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AgriFusion: Soil and Hydroponic Farm Monitoring Hub

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January 9, 2025

Abstract

Agriculture, the backbone of Ethiopia's economy, is facing enormous challenges due to soil degradation, water shortages, and climatic unpredictability, which reduce production and jeopardize food security. To solve these challenges, this study suggests the creation of a Soil and Hydroponic Monitoring Hub that will offer real-time data on crucial environmental factors such as moisture, pH, temperature, and nutrient levels. The hub intends to help small and medium-sized farmers by optimizing resource management, increasing agricultural yields, and encouraging environmentally friendly practices.

The study will focus on developing a low-cost, user-friendly system that incorporates affordable sensors, microcontrollers, and a web-based interface for data display. A prototype will be tested in Ethiopian agricultural settings, both soil-based and hydroponic, to assess its efficacy under local circumstances. This dual applicability bridges the gap in economical, adaptable monitoring options for smallholder farmers.

The findings are intended to illustrate the hub's ability to improve decision-making, save resources, and boost productivity. Furthermore, the study contributes to resource efficiency, environmental preservation, and food security, all of which align with global sustainable agricultural goals. By making modern agricultural monitoring available in low-resource settings, the initiative provides a scalable approach with the potential to transform smallholder farming practices in Ethiopia and beyond.

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1 Background Study

Ethiopia, with its predominantly agrarian economy, relies heavily on agriculture, which accounts for approximately 40% of its GDP and employs around 80% of its workforce. Despite the sector's importance, Ethiopian agriculture has faced longstanding challenges, including erratic rainfall patterns, limited arable land, and soil degradation. Traditional farming methods, combined with population growth, have led to over-reliance on the country's natural resources, resulting in soil erosion, nutrient depletion, and reduced productivity. To address these issues, Ethiopia has made significant efforts to modernize its agricultural practices and promote sustainable farming techniques. In recent years, the Ethiopian government and various NGOs have introduced initiatives to increase productivity and resilience through modern agricultural technology. However, most smallholder farmers still lack access to affordable tools for monitoring soil health and environmental conditions, which are essential for sustainable yield improvements. Hydroponics—a soil-free cultivation method that conserves water and space—has emerged as an effective alternative for addressing Ethiopia's resource constraints. Although hydroponic farming could benefit many regions, its success depends on precise environmental monitoring to maintain nutrient balance, pH levels, and moisture. Given Ethiopia's diverse climates and the variability in water availability, there is a growing demand for monitoring solutions that can optimize resource use, adapt to local conditions, and improve crop resilience. Monitoring environmental parameters like soil moisture, pH, temperature, and nutrient content is vital for maintaining productive, sustainable agriculture in both soil and hydroponic systems. However, existing solutions are often prohibitively expensive or specialized, creating a need for a flexible, affordable monitoring system that can support Ethiopia's unique agricultural landscape.

2 Problem Statement

Agriculture is central to Ethiopia's economy, supporting around 80% of the population and contributing significantly to national GDP. However, the sector faces persistent challenges, including climate variability, soil degradation, and the inefficient use of limited water resources (Central Statistical Agency, 2022). These issues hinder productivity and threaten the livelihoods of many rural communities. Soil health and moisture levels, as well as other environmental factors, play crucial roles in determining crop yield, yet most Ethiopian farmers lack the necessary tools to monitor these parameters effectively. In recent years, hydroponic farming has gained attention as an efficient, water-saving alternative to soil-based agriculture, particularly valuable in areas with limited arable land and rainfall. Hydroponic systems allow plants to grow without soil, relying on carefully controlled nutrient solutions; however, their success depends heavily on precise monitoring of pH, moisture, and temperature levels. Despite the potential benefits, many Ethiopian farmers cannot adopt hydroponics or optimize their soil-based farming practices due to a lack of accessible and affordable monitoring solutions. Current solutions on the market are often specialized, expensive, or limited in adaptability, restricting their practicality for small to medium-scale farms in Ethiopia (Girma & Tadesse, 2021). There is a critical need for a comprehensive, low-cost monitoring system that can support both soil and hydroponic farming by providing real-time data on key environmental factors. A Soil and Hydroponic Monitoring Hub could enable farmers to make informed adjustments, optimizing water and nutrient use to improve crop resilience and yield. By addressing the limitations of existing technologies, this project aims to fill a major gap in accessible monitoring tools, promoting sustainable agricultural practices that are crucial for Ethiopia's long-term food security (FAO, 2023). The motivation for this research stems from the limitations of available monitoring solutions, which are often costly and designed primarily for large-scale operations, making them unsuitable for Ethiopia's predominantly smallholder farming model. This research is justified as it aims to provide an affordable, adaptable solution, supporting Ethiopian farmers in managing resources effectively. The project not only has the potential to improve agricultural productivity but also to contribute to sustainable farming practices that align with Ethiopia's development goals and climate resilience strategies.

