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*Review Article*

# Smart Agriculture and Modern Methods of Data Analysis as Tools for Agricultural Sustainability: A review Study

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Abstract

Smart agriculture is an agricultural practice that uses sustainable methods to meet the growing food needs of the population. It also aims to develop, improve, and sustain the agricultural production system. On the other hand, the integration of modern information and communications technologies used in agricultural machinery and equipment, remote sensors, global positioning systems, and modern agricultural methods, which would increase productivity and quality without depleting natural resources, such as smart irrigation and precision agriculture, led to the development of smart agriculture. Moreover, agricultural practices also need to change because the climate is changing, so it has become necessary to implement more sustainable agricultural practices, to mitigate the pace of severe climate changes, whose goal is to improve the quality of the final agricultural product, increase productivity, and enhance the efficiency of resource use and the effectiveness of agricultural production systems, from point of view the cost. Smart agriculture currently depends on data generated from the Internet of Things devices in real time, geospatial data, and previous and historical information. However, employing big data analysis methods requires significantly diverse skills and deeper knowledge compared to what many possess, such as farmers, agricultural engineers, and graduates of agricultural colleges, which constitutes an obstacle to using this data effectively in making decisions in the agricultural field, etc. This study aimed to summarize and provide insight into smart agriculture tools and modern methods used to analyze data for several agricultural applications, with the aim of applying both smart agriculture methods and modern data analysis depending on the desired goals.

**Keywords**: Sustainability, smart agriculture, smart irrigation, Internet of Things (IoT), precision agriculture, machine learning

## 1. Introduction

Twenty-first- century agriculture must be resource efficient and sustainable in order to ensure a high level of food security and a reliable supply of energy and renewable materials for a growing global population. Currently, approximately 12%

of the global land area is used for crop production (FAO, 2024), and technological innovations, increasing demand for agricultural products, limited (and in some cases declining) availability of arable land, water scarcity, and climate change have intensified agricultural production (Rudel et al., 2009). Agricultural practices also need to change, because the climate is changing, so it has become necessary to implement more sustainable agricultural practices, to mitigate the pace of severe climate changes, whose goal is to improve the quality of the final agricultural product, increase productivity, and enhance the efficiency of resource use and the effectiveness of agricultural production systems, from In terms of cost (Rizkallah, 2020), shown that the sensitivity of agriculture to climate change is an important area of research in the current time, as it is expected that 20% of the damage resulting from climate change will occur in the agricultural sector at the global level (Zaied, 2013). On the other hand, humanity faces a major challenge, which is how to increase agricultural production to achieve food security in the coming years and feed the population (Delgado et al., 2019). Food shortages are linked to population growth, along with some social and economic factors (Slavin, 2016). On the other hand, FAO (2009) estimated that the population growth increase will be more than 30% by the year 2050. This leads to a rise in demand for food, which means it is necessary to achieve an increase in crop production by 60% to 100% by year 2050, to meet the nutritional needs of the future population, which will number from 9 billion to 10 billion people (Delgado et al., 2019; Kamilaris et al., 2017). In turn, this must be done while maintaining sustainable agricultural systems while at the same time confronting challenges such as climate change, depletion of water resources, and the potential for increasing soil erosion and loss of productivity due to the occurrence of extreme climate events (Delgado et al., 2019).

Scientific research indicates that population growth may cause the depletion of non-renewable resources for energy and food, if the population increases too quickly, which could pose a threat to the ecosystem on earth, and with this expected large increase in population. Concerns are increasing regarding providing food, achieving food security for the Earth’s population, and preserving arable land, especially with the worsening problems of climate change, depletion of oil resources, and water and soil pollution. To keep pace with this steady increase, farmers must increase food production while preserving the environment and using natural resources rationally, but they cannot do this alone, and traditional agricultural methods do not enable them to do so (FAO, 2017). Hence, the researchers suggested accelerating the adoption of new sources of food. Such as vertical and laboratory farming, and the production of proteins from alternative sources. Such as microorganisms and modern technologies play a crucial role in helping to meet the growing food needs of the world’s population using data management and analysis systems and remote-control technologies. In addition to the use of technologies such as artificial intelligence, agricultural robots, and the internet of things, in order to make agriculture more productive and profitable, less harmful to the environment, and less consuming of the earth's resources. On the other hand, these technologies fall under the concept of smart agriculture, which can be defined as a system that relies on advanced technology in agricultural production processes in sustainable and clean ways and rationalizes the use of natural resources, especially water and soil. One of its most prominent features is its reliance on information management and analysis systems to make the best possible agricultural production decisions at the lowest costs, as well as the automation of agricultural operations such as irrigation through smart irrigation methods, pest control, soil monitoring, and crop monitoring.

