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Assessing the Technical and Environmental Feasibility of Smart Agriculture Based on Modern Irrigation Systems: A Case Study of a Proposed Agricultural Project in Adrar Province, Algeria

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Abstract:

This study examines the technical and environmental feasibility of adopting smart agriculture technologies based on multi-irrigation systems in desert regions, through a proposed agricultural project in Adrar Province. It focuses on identifying the key parameters required to evaluate the applicability of these technologies under conditions of water scarcity and harsh climate. The study adopts a descriptive-analytical approach by developing a conceptual technical model that integrates smart sensors, such as ESP32 and soil moisture sensors, with cloud-based monitoring platforms. The findings show that the proposed system enables real-time and accurate monitoring of crop water needs, improves resource efficiency, and contributes to reducing water consumption. It also enhances the adaptability of agricultural systems to environmental constraints. The study concludes that these technologies represent a promising solution for improving agricultural sustainability and strengthening food security in desert areas.

Keywords: Smart Agriculture; Technical Feasibility; Environmental Feasibility; Multi-Irrigation Systems; Adrar Province.
JEL Classification Codes: Q15; Q16; Q33.

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Introduction:

In recent years, global agriculture has experienced major transformations driven by technological advancements, particularly in IoT, embedded systems, and artificial intelligence. These developments have led to the emergence of smart agriculture as a key solution to challenges related to food security and resource scarcity. Smart agriculture integrates technologies such as sensors and intelligent irrigation systems to improve resource efficiency and increase productivity, while feasibility studies play a crucial role in assessing their applicability and performance.

In Algeria, especially in desert regions like Adrar, agriculture faces significant challenges including water scarcity, high temperatures, and poor soil conditions. This makes the adoption of smart irrigation technologies necessary to ensure sustainable production. Multi-system irrigation, in particular, offers promising opportunities for optimizing water use and improving productivity. However, its successful implementation requires a thorough technical feasibility assessment under local conditions.

Given these challenges, this study raises the following research question:

What are the parameters for the technical and environmental feasibility study of adopting smart agriculture technologies based on multi-irrigation systems in the desert regions of Adrar Province?

Derived from this problem, the study seeks to answer the following questions:

• What is meant by smart agriculture, and what are the main technologies used in it?

• What is the concept of both technical and environmental feasibility, and what are the main components of their study?

• To what extent are these technologies suitable for the desert environment in Adrar Province?

Study Hypotheses:

H1. There is a high level of technical feasibility for implementing smart agriculture in desert regions.

H2. The multi-irrigation system contributes to improving water-use efficiency compared to traditional systems.

H3. Smart agriculture technologies are technically suitable for the environmental conditions of Adrar Province.

H4. The use of smart systems leads to improved agricultural performance and reduced operational costs.

Importance of the Study:

This study derives its significance from its contribution to highlighting the role of modern technologies in developing the

agricultural sector, especially in desert environments that suffer from limited resources. It also provides an analytical framework for evaluating the technical feasibility of smart agriculture, thereby assisting decision-makers and investors in adopting effective and sustainable solutions. In addition, the study contributes to promoting the use of advanced irrigation systems that help optimize water consumption and improve productivity.

Research Objectives

• Analyze the concept of smart agriculture and its main technologies;
• Study the multi-irrigation system as a technical solution for improving water management;
• Evaluate the technical feasibility of implementing this system in a desert environment;
• Determine the suitability of modern technologies to the conditions of Adrar Province;
• Propose an applicable model that can be implemented in the agricultural sector.

Previous Studies

- **Bouabdelli, Y., & Gharbi, R. (2023) – Smart Agriculture as a Strategic Option to Achieve Food Security in Algeria**

This study addressed smart agriculture as a strategic option for enhancing food security in Algeria. It focused on analyzing the current state of the agricultural sector and the potential for integrating modern technologies, particularly smart irrigation systems, using a descriptive-analytical approach based on reviewing data and indicators related to agricultural production and resource use.

Key Findings:

- Smart agriculture contributes to increasing crop productivity and improving water-use efficiency.
- There is significant potential for implementing smart irrigation technologies in arid and semi-arid regions.
- The study recommends strengthening investment in agricultural technologies and developing digital infrastructure.

- **Biswajyoti, B., Santosh, K., Aritra, G., & Denil, U. (2024) – Impact of Drip Irrigation on Crop Growth, Yield, Water Productivity, and Weed Dynamics: A Review**

This study examined the impact of drip irrigation systems on various agricultural aspects by reviewing multiple previous studies that addressed crop growth, yield, and water-use efficiency, with a focus on evaluating the effectiveness of this system compared to traditional irrigation methods.

Key Findings:

- Drip irrigation significantly increases agricultural productivity.
- It ensures higher water-use efficiency compared to conventional irrigation methods.
- It helps reduce weed growth, thereby lowering production costs.
- It represents a key technical component of smart irrigation systems.

- **Rizan, N., Balasundram, S., Shahbazi, A., Balachandran, U., & Shamshiri, R. (2024) – Internet-of-Things for Smart Agriculture: Current Applications, Future Perspectives and Limitations**

This study explored the applications of the Internet of Things (IoT) in smart agriculture, focusing on its role in improving agricultural resource management, particularly in irrigation systems, through an analytical review of recent studies and applications related to real-time monitoring and data-driven decision-making.