3 Objective of the Research

3.1 General Objective

The general objective of this research is to design and implement a comprehensive monitoring and control system for hydroponic and soil-based farming setups to optimize agricultural productivity, resource utilization, and environmental sustainability.

3.2 Specific Objectives

The specific objectives of the research are as follows:

1. To develop a monitoring system capable of tracking environmental parameters such as temperature, humidity, pH, and soil moisture in real time.

2. To implement a Wi-Fi-enabled communication interface for seamless data transmission to a centralized server and dashboard.

3. To simulate the farm monitoring system using software tools that support Arduino and ESP32 microcontrollers.

4. To provide actionable recommendations and visualizations through a web-based dashboard for improved decision-making and monitoring in farming operations.

5. To integrate automation features such as motor-controlled nutrient delivery and fan systems to control temperature for hydroponic towers.

6. To evaluate the system's performance in terms of accuracy, reliability, and energy efficiency under simulated and real-world conditions.

3.3 SDG Mapping

SDG 2: Zero Hunger
Impact: By monitoring soil and hydroponic environments and automating nutrient delivery, this system will increase the yield of both soil-based and hydroponic farming, contributing to food security.

SDG 11: Sustainable Cities and Communities
Impact: Urban and community farms benefit from integrated monitoring, enabling local food production in modern, sustainable, and resource-efficient ways.

4 Scope and Limitations of the Study

This study aims to create a functional prototype of a Soil and Hydroponic Monitoring Hub, targeting small to medium-scale farms. The scope includes the design, development, and testing of the hub with sensors for essential environmental factors such as moisture, pH, temperature, and nutrient levels, presented through a user-friendly interface for real-time monitoring and visualization.

4.1 Limitations of the Study include

4.1.1 Sensor Types

The selection of sensors will be limited to cost-effective models that are widely available, practical, and affordable for small-scale farmers. While these sensors will measure essential parameters, their accuracy may be lower compared to high-precision sensors used in industrial applications. Certain advanced parameters, such as specific nutrient breakdowns, may not be measurable with the selected sensors due to budget limitations. As a result, the system may provide a generalized assessment rather than in-depth, highly precise data. Environmental durability of these affordable sensors can be lower, meaning they may require more frequent calibration and maintenance to ensure accuracy, especially in outdoor or varying environmental conditions.

4.1.2 Data Processing Capacity

For cost-effectiveness, the system will rely on microcontrollers with limited processing power, such as Arduino or Raspberry Pi. These microcontrollers, while suitable for basic data collection and simple calculations, may struggle with complex real-time data analysis or large volumes of data. Due to processing limitations, the system may need to offload detailed analysis to an external computer or cloud service, which could add to implementation costs and limit accessibility in areas with limited internet connectivity. Data storage and retrieval capacities will also be constrained, potentially affecting the length of historical data the system can store. This may limit users' ability to conduct long-term trend analysis without external storage solutions.

4.1.3 Geographical Constraints

Testing will be conducted in local Ethiopian environments. This means that the sensors and system components will be optimized for Ethiopia's specific soil types, climate, and temperature variations. Therefore, applicability in different climatic zones—such as highaltitude regions, deserts, or areas with extreme temperature fluctuations—may be limited without further adaptation and testing. Since the prototype will only be tested in a limited geographical area, results might not fully account for varying environmental stressors, such as extreme rainfall, humidity, or salinity levels that could influence the system's performance elsewhere.

4.1.4 Prototype Phase

This project will produce a prototype intended primarily for proof-of-concept and small to medium-scale applications. While it will demonstrate the hub's utility, the system may not be immediately scalable to larger agricultural operations or industrial applications without additional $R\&D$ investment. The prototype will also be a preliminary model, which may require further refinement for aspects like energy efficiency, long-term durability, and compatibility with other agricultural monitoring systems. Limitations in prototype hardware may affect its lifespan and resistance to environmental wear-and-tear, particularly in outdoor conditions with high exposure to elements like dust, rain, or temperature swings.

