Dau, Malang District, IoT-based drip irrigation is used in an orange grove. Key components include soil moisture sensors and soil pH sensors that are strategically placed within the orchard. The data captured is relayed to an IoT Module and, leveraging a communication network, sent to a server where it is stored in a database. This data, providing insights about soil moisture and soil pH, can then be viewed on a computer or smartphone (Kusumawardani et al., 2019).

# 3 Macro System Framework

Soil monitoring and chemical monitoring system does not offer the accomplishment of CSA's three pillars, which are increase in productivity, resilience to climate changeand emissions reduction. Which requires active system of irrigation and fertilization, which will be designed and integrated in the next activity. However, the information from sensors can be used to estimate the productivity, water requirement and farmland emission using models (Arif et al., 2020; Saptomo et al., 2023).

The development of a macro-system for the CSA soil moisture and chemical monitoring system is crucial for efficient and sustainable agriculture. To achieve this, a SCADA-like system will be used as the basis of the architectural model. The SCADA-like system will integrate the sensing and control systems, allowing for seamless monitoring and management of soil moisture and chemical levels.

The proposed system will be a comprehensive online automatic monitoring system, utilizing modern monitoring technology, computer system analysis software, and a cloud platform. This system provides real-time monitoring and analysis of soil moisture, which is essential for effective work in agricultural water conservancy. The proposed macro-system will also incorporate the detection of soil chemical levels and automatic irrigation and fertilization capabilities.

This integration will enhance the overall effectiveness and efficiency of soil management, providing farmers with valuable data and decision-making tools. By leveraging the capabilities of the system, the macro-system will acquire, persist, and process sensor data related to soil temperature, moisture and chemical levels. This will enable efficient monitoring of specific crop comfort levels and serve as an accurate and useful decision tool for farmers (Qamar & Zakaria Bawany, 2023). The proposed macro-system will also utilize a cloud-based solution, which will enable farmers to access and analyze the collected data remotely.

This access to real-time data and analysis will enable farmers to make informed decisions regarding irrigation, fertilization, and other soil management practices, leading to improved crop yields and resource utilization. Furthermore, the proposed macro-system will incorporate a web-based system, which will assist farmers in scheduling irrigation processes. By implementing a SCADA-like system as the foundation of the macro-system for CSA soil moisture and chemical monitoring, farmers will have access to a comprehensive online monitoring system that provides real-time data on soil moisture and chemical levels. This will enable them to make timely and informed decisions regarding irrigation and fertilization, ultimately improving the efficiency and effectiveness of their farming practices.

## 3.1 Hardware

The on-site implanted sensors are the primary technology used in the framework. These sensors are designed with a capacitive approach and can produce valuable information about soil moisture, temperature, and soil electrical conductivity. This information not only covers moisture conditions but also provides a general overview of soil nutrients.

The sensors are implanted in the soil at various depths. This allows for the collection of data from different soil layers, providing a more comprehensive understanding of

soil conditions. The sensors are also equipped with a wireless communication module, allowing them to transmit data to a central server.

UAVs are also used as a subsystem in the framework for periodic monitoring together with remote sensing data. UAVs provide the ability to monitor soil and crop conditions from the air, allowing for problem identification before they have detrimental impacts on crops. UAVs are equipped with spectral sensors that collect data on soil moisture, temperature, crop health, and other factors. The data collected by UAVs is transmitted to a central server, where it can be analysed and used to make informed decisions about crop management.

Remote sensing spectral and SAR data will provide data with a lower temporal resolution but covering the entire management area. Remote sensing data provides information on soil moisture, vegetation cover, and other factors. The combination of on-site implanted sensors, UAVs, and remote sensing data provides a comprehensive way to monitor and manage soil conditions. This approach helps improve crop yields, reduces the use of agricultural chemicals, and protects the environment.

Figure 3.1 shows the proposed hardware of the macro system framework for soil moisture and chemical monitoring and control based on SCADA architecture, to build the supervised control system, indicating four layers: on the land scale, sensors, actuators (e.g., pumps or valves), and warning systems are installed and operate. The sensor in question is an on-site implanted sensor that can measure the required parameters, which are soil moisture and chemical (pH, Electro conductivity, temperature etc.) using various types of sensors, as long as they can be connected or have a system that enables human interaction and tools, data acquisition, and data transmission to the server.