Key Findings:

- IoT technologies significantly enhance irrigation efficiency through real-time data monitoring.
- They support precise agricultural decision-making based on data analysis.
- These technologies face challenges related to cost and infrastructure limitations.
- The study recommends integrating artificial intelligence to further improve smart agricultural systems.

Research Gap

Despite the growing number of studies on smart agriculture worldwide, there is a clear lack of applied research focusing on evaluating the technical feasibility of these systems in desert

environments, particularly in Algeria. Moreover, most existing studies emphasize theoretical or environmental aspects without delving into practical technical analysis related to system efficiency and compatibility with local conditions. This is the gap that the present study seeks to address.

Research Methodology

This study adopts the descriptive-analytical approach by examining theoretical concepts related to smart agriculture and irrigation systems. It also employs an applied approach (case study) to evaluate the technical feasibility of a hypothetical smart agricultural project in Adrar Province. This is done based on available technical and environmental data, along with an analysis of the system components and their efficiency in practical conditions.

Firstly. Literature Review

1. Smart Agriculture

1.1 The concept of Smart Agriculture

Technological developments in the agricultural sector have not been purely internal in origin; rather, they are the result of integrating leading external innovations. Just as agriculture in the previous century absorbed internal combustion engines and electricity, it also incorporated precision agriculture technologies in the late 1990s, such as GPS, GIS, and remote sensing systems, which were originally developed in defense and information sectors. This integration between external information technologies and internal agricultural innovations (such as soil sensors and variable-rate fertilization systems) marked the true starting point toward the era of smart agriculture. Agricultural practice thus shifted from a mere mechanical application of technology to an integrated "smart" system based on real-time data management and advanced knowledge. This transformation made precision agriculture the bridge through which the sector moved toward the third green revolution, driven by artificial intelligence and the Internet of Things. (Council , 1997, p. 27)

According to the Food and Agriculture Organization of the United Nations (FAO), smart agriculture is defined as agriculture that sustainably increases productivity, enhances resilience (adaptation), and reduces or removes greenhouse gas emissions (mitigation), while also supporting the achievement of food security and national development goals. (FAO, 2010, p. 4)

It involves the use of various tools and technologies to collect data related to crop growth, soil conditions, climate patterns, and other environmental factors as well as analyzing this data and taking the

necessary actions based on it. (Kamilaris, Kartakoulis, & Pretenfa , 2017, p. 25)

It is also defined as agriculture in which farmers use mobile phones and other digital technologies to access specialized and actionable agricultural information without delay. (Ben Aichouba & Sedkaoui , 2022, p. 456)

Smart agriculture systems rely on the use of modern technologies such as remote sensing devices, Geographic Information Systems (GIS), the Internet of Things (IoT), drones (UAVs), artificial intelligence (AI), and data analysis and processing systems. These technologies are used to improve farm management efficiency throughout all stages, starting from land preparation, through planting, irrigation, fertilization, and pest and disease control, and ending with the final harvesting stage. (Kellou & Belhaoues, 2024, p. 14)

Based on the above, an operational definition of smart agriculture can be formulated as follows: it is an integrated agricultural system based on the use of modern digital technologies (such as sensors, Geographic Information Systems, the Internet of Things, and artificial intelligence) for collecting and analyzing real-time data related to crops and natural resources, and using it to support agricultural decision-making across different production stages. The aim is to improve productivity, optimize resource use, enhance resilience to climate change, reduce environmental impacts, and ultimately achieve sustainability and food security.

1.2 **Key Technologies of Smart Agriculture**

Smart agriculture includes a set of modern technologies that work in an integrated manner to form a data- and technology-driven intelligent agricultural system. The main components include the following:

1.3 Sensors (IoT Sensors)

Sensors are considered one of the most important components of smart agriculture, as they collect data on soil moisture, temperature, humidity levels nutrient content, and pest spread. This data is then transmitted to analysis systems (often via the Internet) to support accurate decision-making. (Rizan , Balasundram, Shahbazi, Balachandran, & Shamshiri, 2024, p. 1448)

The role of sensors can be summarized in the following points: (Prasad , Venathi , & Devi , 2023, p. 683)

- **Data Collection Function:** through devices installed in agricultural fields to collect data remotely and transmit it to the farmer or producer in a timely manner.

- **Network Integration:** sensors equipped with communication technologies that enable them to exchange information with other devices via the Internet.
- **Versatility:** these sensors include different types, some designed to monitor soil moisture, others linked to weather stations, vehicles, and even agricultural machinery, ensuring real-time monitoring and maintenance.