4.1.5 Connectivity and Acessibility

The prototype's ability to transmit data may be limited by the availability of internet and power sources, especially in rural or remote areas where reliable connectivity can be inconsistent. Data visualization may be restricted to the local device, which could limit remote monitoring options for users who need offsite access to data. If Wi-Fi or cellular networks are not available, the system may only be accessible on-site, potentially limiting the effectiveness of real-time monitoring and decision-making.

5 Significance of the Study

The Soil and Hydroponic Monitoring Hub addresses a pressing need for accessible, real-time agricultural monitoring, enabling farmers, researchers, and urban gardeners to make datadriven decisions. By providing critical insights into soil and hydroponic conditions—such as moisture, pH, temperature, and nutrient levels the hub empowers users to optimize growing environments and manage resources more effectively. This has direct implications for crop yield enhancement, resource conservation, and cost reduction, particularly for small to medium-scale farms where investment in high-end technology is often unfeasible. For Ethiopian farmers, who face challenges like soil degradation, variable rainfall, and limited access to advanced agricultural technology, this hub offers an affordable and practical solution. By making real-time environmental data available, the monitoring hub could help farmers adapt to Ethiopia's diverse climates, maximize crop resilience, and improve productivity, thus contributing to both household food security and the broader agrarian economy.

Researchers could also benefit from this tool, as it provides a low-cost means to gather environmental data, facilitating studies on crop response to various environmental conditions. On a larger scale, the Soil and Hydroponic Monitoring Hub supports global sustainable agriculture goals, as it addresses key issues like food security, resource efficiency, and environmental sustainability. By promoting resource-efficient practices, the hub aligns with eco-friendly agricultural solutions that prioritize water conservation, soil health, and responsible land use. This project has the potential to advance sustainable agriculture by offering an affordable model that could be adapted for different farming contexts, especially in areas with water scarcity and limited arable land. Ultimately, this project could play a vital role in the future of agriculture, as demand for efficient, sustainable, and technology-driven solutions continues to grow. By offering a comprehensive yet affordable tool, the Soil and Hydroponic Monitoring Hub has the potential to inspire further innovation in agricultural technology, serving as a foundation for similar initiatives that address the unique needs of farmers in resource-limited settings.

6 Literature Review

Agriculture is the backbone of many economies, particularly in developing countries like Ethiopia, where a large portion of the population depends on farming for livelihood. However, traditional farming practices face challenges such as limited access to water, soil degradation, and fluctuating climatic conditions, which can reduce crop yield and affect food security [1]. In response, modern agricultural practices increasingly emphasize the importance of monitoring key environmental factors—like moisture, pH, and nutrient levels—to optimize crop growth and enhance resource efficiency. This literature review explores current research on soil and hydroponic monitoring technologies, sensor systems, and data analysis tools, identifying critical gaps that the proposed study aims to address.

6.1 Sensor-Based Monitoring in Soil and Hydroponic Agriculture

Research on sensor-based monitoring in agriculture has demonstrated that real-time tracking of environmental conditions can significantly improve crop health and yield. Sensor technologies, such as soil moisture sensors, pH probes, and temperature sensors, are commonly used to assess the conditions that affect plant growth in both soil and hydroponic systems [2]. In soil-based agriculture, sensors help farmers make informed irrigation decisions, optimizing water use and reducing waste [3]. Similarly, in hydroponics, monitoring nutrient concentration and pH levels is essential to maintain balanced nutrient solutions and prevent issues like root rot or nutrient deficiencies [4].

Studies by [5] emphasize that, although these sensors are effective, they are often costly and require specialized knowledge to operate and maintain, making them less accessible for small-scale farmers in Ethiopia and similar regions. Additionally, many sensor systems are designed for either soil or hydroponic use, rather than integrating both, which limits their versatility for farmers interested in a range of cultivation methods.

6.2 Role of IoT and Data Analytics in Agricultural Monitoring

The integration of the Internet of Things (IoT) in agriculture has revolutionized how data is collected, analyzed, and utilized in decision-making. IoT-based monitoring systems enable remote monitoring by linking sensors to cloud platforms where data can be accessed and analyzed in real-time [6]. Data analytics can help identify trends, predict crop needs, and facilitate resource-efficient farming practices. IoT and cloud-based monitoring systems are particularly useful in precision agriculture, where real-time data enables tailored management practices that improve efficiency and reduce costs [7].