Data from sensors will be sent to the supervised control system via the internet network after being acquired by RTU/PLC/HMI, which can be in the form of telemetry data loggers or other programmable systems. The data received by SCADA will be the basis for making decisions on what actions to take relevant to climate, such as when and in what quantity to irrigation and to add fertilizers. All data will be saved to the database, managed by groups of farmers or institution that responsible to use the data to improve agriculture practices and water management. The data can be stored in local server or cloud server.

Once a decision has been made, the control system can send commands to the actuator via RTU/PLC to turn the actuator on or off and function as a control system. However, this control authority can also be owned by RTU/PLC/HMI, depending on the needs and flexibility of customisation.

The control system computer functions can be redeveloped not only to receive measurement data and send control commands, but also to relate to other systems. Optionally, remote sensing data and spectral sensor data from the UAV can also be transmitted from the image data server to the control system. This way, the decision-making process can be better supported by monitoring data for the entire land area, even at low temporal resolution.

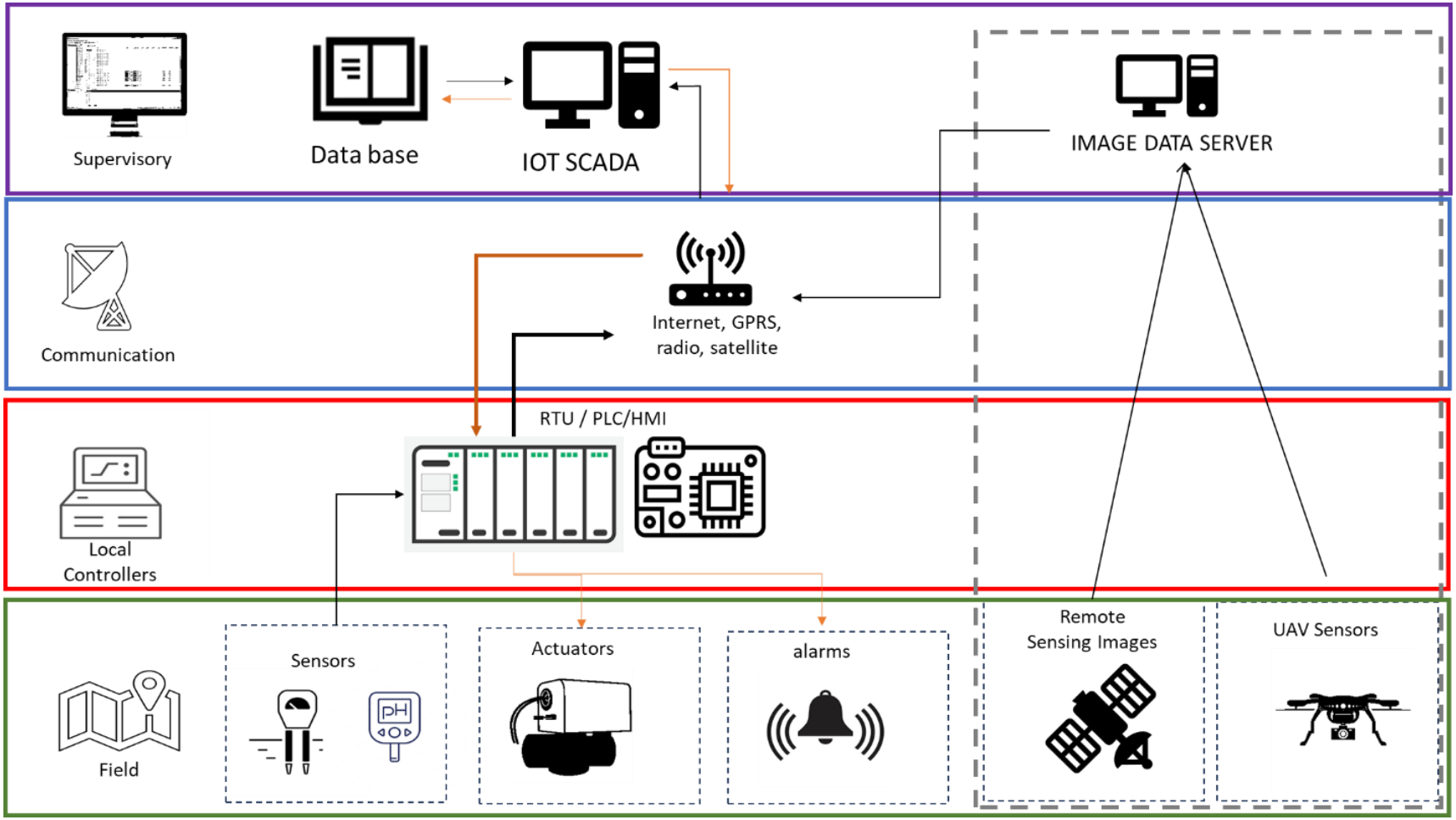


Figure 3.1 Hardware for macro system framework for soil moisture and chemical monitoring and control.

A specific example for the case where the field implanted sensor has been selected, namely 5TE which can measure soil moisture, electroconductivity and temperature parameters (two of the related soil climate parameters) (Figure 3.2), without other additional sensors and subsystem. These two parameters can indicate the status of water and soil nutrient content so that they can indicate water and nutrient needs and can be used to decide irrigation and fertilization needs.

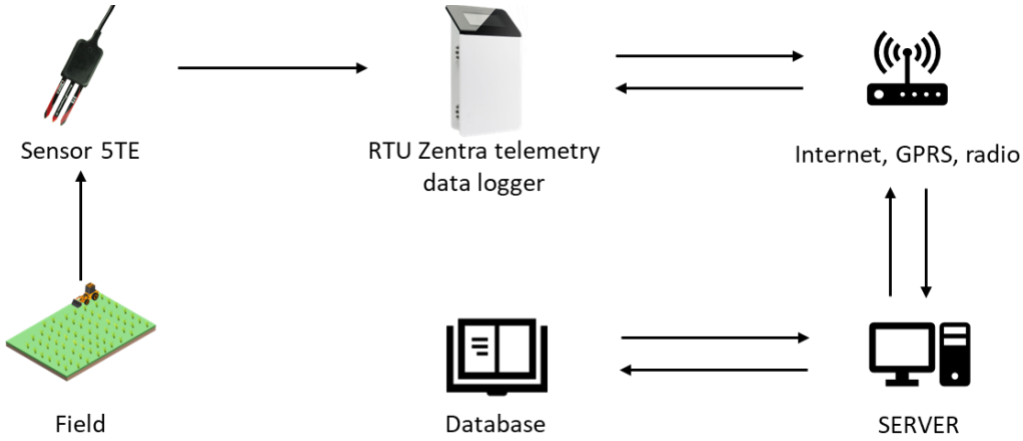


Figure 3.2 System to monitor soil with 5TE sensor and Zentra telemetry.

This sensor is installed by inserting the probe into the soil according to the position to be measured. The sensor is connected to a Zentra ZL-6 telemetry data logger (as RTU/MHI) which will upload data to the server via the internet network. The data will be stored in the database and can be downloaded at any time and analysed. For development towards an irrigation automation system, a device that can be programmed to perform measurement and control will be needed to replace the Zentra ZL6 data logger.