1.4 Drones (Unmanned Aerial Vehicles)

Drones, also known as unmanned aerial vehicles (UAVs), are aircraft that can be remotely controlled or programmed for autonomous flight. They are used in agriculture for crop monitoring, soil analysis, and precision spraying of fertilizers and pesticides. They also provide high-resolution images that help detect plant diseases, nutrient deficiencies, and water stress. (Supriya, Shiksha, Kavita, & Isha , 2021, p. 503)

1.5 Agricultural Robots (Robotics)

Robots are another key component of smart agriculture, with applications ranging from planting seeds, harvesting crops, and removing weeds to spraying pesticides and other related agricultural tasks. (Shamshiri, Weltzien , Hameed , & et al, 2018, p. 2)

1.6 Artificial Intelligence

Artificial intelligence is a key enabler of smart agriculture, as it allows farmers to make data-driven decisions based on real-time insights. AI algorithms can analyze large volumes of data collected from IoT sensors, drones, and other sources, providing practical recommendations to improve crop growth and optimize resource use. (Mirani, Memon, Chohan, Wagan, & Qabulio, 2021, p. 234)

Artificial intelligence can also be used for crop yield prediction based on various factors such as weather conditions, soil properties, historical data, and other relevant variables. In addition, AI can be applied in the detection and diagnosis of crop diseases, enabling farmers to take proactive measures to prevent crop losses. (Van, Kassahun, & Catal , 2020, p. 2)

Based on the above, it can be stated that smart agriculture relies on the integration of a set of modern technologies such as sensors, drones, robots, and artificial intelligence, with the aim of improving agricultural resource management, increasing production efficiency, reducing costs, and achieving environmental sustainability.

2. Technical Feasibility Study

A technical feasibility study is of great importance in evaluating investment projects, as it aims to determine the extent to which a proposed solution can be implemented under specific constraints, taking

into account the availability of resources, the level of technology used, and the potential difficulties that may arise during implementation. In short, a technical feasibility study is an essential part of the overall feasibility analysis of any project. (Vankatesh, 2022, p. 126)

2.1 Concept of Technical Feasibility

A technical feasibility study is defined as an analytical process aimed at assessing the extent to which a project can be implemented from a scientific and technical perspective. This is done by verifying the suitability of the technology used in relation to the project's objectives and plans, as well as its compatibility with the implementation system and operational details. The study also includes evaluating the level of the adopted technology and its competitiveness, analyzing its ability to keep pace with recent technological developments and reduce the technological gap compared to advanced countries, in addition to examining the degree of similarity or overlap between the project and existing technologies or projects in terms of scale and level. This evaluation is generally carried out in a qualitative manner in order to judge the project's technical suitability for implementation. (Donghun, 2021, p. 181)

This phase is associated with conducting a comprehensive technical and engineering study that includes various disciplines related to equipment works, construction, building, and other related activities, with the aim of reaching the final delivery stage of the project, including all its equipment, systems, and software. This study should also include all details related to the project's start-up phase, along with a precise identification of all costs in accordance with the conditions and requirements of the target markets. (Heralova, 2024, p. 567)

Based on the above, the following operational definition of technical feasibility can be proposed: it is an applied analytical process aimed at verifying the possibility of implementing a project from a technical and engineering perspective. This is achieved by assessing the suitability of the technology used, identifying implementation requirements in terms of equipment, materials, and resources, and examining various aspects related to construction and operation. It also includes accurately estimating technical costs and ensuring the project's compatibility with market conditions, thereby enabling a practical judgment on the project's feasibility for efficient and successful implementation.

2.2 Objectives of the Technical Feasibility Study:

The technical feasibility study aims to achieve a set of objectives, which can be summarized as follows: (Hossain, Wang, Tsang, & Poon, 2018, p. 576)

- Assess the project's ability to meet established industry standards;
- Determine the most suitable location for the project to ensure operational efficiency;
- Define the optimal project size or appropriate production capacity;
- Analyze the availability of production factors (raw materials, energy, water, labor, transportation);
- Evaluate the cost, quality, and accessibility of essential goods and services;
- Identify potential technical constraints that may affect project implementation.

2.3 Stages of the Technical Feasibility Study of a Project:

The technical feasibility study is carried out through a set of structured stages aimed at assessing the technical viability of the project, ensuring its success, and minimizing associated risks, as follows:

Table N01. Stages of the Technical Feasibility Study of the Project

Stage Name	Explanation
1. Identifying technical requirements	This stage involves identifying all the technical requirements of the project, such as the technology to be used, expected performance, and operational needs, in coordination with the different concerned teams.
2. Defining constraints and assumptions	It includes identifying constraints that may affect project implementation, such as budget, available resources, and time, as well as defining the assumptions on which the study is based.
3. Establishing evaluation criteria	Precise evaluation criteria are established to assess technical feasibility, such as efficiency, performance, scalability, and cost, ensuring an objective analysis.
4. Research and comparative analysis	It involves analyzing similar projects or products to better understand the technologies used, identify potential risks, and extract best practices.
5. Concept testing	The project idea is tested through a simple prototype to ensure its technical applicability.

6. Performance testing	This stage aims to evaluate the system or product's efficiency in terms of speed, quality, and ability to meet requirements.
7. Resource and security evaluation	It includes assessing the availability of human and technical resources, as well as evaluating security aspects and data protection.
8. Risk analysis and mitigation planning	Potential technical risks, such as system failure or integration issues, are identified along with mitigation strategies to reduce their impact.
9. Cost-benefit analysis	Expected costs are compared with potential benefits to determine the project's economic feasibility.
10. Documentation and decision-making	Finally, all study results are consolidated to make a final decision regarding whether to implement, modify, or reject the project

Source: (Chisel, 2026)

3. Environmental Feasibility Study

The relationship between the environment and the project is not one-sided; rather, it is a reciprocal (feedback) relationship. The environment, with all its components, has an impact on the project, and the project in turn affects the environment, whether this impact is positive or negative. Therefore, a comprehensive analysis of the environmental feasibility study of a project must take both impacts into consideration. (Bakhoum , 2023, p. 1)

3.1 Definition of Environmental Feasibility

An environmental feasibility study is a means of protecting nature from damage and pollution. Its main objective is to ensure that the Earth's resources (such as water, soil, and air) are used wisely, so that future generations can inherit a clean and livable environment similar to the one we enjoy today.