However, such systems are often designed for large-scale operations, requiring significant investment and technical expertise to implement and maintain [8]. Smallholder farmers, who make up the majority of Ethiopia's agricultural sector, often lack access to the infrastructure needed to support IoT-enabled systems, including reliable internet connectivity and consistent power sources [1]. This highlights a gap in technology that is both affordable and accessible for small to medium-scale farmers in developing countries.

6.3 Soil and Hydroponic Monitoring Systems: Current Challenges and Limitations

Although sensor and IoT-based systems have shown promise in agricultural applications, there remain several challenges to their widespread adoption, particularly in developing regions. High costs, technical complexity, and limited adaptability to different agricultural contexts are frequently cited limitations. Studies by [9, 4] indicate that while sensor technologies for monitoring soil and hydroponic systems exist, most are designed for high-input, controlled environments where cost and maintenance are less of an obstacle.

Additionally, existing literature reveals a lack of comprehensive solutions that can be used interchangeably in soil and hydroponic settings. Most research has focused on either soil or hydroponic systems in isolation, overlooking the potential benefits of a unified system that could serve both types of agriculture. According to research by [3], the ability to seamlessly transition between soil and hydroponic monitoring could provide significant advantages, allowing farmers to adopt the system that best fits their available resources and specific growing conditions.

6.4 Addressing the Gaps in Agricultural Monitoring Technology

The gap in affordable, versatile monitoring systems for small-scale applications points to a need for innovation in agricultural technology that caters specifically to low-resource environments. While advanced monitoring systems are commercially available, they remain out of reach for many smallholder farmers due to cost, infrastructure requirements, and operational complexity [8]. In addition, few systems offer the flexibility to adapt to both soil and hydroponic environments, which limits options for farmers exploring alternative growing methods or mixed-use systems.

The proposed Soil and Hydroponic Monitoring Hub aims to fill this gap by offering a cost-effective, adaptable solution that leverages low-cost sensors and microcontrollers to monitor critical environmental parameters. Unlike most commercially available solutions, this hub will target smallholder farmers, integrating affordable sensors and a user-friendly interface to ensure accessibility and ease of use.

6.5 Proposed Contribution of the Study

The proposed research will build on existing knowledge by developing a prototype that combines real-time monitoring for both soil and hydroponic applications. By addressing the limitations identified in current systems—namely cost, accessibility, and limited dual-functionality—this study seeks to make advanced monitoring technology available to a broader range of users. Additionally, the study will contribute to Ethiopia's sustainable agriculture goals by promoting practices that improve water efficiency, optimize nutrient use, and enhance crop productivity.

7 Methodology

The methodology for this research involves the design, development, and testing of a Soil and Hydroponic Monitoring Hub that uses sensors and microcontrollers to monitor key environmental parameters. This study focuses on small to medium-scale agricultural setups, ensuring the hub's adaptability, cost-effectiveness, and usability for resource-limited farming environments. The steps below outline the approach to achieve the project's objectives.

7.1 Research Design

This study employs a prototype-based design that incorporates elements of experimental testing and iterative development. The research is divided into the following phases:

1. Requirements Analysis
2. System Design
3. Prototype Development
4. Testing and Validation
5. Evaluation and Optimization

This design approach allows for continuous refinement of the monitoring hub based on feedback obtained from testing, ensuring the final system meets the intended functionality and performance criteria.

7.1.1 Phase 1: Requirements Analysis

In this phase, a detailed assessment of the environmental parameters to be monitored is conducted. For this study, the parameters include:

- **Soil Moisture**: Essential for determining water availability in soil-based setups.

- **pH Levels**: Important in both soil and hydroponic systems to maintain suitable conditions for nutrient uptake.
- **Temperature**: Critical for optimal growth conditions in both environments.
- **Nutrient Levels**: Particularly important in hydroponic systems where plants rely entirely on nutrient solutions.

The selection of sensors focuses on affordability, availability, and compatibility with the chosen microcontroller (e.g., Arduino or Raspberry Pi). The system requirements include functionality for data logging, real-time data visualization, and alarm triggers for extreme conditions.

7.1.2 Phase 2: System Design

The system design phase involves creating a framework for the hardware and software components of the monitoring hub. The key components include:

- **Sensors**: Specific sensors for moisture, pH, temperature, and nutrients.
- **Microcontroller/Processor**: Choice of a microcontroller like Arduino or Raspberry Pi for efficient data acquisition and processing.
- **Communication Module**: Integration of Wi-Fi or Bluetooth modules for remote data access via a smartphone app or web interface.
- **Power Supply**: Design of an efficient power solution, potentially incorporating battery or solar power for off-grid compatibility.