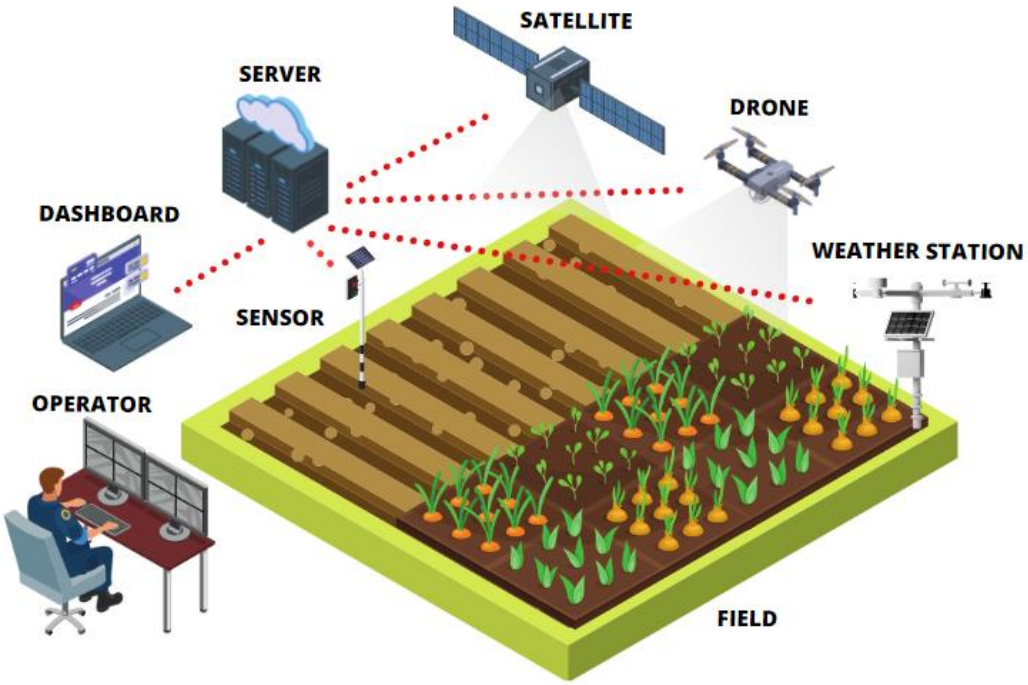


Figure 3.3 Illustration of the soil moisture monitoring system

This 5TE sensor produces enough data to determine water and nutrient needs in real time. If more detailed information about macro elements is needed, other sensors can be used as additions or periodic instantaneous measurements with measuring devices such as pH meters, saline meters and others. Weather sensors or automatic weather stations (AWS) can be added to the system to acquire near surface atmospheric data consists of air temperature and humidity, wind speed, solar radiation, air pressure and rainfall. The data can be analysed to determine evapotranspiration and soil moisture deficit.

The complete system consisting of field implanted sensors, spectral subsystem (remote sensing and UAV) and additional AWS is illustrated in Figure 3.3. Client devices, including PCs and other gadgets, ensure that users, irrespective of gender, can easily access the vital information these devices provide.

## 3.2 Sub-system Spectral System

The system harnesses the power of remote sensing to acquire daily spectral and SAR data. Unmanned Aerial Vehicles (UAVs) equipped with spectral sensors follow routine flight plans, capturing surface spectral data while also overseeing device security surveillance. All these collected spectral data are stored and served from the Spectral data server.

## 3.3 Field Power Supply

Power is a crucial element of this system. It employs rechargeable Lithium/SLA batteries complemented by solar power charging through solar panels and charge controllers. By emphasizing the use of renewable energy sources, the system offers opportunities for women, especially in rural areas, to be at the forefront of sustainable farming practices.

## 3.4 Communication

Robust communication forms the backbone of this system. The RTU/PLC and Central Computer communicate via Ethernet, Wifi, and Cellular Internet, ensuring seamless data transfer. Similarly, sensors and actuators connect with the RTU/PLC through wired and wireless means, employing technologies like Wifi and LoRA. This broad spectrum of connectivity methods promotes inclusivity, ensuring that individuals of all genders, even in the most remote locations, can be a part of this technological revolution.

## 3.5 Software

Customized software ensures data is not just collected but also effectively utilized. The RTU/PLC is responsible for data acquisition from sensors, data unit conversion, and both local and cloud storage. On the central computer, sophisticated programs analyze various parameters like soil water condition for crop productivity, water consumption, availability for resilience against climate change, and carbon emissions based on soil and weather data. Operator dashboards and client dashboards further make this analysis accessible and comprehensible to users, promoting equal involvement and understanding among men and women.

## 3.6 Security

Security measures are paramount. Installations, whether it's the soil sensor at the rooting depth, device enclosures, or the fixation systems for solar panels and weather stations, are designed with durability and safety in mind. Physical security, with fences, cages, and locks, ensures the safety of the equipment and the operators, irrespective of gender.

## 3.7 Human Resources

The success of the system depends on its operators, technicians, and programmers. Both male and female operators are trained to manage the data storage, central computer, UAVs, remote sensing data acquisition, and the spectral data server. Technicians handle the installation, security, and maintenance of RTUs/PLCs, while programmers work on diverse elements from the RTU/PLC to dashboards.

Standard Operating Procedures (SOPs) guide these professionals, ensuring that both genders have a clear and inclusive pathway to operate within the system. Lastly, capacity-building initiatives are focused on providing comprehensive training to operators, technicians, and users, emphasizing gender inclusivity and equal opportunity.