It can also be defined as a process of examining the relationship between new projects and the surrounding environment. This study aims to prevent any harmful impacts of the project on nature or human health, while also seeking to enhance its positive effects.

It is also considered a measure that reflects the extent to which a project is concerned with environmental protection. It examines the project's impact from the present into the future, and considers this impact not only at the local level but also at the regional and global

levels, ensuring that development is aligned with environmental safety standards. (yahyaoui, Gasmi , Brouki , & Mouloudi, 2024, p. 8)

3.2 Importance of the Environmental Feasibility Study

The importance of environmental assessment and environmental feasibility studies can be summarized in the following points:

- Ensuring project acceptance and approval by the competent authorities, and obtaining the necessary licenses required to commence its activities;
- Serving the interests of investors, especially when seeking funding from international institutions, as many development financing organizations now require an environmental assessment of investment projects particularly industrial ones before approving funding;
- Avoiding the selection of unsuitable project locations, due to the potential environmental pollution and serious damages that may result from establishing projects in such areas, which may be difficult or impossible to remediate in the future;
- Preventing the emergence of environmental disputes between project owners and other stakeholders, as such disputes may lead to significant financial compensation or high costs for mitigating environmental damage and restoring affected areas;
- Contributing to the estimation of the environmental benefits and costs of the project within a comprehensive social and economic framework, whether at the local, national, or even international level, depending on the nature of the external impacts resulting from project implementation. (Kafi, 2012, p. 8)

3.3 Characteristics of the Environmental Feasibility Study

From our attempt to present the concept and importance of the environmental feasibility study, we find that it is characterized by several features, the most important of which are: (Kadawi, 2008, p. 28)

- **Future-oriented approach:** Since a feasibility study involves assessing the possibility of implementing an investment idea that may extend over an indefinite number of years, the environmental feasibility study shares this analytical nature. It is therefore a forward-looking study based on existing data, meaning that its content and results represent probable estimates with varying degrees of uncertainty.
- **Universality principle:** Such studies are characterized by general applicability and are required for all types of projects regardless of their objectives. They are necessary for public and private projects alike, as well as for industrial, agricultural, and service projects, among others.

- **Time factor:** The time element refers to the period between preparing the environmental feasibility study and obtaining the required permits and approvals from the relevant authorities, and the actual start of project implementation. The time required for the study varies depending on the type of project, its scale, and the quantity and quality of available environmental data.
- **Flexibility:** The environmental study is characterized by flexibility, as it is designed to suit different types of projects. Flexibility here refers to the ability to adapt and adjust study results when new variables emerge that were not previously considered. There is no fixed set of issues that must be addressed in every environmental study.
- **Effectiveness:** The environmental feasibility study is highly effective because its results are made available at an early stage of project preparation. Even if preliminary, these results allow for a realistic assessment of alternatives that may be environmentally preferable.
- **Cost factor:** The cost of preparing an environmental feasibility study varies depending on the type of project, its size, its level of complexity, and the nature of the environmental data required for evaluation and impact assessment. Therefore, environmental studies impose additional financial costs on project developers.

Secondly. Reality and Prospects of Smart Agriculture Projects in Algeria

1. The Reality of Smart Agriculture in Algeria

Algeria is witnessing a strategic shift toward modernizing the agricultural sector through the "Economic Recovery Plan" and the revitalization of the "Green Dam," with a focus on digitalization and innovation. Despite the availability of land, smart agriculture faces complex technical challenges, particularly in arid regions, including water scarcity, soil degradation, and weak energy infrastructure in rural areas, in addition to the high cost of modern technologies.

To address these gaps, there is a growing need to expand the use of solar energy and develop platforms for crop monitoring via satellite systems. In addition, improving value chains and reducing agricultural waste through the establishment of processing and cooling units close to production sites is considered a crucial step in supporting food security.

As for desert agriculture, it is considered the most important axis of economic foresight due to the availability of groundwater and high solar radiation, which requires incentive policies such as tax exemptions and simplified contracts. In response to climate change, Algeria is adopting the "Climate-Smart Agriculture" (CSA) approach to increase productivity and enhance adaptation. The outlook toward 2030 remains

promising, provided that effective coordination between the public and private sectors is achieved and national innovation is properly leveraged. Algeria has witnessed a strategic shift toward smart agriculture to enhance food security, with the agricultural technology market expected to grow to over 5.8 billion USD by 2028. These technologies such as the use of drones and smart irrigation systems contribute to increasing crop productivity by approximately 21% to 28%, and reducing water consumption by around 35%, while the agricultural sector accounts for 14.7% of the gross domestic product (GDP). (Agriculture, 2026)

2. **Key Statistics and Indicators of Smart Agriculture in Algeria:**

- **Market size:** The value of Algeria's agricultural market was estimated at $4.64 billion in 2023, and it is expected to reach $5.82 billion by 2028, with an annual growth rate of 4.65%.
- **Production growth:** The overall agricultural market is expected to grow and reach $40.95 billion by 2030.
- **Production efficiency:** Artificial intelligence and precision agriculture technologies can increase crop yields by 21–28%.
- **Resource management:** Smart irrigation systems contribute to reducing water waste by 35% and reducing the use of chemical inputs by 12%.
- **Sector contribution:** The agricultural sector accounts for 14.7% of GDP and employs approximately 2.7 million workers.