7.1.3 Phase 3: Prototype Development

The prototype development involves assembling the hardware and programming the software to enable data collection, processing, and display. The main tasks in this phase include:

- **Hardware Assembly**: Integration of sensors with the microcontroller, ensuring accurate sensor placement for soil and hydroponic configurations.
- **Software Development**: Creation of a program that collects data from sensors, processes it, and sends it to a user-friendly interface.
- **User Interface Design**: Development of an intuitive interface (mobile app or web-based) for real-time data visualization.
- **Data Storage**: Setting up local data logging, with an option to send data to a cloud server for historical analysis and tracking.

7.1.4 Phase 4: Testing and Validation

The prototype undergoes controlled tests to ensure accuracy, reliability, and performance in both soil and hydroponic setups. Key testing activities include:

- **Accuracy Testing**: Comparing sensor readings with calibrated equipment to ensure data accuracy.
- **System Performance**: Testing data transmission, power efficiency, and alert response times.
- **Usability Testing**: Gathering feedback from potential users (e.g., farmers, agricultural researchers) on the interface and functionality.
- **Environmental Robustness**: Evaluating durability under fluctuating environmental conditions, such as temperature and humidity changes.

7.1.5 Phase 5: Evaluation and Optimization

This phase involves analyzing test data to identify areas for improvement, including:

- **System Refinements**: Adjustments to sensor calibration, interface design, and power management based on testing feedback.
- **Cost Analysis**: Evaluating cost-effectiveness and identifying ways to reduce expenses without compromising functionality.
- **Performance Analysis**: Assessing how well the hub meets original requirements and its overall effectiveness.

7.2 Data Collection and Analysis

Data collected from sensors will be analyzed to determine patterns and relationships among environmental parameters, focusing on:

- **Parameter Correlations**: Examining how changes in one parameter (e.g., moisture) affect others (e.g., pH or temperature).
- **Threshold Testing**: Identifying optimal ranges for each parameter.
- **System Feedback**: Evaluating the effectiveness of alarm triggers based on real-time monitoring data.

7.3 Ethical Considerations

This research emphasizes sustainable and ethical technology usage, minimizing environmental impact through low-power sensors and renewable energy sources like solar panels.

7.4 Expected Outcomes

The anticipated outcomes of this methodology include:

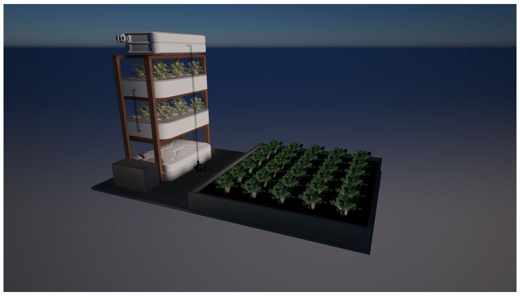
- A functioning prototype of a Soil and Hydroponic Monitoring Hub.
- Accurate, real-time data on critical environmental parameters.
- A cost-effective and accessible solution for small to medium-scale farms.
- Adaptability for both soil and hydroponic systems.

7.5 Project Approach

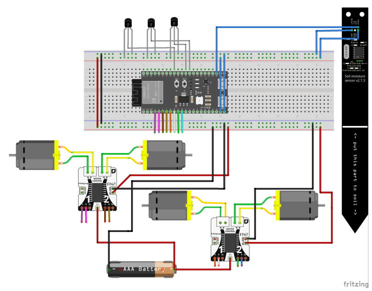
The project was approached with a clear methodology, emphasizing careful planning, teamwork, and efficient resource management to create a cost-effective and sustainable monitoring system. We started with research, identifying essential components and methodologies for integrating IoT-enabled sensors with microcontrollers for real-time data monitoring. Key tasks included prototyping, sensor calibration, and structural development, all aimed at optimizing the design for smallholder farmers. Despite our systematic approach, the team encountered several challenges that required adaptability and problem-solving. Initially, locating vendors who could provide electronics and materials with receipts proved difficult, slowing the procurement process. Once materials were sourced, delays in project funding and the limited time left to execute tasks created significant pressure. The workshop was frequently overcrowded with students, causing long wait times and hindering progress on assembly and testing. Financial constraints further limited our ability to design and implement the project to its full potential. During construction, shortages of essential materials and tools added additional hurdles, necessitating quick adjustments and resource reallocation. Additionally, poor internet quality impeded research and coordination efforts, affecting overall efficiency. Despite these struggles, the team remained committed, finding creative solutions to complete the project while ensuring it met its primary objectives. The experience reinforced the importance of resilience, planning, and teamwork in achieving success under challenging conditions.