Table 3.1 lists the components of the macro-system and the types or functions. This integrated agricultural system symbolizes a future where technology and gender equality merge, offering brighter prospects for sustainable and inclusive agricultural practices.

Table 3.1 Components of The Macro-system Framework of Soil Monitoring System

| **Components** | **Type/ Functions** |
|---|---|
| Devices Hardware | |
| Sensor | soil moisture, temperature, electro conductivity, pH on-site measurement |
| RTU/PLC | data logger with telemetry function at the site |
| Central Computer | Cloud/local computer |
| Data server | Cloud/local server with API |
| Additional sensors | Automatic Weather Station |
| | Macro nutrient sensors |
| Clients' devices | PC, gadget |
| Field Power Supply | |
| Battery | Rechargeable Lithium/SLA |
| Solar power charging | Solar panel |
| | Charge controller |
| Communication | |
| Wireless/wired internet connection RTUs/PLC - Central Computer | Ethernet, Wifi, Cellular Internet |

| Components | Type/ Functions |
|---|---|
| Wired/Wireless connection Sensors/Actuators - RTUs/PLC | Wire, Wifi, LoRA |
| Wireless/wired internet connection Spectral data server - Central Computer | Ethernet, Wifi, Cellular Internet |
| Sub system spectral system | |
| Remote Sensing | Daily spectral and SAR data acquisition |
| UAV with spectral sensor | Routine Flight plan to cover surface spectral data and device security surveillance |
| Spectral data server | Store and serve spectral data |
| Software | |
| Sensor data acquisition and storage | Program in RTU/PLC responsible to read sensors, convert data to respective unit, upload and store data to local and cloud |
| Analysis of optimum water for crop production (productivity) | Program in Central Computer to analyse soil water condition and estimate crop, land and water productivity |
| Analysis of Water consumption and availability (resilience) | Program in Central Computer to analyse water use and water availability, to estimate the resiliency to climate change |
| Analysis of Carbon emission calculation (emission) | Program in Central Computer to analyse analyse carbon emission, based on soil and weather data |
| Operator Dashboard | Program in Central computer as front end/user interface to operator |
| Client Dashboard | Program in clients' devices to connect to data storage and central computer to view reports |
| Security | |
| Installation | Soil Sensor instalment at rooting depth |
| | Devices enclosure (RTU, battery, charge controller, wiring terminals) |
| | Tripod/Pole for enclosure, solar panel, weather station fixation |
| Security Measures | Fence, cages and locks |
| Human resources | |
| Operators | Responsible for operation of data storage and central computer |
| | Responsible for operation and maintenance of UAV, remote sensing data acquisition, spectral data server |
| Technicians | Responsible for installation, securing, operating, maintenance RTU/PLC |

| Components | Type/ Functions |
|---|---|
| Programmers | Responsible for programming RTC/PLC, Central Computers, Data servers, Operator Dashboards, User Dashboards |
| Standard operation procedures | SOP for installation, operation and maintenance field level devices (sensors, RTU) |
| | SOP for installation, operation and maintenance communication |
| | SOP for installation, operation and maintenance central computer |
| | SOP for installation, operation and maintenance operator and user dashboard |
| | SOP for installation, operation and maintenance UAV, Spectral data centre |
| Capacity buildings | Training for instalment, operation and maintenance to operators and technician |
| | Training for instalment, operation and maintenance to users |

# 4 Conclusion

This document presents a framework for soil moisture and chemical data acquisition technology based on Supervisory Control and Data Acquisition (SCADA) architecture, a powerful, real-time data collection and analysis system. The framework's components encompass soil sensors, Remote Terminal Units (RTUs), a communication system, a central computer system, a user interface, a system data historian, an alarm management system, actuators and control devices, and potential integration with other systems. The focus of the application case is on the use of field implanted sensors: soil moisture and chemical sensors weather sensors, with spectral sub-system of Unmanned Aerial Vehicles (UAVs) for regular monitoring, and remote sensing for broader, less frequent data acquisition. The flexible and scalable design allows for easy addition of extra sensors and other technologies to meet evolving needs and objectives. The macro system should consider components of hardware, software, power supply, security, communications and human resources. The implementation of the system will contribute on estimation on productivity, water requirements and carbon emissions.

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