Algeria aims to increase agricultural productivity and modernize the sector to cope with climate change, with the potential to produce up to 30 million tons of cereals annually using modern technologies. (Rezki, 2014, p. 4)

3. Main Challenges and Obstacles of Smart Agriculture in Algeria

Algeria faces a strategic imperative to transition toward smart agriculture as an unavoidable option to address climate change and ensure sustainable food security. However, this vision is confronted with a set of structural and technical challenges that can be summarized as follows:

3.1 Technical and Infrastructure Challenges

- **Digital infrastructure fragility:** There is an urgent need to strengthen the telecommunications infrastructure and expand high-speed internet coverage, as it represents the backbone for operating monitoring and remote-control systems.
- **Development of production systems:** Traditional practices suffer from a lack of available information tools for farmers, which requires the use of modern technologies to transform large farms into units managed through smartphone applications.

- **Modernization of protected agriculture:** There is a need to shift toward smart management of greenhouse farming and its related logistical systems in order to increase productivity.

3.2 Human and innovation-related obstacles

- **Research–practice gap:** There is a need to activate scientific research activities and valorize national capacities to design local technological solutions adapted to the Algerian environment.
- **Integration of youth and innovators:** Young project holders and innovators face difficulties in effectively entering agricultural investments, which requires guidance and close support to transform their ideas into productive economic projects.
- **Training and capacity building:** There is a need to raise the digital awareness of traditional farmers to facilitate their adoption of smart transformations in daily practices.

3.3 Regulatory and investment constraints

- **Investment climate:** Lack of a clear incentive policy to attract additional domestic and foreign investments specialized in precision agricultural technologies.
- **Bureaucracy and facilitation:** Insufficient administrative facilitation mechanisms to enable innovators to access agricultural land and develop production systems flexibly.
- **General policy framework:** The need to create a favorable political and legislative environment that encourages investment in the agricultural knowledge economy and provides legal and financial protection for farmers engaged in digital transformation.

3.4 Challenges of international cooperation

- **Technology transfer:** There is a necessity to establish international partnerships with leading countries to exchange expertise, transfer successful smart agriculture models, and adapt them to the national context. (Bouabdelli & Gharbi, 2023, p. 325)

Thirdly. Technical and Environmental Feasibility Assessment of a Proposed Smart Agricultural Project in the Desert Environment of Adrar Province

The agricultural sector in Algeria represents a strategic pillar for achieving food security and diversifying economic resources beyond the hydrocarbons sector. However, this sector faces increasing structural and environmental challenges, most notably water scarcity and rising production costs associated with material and human resource inefficiencies. In this context, smart agricultural irrigation systems based on Internet of Things (IoT) technologies emerge as leading technical

solutions aimed at digitizing agricultural practices and transforming them from traditional, unstructured farming into precise smart agriculture systems.

1. Presentation of the Project Under Study

This project involves establishing a smart farm for vegetable production (tomatoes and peppers) in the Algerian desert environment, specifically in Adrar Province, over an area of approximately 10 hectares. This province was selected based on several scientific and technical considerations that make it a suitable environment for the implementation of smart agriculture systems, despite its harsh desert conditions. The region is characterized by the availability of deep groundwater resources, particularly from the large aquifer system, as well as vast areas of non-agricultural land that allow for the expansion of modern agricultural projects. In addition, the dry climate and low rainfall, although challenging, provide a strong incentive for adopting smart irrigation technologies aimed at rationalizing water consumption and achieving maximum efficiency.

Furthermore, the high solar radiation in Adrar represents a strategic advantage that can be exploited to power systems using solar energy, thereby reducing long-term operational costs. Accordingly, the selection of this location was not random but based on the principle of transforming environmental constraints into technological opportunities, which is the essence of smart agriculture in arid regions.

2. Farm Setup and Construction (Technical and Analytical Perspective)

2.1 Soil Composition and Characteristics

Soil is considered a complex living system formed through the interaction of parent rock with environmental factors, topography, and time. An ideal soil is composed of 45% mineral materials, 25% water, 25% air, and 5% organic matter, (Gurpal, Toor, Amy, & Shober, 2019, p. 1):

Soil properties vary according to differences in formation conditions. They include physical properties such as texture and porosity, which affect drainage and water retention; chemical properties such as pH and cation exchange capacity (CEC), which control nutrient availability; and biological properties related to organic matter and microbial activity. Soil study is of great importance in agriculture, as it helps improve crop selection and optimize irrigation practices. It also plays an environmental role in filtering pollutants, and an urban engineering role

in ensuring the stability of structures by understanding soil density and compressibility. (Wijmini, 2025, p. 1)

Based on the previously provided information, the farm preparation process begins with the land preparation phase, which includes clearing the land of impurities and conducting a comprehensive soil analysis in terms of pH levels.