Recently, information and communication technology has developed rapidly, which has had a significant impact on agriculture and has the potential to solve food shortage problems (Kamilaris et al., 2017). To face the increasing challenges of the shortage of agricultural products, it is necessary to understand the working mechanisms of agricultural systems in their various forms, to improve and develop them, and this can happen through modern digital technologies, which monitor such systems continuously. These digital technologies, such as sensors, remote sensing systems, the (IoT), navigation and location systems, etc., have opened many new opportunities for automating agricultural operations. On the other hand, these and other technologies produce large amounts of data at an unprecedented pace, and analyzing this large amount of data would enable farmers and agricultural project owners to extract information that can be used and make appropriate decisions. Although the analysis of the large amount of data that has been done obtaining it previously or in real time has led to progress in various industries, it has not yet been widely applied in agricultural production processes, both plant and animal (Kamilaris et al., 2017). On the other hand, many methods and tools have been developed for analyzing big data in the past years, with the aim of facilitating its use. However, their application in the agricultural field requires somewhat different knowledge of these methods and experience, compared to what agricultural engineers and other workers in the field possess. In the field of agriculture, the problem is exacerbated because many of them are not specialized engineers, which limits the possibilities for the effective application of smart agriculture. Therefore, it is important that workers in the agricultural field and graduates of agricultural colleges have sufficient principles and information about the different methods of data analysis (Evstatiev and Gabrovska-Evstatieva, 2020).

Therefore, this study aims to conduct a review of smart agriculture methods to sustain agricultural production processes, both plant and animal, and address common methods for analyzing agricultural data, as well as the field of their application, and determine the characteristics of data analysis to facilitate agricultural specialists when choosing the appropriate method, based on the desired goals.

## 2. Sustainable agriculture and its importance

Sustainable agriculture is the wave of the future and sustainability has many facets. Environmental sustainability, for example, means good management of the natural systems and resources on which farms depend. This includes building healthy soil and preventing erosion, managing water wisely, reducing air and water pollution, increasing resilience to extreme weather conditions, and enhancing biodiversity. An economically and socially sustainable agricultural system is one that enables farms of all sizes to be profitable and contribute to their local economies. Such a system supports the next generation of farmers, deals fairly with labor, promotes equality and justice among workers, creates access to healthy food for all, and prioritizes people and communities over corporate interests.

Sustainable agriculture is defined as an agricultural system that aims to preserve the best resources used in agriculture and farming communities by promoting agricultural practices and methods that are profitable, environmentally sound, and beneficial to them. Sustainable agriculture is compatible with modern agriculture, through the use of the best modern agricultural techniques in producing crops and facilitating agricultural production processes. The concept also includes preserving the environment by using many useful methods that limit the degradation of agricultural lands, and they contribute to preserving the survival of agricultural lands and their resources for the longest period. Possible time frame (SAER, 2024). The importance of sustaining agriculture is to meet the population's requirements for agricultural crops and livestock, and with the emergence of many problems in the agricultural environment, such as the deterioration and dryness of the surface soil, groundwater, and air pollution, the use of chemicals in agriculture, and a shortage of irrigation water, energy, and others, this has led to the difficulty of agriculture. In light of many obstacles, including physical and climatic ones, researchers must search for new and sustainable ways to preserve the agricultural environment and meet the increasing demand for food. Whereas in the study of Abdelhakim and Helal (2022), they found that creating smart scheduling for open hydroponic farming systems increases the water use efficiency of the cucumber crop in an agricultural greenhouse by creating and building a smart control unit based on wireless communication technology based on sensing a specific level. For moisture in the growth medium (sand), after adding materials that retain water for long periods to the growth medium, such as composite material, which contains 90% Aswan clay and 10% hydrogel and perlite, compared to sand only. The agricultural practices shown in Figure (1) have proven effective in achieving agricultural sustainability, especially when used together.