8 Project Design

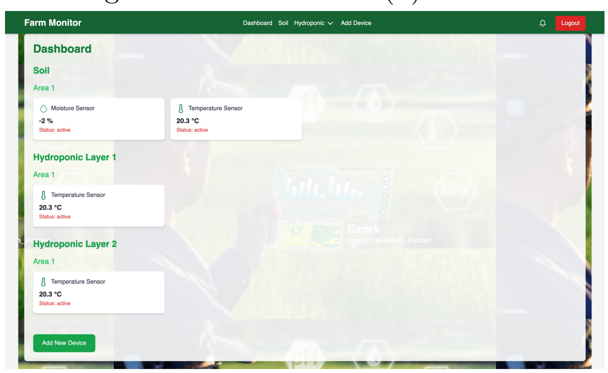
The design of the Soil and Hydroponic Monitoring Hub focused on integrating cost-effective technology to provide real-time monitoring for both soil-based and hydroponic farming systems. The project employed a modular approach, ensuring adaptability, scalability, and ease of maintenance for smallholder farmers. The hardware components consisted of IoT-enabled sensors for measuring key parameters such as soil moisture, pH, temperature, and water levels. These sensors were connected to a microcontroller, which facilitated data collection and transmission to a central interface. The interface, designed to be user-friendly, provided real-time data visualization, enabling farmers to make informed decisions to optimize crop health and resource use. To ensure functionality, the structural design accommodated both indoor and outdoor environments. The hub's enclosure was designed for durability, offering protection against environmental factors like dust and moisture while maintaining accessibility for maintenance and upgrades. The project also prioritized energy efficiency, leveraging low-power components and incorporating options for renewable energy sources such as solar panels. This aligns with the project's goal of promoting sustainability and reducing operational costs for users.



(a) Structural Design



(b) ElectroMechanical Design



(c) Software Design

Figure 1: System Design

Despite the well-thought-out design, several challenges emerged during the implementation phase:

1. **Material and Tool Shortages:** A lack of certain materials and tools during construction forced the team to improvise and adjust the design.

2. **Financial Constraints:** Budget limitations restricted access to high-quality components, leading to compromises in some areas of design.

3. **Workshop Delays:** Long wait times at the workshop impacted the timeline for assembling the structure and integrating components.

4. **Connectivity Issues:** Low-quality internet hindered the testing and configuration of IoT functionalities.

5. **Time Constraints:** Delayed release of project funds left limited time to refine and test the final design thoroughly.

Despite these obstacles, the team successfully developed a functional prototype, balancing cost, efficiency, and sustainability while addressing the challenges through creative problem-solving and collaboration.

8.1 Project Task Allocation

In the Soil and Hydroponic Monitoring Hub project, each engineering discipline contributed specific expertise, enabling a well-rounded and collaborative approach. The roles, contributions, and challenges faced by the team are detailed below:

1. **Group Leader: Electrical Engineer (Kaleab Tadesse)** Kaleab led the team, ensuring clear communication, task allocation, and adherence to project deadlines. He also supervised the integration of electrical components, such as sensors and microcontrollers, into the system. Challenges included coordinating the team amidst workshop delays and ensuring all members had access to the required tools and materials. Kaleab's leadership kept the team focused, even under tight time and budget constraints.

2. **Software Engineering** The software engineer focused on programming microcontrollers and developing a user-friendly interface for real-time data monitoring. They ensured seamless communication between the sensors and the cloud-based system. Challenges included low-quality internet, which slowed testing and cloud integration, and adapting the interface for both soil and hydroponic use.

3. **Electrical and Computer Engineering (Two Members)** The electrical and computer engineers collaborated on selecting and testing electronic components, including sensors, communication modules, and power systems. They were responsible for prototyping and sensor calibration. Finding vendors willing to provide receipts, material shortages, and delays in workshop access were key challenges. Despite this, they ensured the system's electrical components met the project's requirements.

4. **Electromechanical Engineering** The electromechanical engineer worked on integrating mechanical and electrical components, focusing on energy efficiency and system durability. They designed mounts for sensors and solar power options. A major hurdle was limited access to advanced tools due to workshop congestion and financial constraints, which required innovative problem-solving.