2.2 **PH Level**

In Adrar, soils tend to be alkaline (pH > 7.5) (alkali soil) and are characterized by a high level of exchangeable sodium percentage (ESP > 15%). This leads to soil particle dispersion, poor drainage, and the formation of a dark or hard surface layer (salt crust). Such soils hinder the growth of most crops due to poor aeration and reduced nutrient uptake. They can be improved by adding agricultural gypsum, sulfur, organic matter, and by enhancing drainage systems.

The acceptable pH range for agricultural soils in Adrar should be between 5.5 and 7.0 (slightly acidic to neutral).

2.3 Salinity (EC – Electrical Conductivity)

Soil salinity refers to the presence of dissolved salts in the soil or soil water at levels that negatively affect plant growth. It is a widespread global phenomenon, with affected areas estimated at approximately 3.23 million square kilometers. Salinity may occur naturally or as a result of human activities such as uncontrolled irrigation and vegetation removal. It affects plants by reducing the roots' ability to absorb water due to decreased osmotic potential, causing ionic toxicity from elements such as sodium, chloride, and boron, as well as hindering nutrient uptake. Soil salinity is commonly measured using electrical conductivity (EC), which reflects salt concentration, as EC values increase with higher salinity levels. It can also be assessed through total dissolved solids (TDS) or by analyzing ions such as Na^+, Ca^{2+}, and Cl^-. These measurements can be taken in the field using electromagnetic induction (EM) techniques or in laboratories through soil solution analysis, with temperature correction required for accurate readings. This allows for a precise assessment of the impact of salinity on agricultural production. (Marcus & Richard, 2021, p. 416)

Tomatoes and peppers are sensitive to high salinity levels. If the value increases, the system should trigger a "soil flushing" action by increasing the programmed irrigation volume. The acceptable soil salinity level (EC) in the Adrar region should be below 2.5 dS/m.

2.4 Cation Exchange Capacity (CEC):

Cation Exchange Capacity (CEC) refers to the soil's ability to retain positively charged nutrients and prevent their loss through leaching,

making it one of the most important indicators of soil fertility. The CEC value mainly depends on the soil's clay and organic matter content, with organic matter playing a particularly crucial role in sandy soils.

The acceptable value should be higher than 25 cmol(+) kg^{-1}. However, sandy soils in Adrar usually have low cation exchange capacity (CEC) values; therefore, the addition of organic matter is recommended to improve this property. (Vladimir, 2023, p. 117)

2.5 Soil Temperature:

The acceptable soil temperature range should be between 18°C and 28°C. In Adrar, soil temperature may exceed 35°C, which represents a major challenge. This is where the usefulness of the DS18B20 sensor becomes evident, as the system can activate light "cooling irrigation" to protect plant roots.

The DS18B20 sensor is among the sensors used to measure soil temperature, and the following table illustrates the temperature range within which this sensor can operate:

Table N02.The operating parameters of the DS18B20 sensor

Parameter	DS18B20	Units
Supply Voltage	3–5.5	V
Resolution	9–12	bits
Measure Range	−55 to +125	°C
Thermometer error −10 °C to 85 °C	± 0.5	°C
Thermometer error −30 °C to −10 °C	± 1	°C
Stand by current	750	nA
Active current	1	mA
Communication protocol	1 wire	
Cost (stainless steel shell) (2019)	2	€

Source: (Jose, Luis, Elvira, & Rafael, 2020, p. 3)

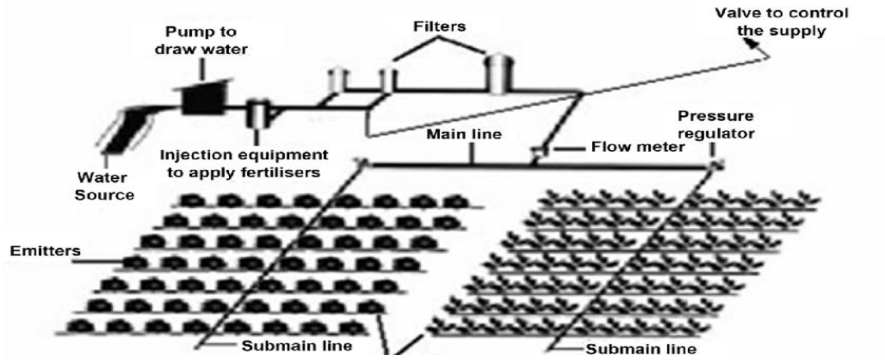
3. Drip Irrigation Network Design

Drip irrigation technology is considered one of the most efficient and sustainable modern irrigation systems in agriculture. It works by delivering water directly to the plant root zone in small and regular amounts through a network of pipes and filters, thereby reducing losses caused by evaporation and surface runoff compared to traditional irrigation methods. This system is characterized as a pressurized irrigation network that relies on a pump to distribute water at low to medium pressure. Water is released at flow rates ranging from 2 to 20 liters per hour depending on the type of plant and its water requirements. Studies have shown that drip irrigation can achieve water use efficiency of up to 95%, with water savings of up to 80% compared to conventional irrigation methods, in addition to improving crop yields such as tomatoes and cucumbers. The system can also be automated using timers

and sensors, which reduces human effort and improves irrigation management accuracy. This makes it particularly suitable for regions suffering from water scarcity or high-water costs, and an effective option for achieving sustainable agriculture and enhancing food security. (Barsha, Rahul, & Subrata, 2023, p. 12)