5. **Civil Engineering** The civil engineer (User's Role) designed and built the structural housing for the hub, ensuring durability and protection for the electronics. They also optimized the design for environmental conditions and ease of assembly. Challenges included material shortages, tool access issues, and adapting the design within a limited budget. Their expertise in construction and adaptability was critical to the project's success.

6. **Architecture** The architect contributed by designing the aesthetic and functional layout of the system's structure. They ensured the project's physical design was both

user-friendly and visually appealing. Budget limitations required creative solutions to maintain functionality without compromising design.

7. **Mechanical Engineering** The mechanical engineer handled the mechanical assembly of the monitoring hub, including sensor placement and moving parts. They optimized the energy system by incorporating mechanical features to improve efficiency. Limited workshop access and insufficient funds for advanced tools were significant obstacles.

8. **Chemical Engineering** The chemical engineer focused on analyzing potential chemical interactions in hydroponic systems and ensuring sensor accuracy for pH and nutrient monitoring. They faced challenges with sourcing affordable, high-quality calibration solutions but overcame them through resourceful procurement strategies.

9. **Environmental Engineering** The environmental engineer ensured the project adhered to sustainability principles, analyzing the system's environmental impact. They suggested using eco-friendly materials and renewable energy sources. Challenges included balancing sustainability with budget constraints, particularly in sourcing green materials.

10. **Mining Engineering** The mining engineer provided expertise in resource evaluation, helping identify affordable and locally available materials. They also contributed to assessing the system's durability under harsh conditions. Challenges included limited material availability and ensuring compatibility with the project's design requirements.

Team Challenges and Resilience

The team faced shared obstacles, such as delays in funding, workshop congestion, and material shortages. Despite these challenges, each member's dedication and adaptability ensured that the project was completed successfully, showcasing the strength of interdisciplinary collaboration.

8.2 Resources and Materials Required

Here's a detailed discussion of each of the resources and materials listed, considering the costs involved:

1. **IoT Sensors (Moisture, pH, Temperature)** Price: 3 units * 700 ETB = 2,100 ETB These sensors will play a vital role in gathering real-time environmental data for the soil and air quality, which is crucial for monitoring hydroponic systems in your project. Moisture sensors will help track soil or water content, while pH and temperature sensors will ensure the optimal conditions for plant growth. The price of 700 ETB per unit seems reasonable given their functionality and expected longevity in the project.

2. **Microcontrollers** Price: 2 units * 800 ETB = 1,600 ETB Microcontrollers are the brains of the IoT system, receiving data from sensors, processing it, and sending it to a cloud-based system or actuators for necessary actions. With a cost of 800 ETB per

unit, it's important to choose reliable microcontrollers, such as those in the Arduino or Raspberry Pi families, which offer sufficient computing power for handling the sensors and modules.

3. **Communication Modules** Price: 2 units * 600 ETB = 1,200 ETB Communication modules allow data transmission between the sensors, microcontrollers, and cloud services or mobile apps. These could include Wi-Fi, Bluetooth, or LoRa modules. At 600 ETB per unit, it's essential to choose modules with good range and low power consumption, particularly for IoT applications where remote data transfer is crucial.

4. **Power Supply (Rechargeable Batteries)** Price: 2 units * 500 ETB = 1,000 ETB Rechargeable batteries are necessary for providing power to the IoT system, especially when devices are deployed outdoors or in remote locations. Depending on the project's power consumption, selecting high-capacity batteries will ensure the longevity of the system between charges. The price of 500 ETB per unit is reasonable for medium-range battery packs, such as Li-ion or Li-polymer, which are common in IoT applications.

5. **Structural Materials (Enclosures and Mounting)** Price: 800 ETB The enclosures and mounting materials protect the sensitive electronic components from environmental factors such as dust, moisture, and physical damage. The cost of 800 ETB for durable, weatherproof enclosures is reasonable. Choosing materials such as plastic or aluminum can balance cost and protection for outdoor use.

6. **Mechanical Components (Pipes, Regulators, Tubing)** Price: 700 ETB These materials will be used for connecting and routing water, nutrients, or air in the hydroponic system. At 700 ETB, these are relatively inexpensive but essential components for maintaining the system's physical structure and flow. It's important to choose high-quality piping and regulators that can handle fluid pressure and prevent leakage.

7. **Prototyping Materials (Breadboards, Resistors, Capacitors)** Price: 600 ETB Prototyping materials will be necessary during the testing and assembly phase, particularly for building and modifying circuits. Breadboards allow for quick circuit prototyping without soldering, and the inclusion of resistors and capacitors ensures proper circuit functioning. The price of 600 ETB will likely cover basic prototyping needs for this stage.

8. **Software and Cloud Services** Price: 500 ETB Software and cloud services are crucial for managing and analyzing the data gathered by the IoT system. This can include purchasing cloud storage, platforms for data visualization, or services for remote monitoring and control. The cost of 500 ETB seems modest but should be enough for initial cloud hosting or using a service like Google Firebase, which provides free tiers for small-scale applications.

9. **Miscellaneous Items (Wiring, Adhesives, Tools)** Price: 500 ETB Miscellaneous items such as wiring, adhesives, and tools are necessary for assembling the IoT system and ensuring that all components are properly connected. The cost of 500 ETB is a general allowance for these essential components, ensuring that all physical connections are secure and well-organized.

Total Estimated Cost: 10,000 ETB This breakdown ensures that all the essential resources for developing the IoT-based Soil Hydroponic Monitoring Hub are covered. With a well-planned allocation, the project is set up for success while staying within budget. If any resources can be sourced at lower costs or provided by partners, this could free up funds for any unforeseen needs or additional components.

9 Financial Request

This financial request outlines the estimated costs for the components and materials required to develop the prototype for the hydroponic monitoring system. The system includes an MCU, sensors, pumps, cooling fans, and other essential components. This funding is critical to ensure the successful implementation of the project.

Itemizecd Financila Request

The table below provides a detailed breakdown of the items, quantities, unit prices, and total costs for the prototype development:

Item	Quantity	Unit Price(ETB)	Total (ETB)
ESP32 Microcontroller	1	1,200	1,200
DHT22 Temperature and Humidity Sensors	3	600	1,800
Soil/Water pH Sensor	1	1,500	1,500
Humidity Sensor (additional)	1	800	800
Jumper Cables (set)	2	200	400
Breadboard	2	300	600
Battery (to power components)	2	200	400
Cooling Fans	2	550	1,100
Water Pumps	2	600	1,200
Miscellaneous (wires, connectors, adhesives)	-	1,000	1,000
Total			**10,000**

Table 1: Budget Breakdown

Additional Notes

1. Prices are based on current market rates and may vary slightly depending on supplier availability.

2. Miscellaneous costs include additional items required during assembly and testing, such as connectors, wires, and adhesives.

10 Budget

The budget for this project is 10,000 Birr.

11 Proposed Schedule

The following tables outline the detailed timeline for the development and integration of the hydroponic monitoring system, focusing on building the hydroponic farm, simulating the electronics and software, and testing components.

Phase 1: November Tasks

Table 2: Phase 1: November Tasks

Date Range	Task and Description
November 15 – November 20	**Hydroponic farm construction:** Build the hydroponic farm structure, including water tanks, pumps, and plant trays. Ensure compatibility with monitoring components.
November 15 – November 25	**Electronics and software simulation:** Simulate the electronics and software components using tools like Proteus or Tinkercad. Verify sensor integration, data flow to the server, and database operations.
November 21 – November 25	**Sensor selection and acquisition:** Choose and procure sensors for moisture, pH, temperature, and nutrients.
November 26 – November 30	**Microcontroller setup:** Configure the MCU (e.g., ESP32) and test basic communication with sensors.

Table 3: Phase 2: December - January Tasks

Phase 2: December - January Tasks	
Date Range	**Task and Description**
December 1 - December 5	**Sensor calibration:** Calibrate the sensors for accuracy in soil and hydroponic environments.
December 6 - December 10	**Database design:** Design the database schema to store environmental parameters and historical data.
December 11 - December 15	**Server development:** Set up the server to collect and manage sensor data. Implement data storage in the database.
December 16 - December 20	**Web dashboard development:** Create the dashboard interface for data visualization. Develop features like real-time monitoring and historical trends.
December 21 - December 25	**Integration testing:** Test the MCU-sensor system, server, database, and dashboard as a single workflow. Debug issues.
December 26 - December 28	**Full system integration:** Deploy the system on the hydroponic farm. Ensure all components work seamlessly.
December 29 - January 1	**Performance testing:** Test the full system under real conditions. Collect data and adjust configurations as needed.

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