As shown in the following figure:

Figure N01.Schematic Layout of a Drip Irrigation System



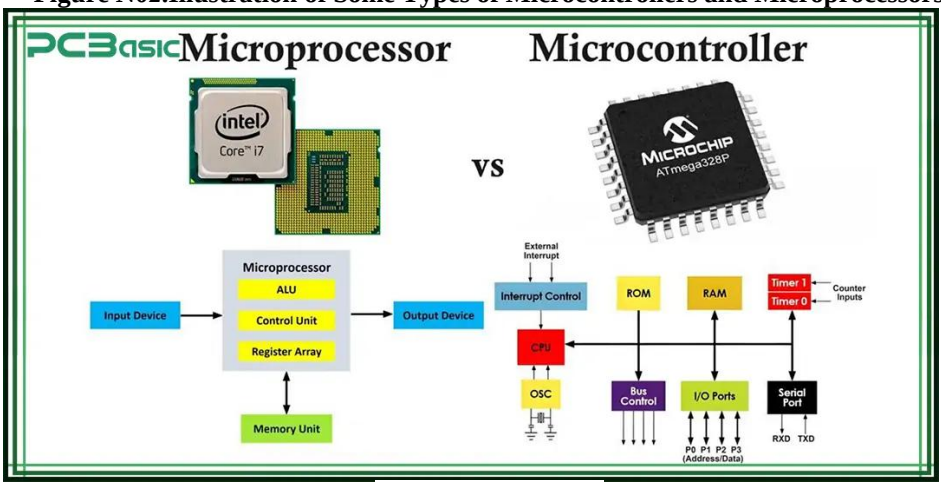
Source: (Elheesin & Zhongming , 2019, p. 1136)

4. Installation of a Smart Control System in Agriculture

The field of the Internet of Things (IoT), embedded systems, and smart home applications is witnessing rapid development, directly linked to advancements in electronic hardware and microprocessors. The ESP32 controller is currently one of the most widely used and popular chips, representing an advanced evolution of the ESP8266. It features integrated Wi-Fi and Bluetooth connectivity, along with a high-performance dual-core processor operating at up to 240 MHz, as well as internal memory and expandable external memory support. It also includes a large number of GPIO pins and supports multiple communication protocols such as SPI, I2C, UART, and Ethernet, in addition to built-in sensors such as a temperature sensor and a hall-effect magnetic sensor. Furthermore, it supports encryption and hardware acceleration technologies such as AES, RSA, and SHA, making it suitable for secure applications. Various companies offer different versions of this controller, including Espressif, SparkFun, and Adafruit, which has expanded its use across multiple fields such as environmental monitoring, solar energy systems, healthcare, gas leakage detection, industrial systems, and robotics. The ESP32 is widely used as a data acquisition system or as a web server in IoT applications due to its low cost, high flexibility, and strong real-time communication and processing capabilities. (Marek, Peter, & Pavel, 2019, p. 2)

As shown in the following Figure No. (02):

Figure N02.Illustration of Some Types of Microcontrollers and Microprocessors

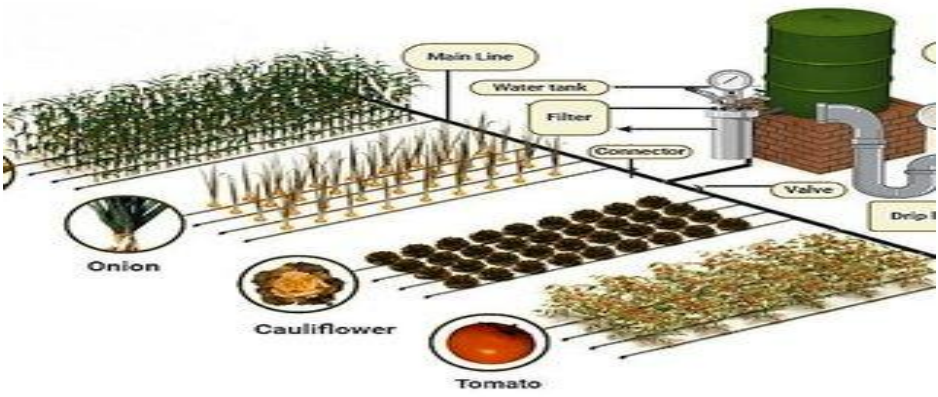


Source: (John, 2026)

5. Dividing the Farm into Multiple Irrigation Zones

The use of electric valves and smart pumps enables the farm to be divided into multiple irrigation zones, each controlled independently, representing a significant advancement compared to traditional systems that rely on non-targeted, uniform irrigation. This division helps improve water distribution according to the needs of each part of the farm. (Siham, Amraouy, & Mohammed, 2026, p. 10) In the following figure, we present a model of a farm based on a multi-zone drip irrigation system:

Figure N01.Illustration of Multiple Drip Irrigation Zones



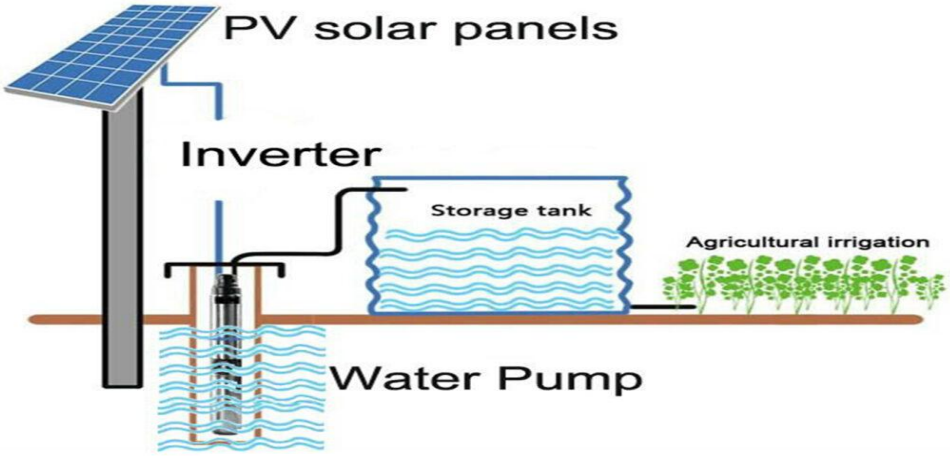
Source: (Biswajyoti, Santosh, Aritra, & Denil, 2024, p. 743)

6. Reliance on Solar Energy

Irrigated agriculture worldwide relies heavily on surface and groundwater resources. Although it covers less than 20% of agricultural land, it accounts for more than 40% of global food production, while the agricultural sector consumes around 70% of total freshwater use globally, a significant share of which comes from groundwater. With the global population expected to reach 10 billion by 2050, alongside the impacts of climate change, pressure on water resources is increasing, making it necessary to adopt sustainable and climate-resilient irrigation strategies.

In this context, solar-powered irrigation systems emerge as an innovative solution that combines water and energy efficiency, enabling reliable water pumping without dependence on fossil fuels, thereby reducing costs and carbon emissions by up to 95–97%. The following figure illustrates the system components:

Figure N01.Components of a Typical Solar Irrigation System



Source: (Solar Water Pumping Systems, 2026)

These systems also contribute to improving agricultural productivity and reducing its variability, while supporting food security and rural development, especially in remote areas with limited access to electricity such as the Algerian Sahara. Technological advancements have significantly improved the efficiency of solar panels and reduced their cost, making these systems more viable and widespread. This is further enhanced by their integration with smart irrigation systems, which enable remote monitoring and control, improve water use efficiency, and increase crop productivity.

Conclusion

In light of what has been addressed in this study, it can be confirmed that the adoption of smart agriculture technologies, particularly those based on multi-zone irrigation systems, represents a promising technical option for improving the efficiency of agricultural resource utilization in desert environments. This study focused on assessing the technical feasibility of a hypothetical agricultural project aimed at cultivating tomatoes and peppers over an area of 10 hectares in Adrar Province. The results showed that the integration of smart sensors, microcontrollers, and automated control systems enables precise irrigation management according to plant needs, soil conditions, and climate factors, thereby contributing to reducing water waste and improving agricultural growing conditions.

The study also demonstrated that the multi-zone irrigation system provides high flexibility in water distribution by adapting to soil characteristics and crop types, making it suitable for the harsh conditions of desert regions. The applied results indicated that, when supported by IoT technologies, this system can achieve a high level of operational efficiency and real-time control, which enhances agricultural production stability. However, it should be noted that this study was limited to the technical aspect and did not provide a detailed analysis of economic dimensions, particularly operational and production costs, which represents one of its limitations and opens the way for more comprehensive future research.

Study Results

The study identified several key theoretical and practical findings, the most important of which are as follows:

- Smart agriculture represents a modern transformation in agricultural system management by relying on digital technologies to enhance resource efficiency, particularly in arid and challenging environments.
- The technical feasibility of smart agricultural projects depends largely on the compatibility of system components (sensors, controllers, and communication networks) with local environmental conditions such as soil and climate.
- The proposed project in Adrar Province (10 hectares for tomato and pepper cultivation) demonstrates strong technical feasibility and applicability under desert conditions.

- The use of smart sensors and microcontrollers enables real-time monitoring of soil parameters, which significantly improves the accuracy and efficiency of irrigation and agricultural decision-making.
- Multi-zone smart irrigation systems contribute to reducing water consumption compared to traditional irrigation methods, making them highly suitable for water-scarce regions.

Recommendations

- Conduct further comprehensive studies incorporating economic feasibility, particularly operational costs and expected returns, to complement the technical and environmental assessment.
- Promote the adoption of multi-zone smart irrigation systems in desert and semi-arid regions to improve water-use efficiency.
- Strengthen digital infrastructure to support the implementation and scalability of smart agriculture technologies.
- Provide training programs for farmers to enhance their skills in using smart irrigation systems, sensors, and modern agricultural technologies.
- Encourage investment in smart agriculture projects, especially those focused on high-value crops and sustainable production systems.

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