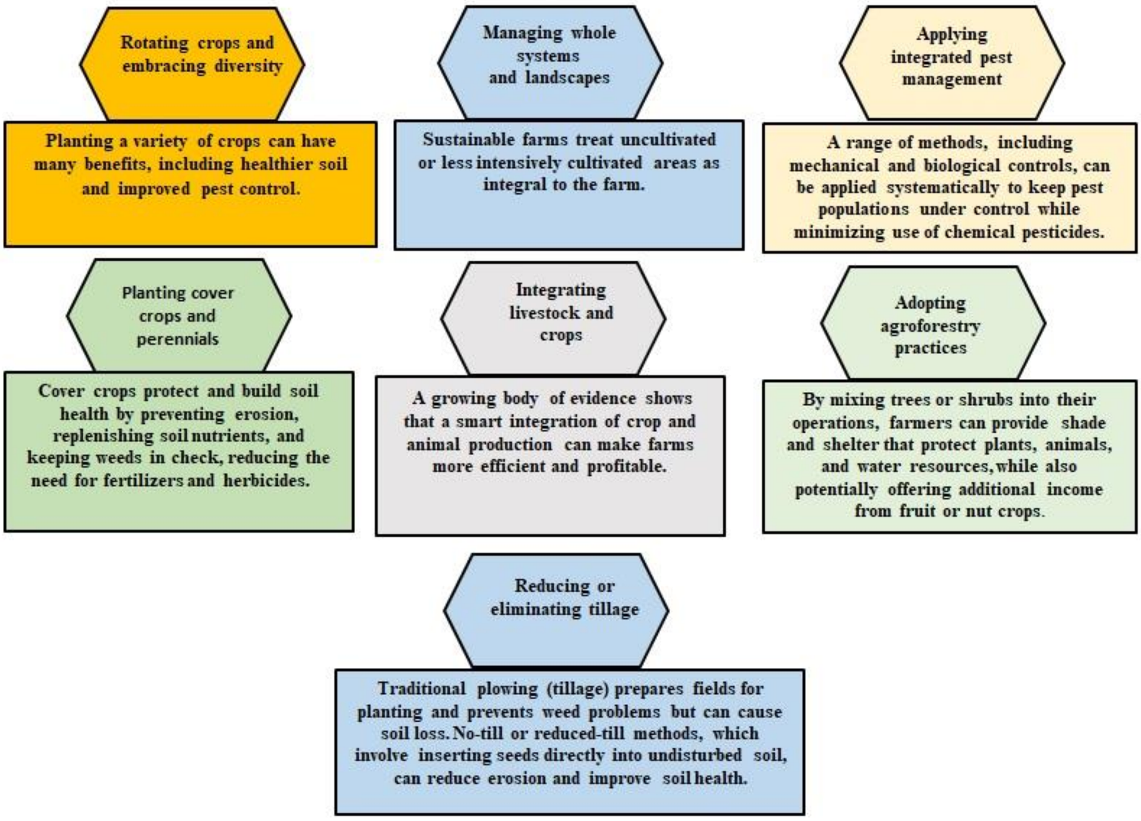


**Figure (1). Sustainable agriculture practices (Union of Concerned Scientists, 2017)**

The application of smart agriculture is increasingly becoming a decisive force in transforming traditional methods of agricultural production in most countries of the world. This change, based on technological innovation, is necessary to enhance the sustainable production system on farms, whether large or small (Hu et al., 2023), knowing that the use and analysis of big data is one of the keys to creating a modern farm, and in return it is to develop a smart farm and maintain smart on soil and water, as proposed in Wolfert et al. (2017) (Figure 2), the conceptual frameworks for smart farm and smart soil and water conservation focus on a cyber-physical management cycle built on a cloud-based infrastructure that manages all farm operations. There are multiple tools to make the farm smart.

There is specific equipment for smart agriculture (Dhanaraju et al., 2022), such as the (IoT), including smart sowing equipment, smart spraying, and smart tillage equipment. Network-controlled machines belonging to the assembly and operation office for real-time monitoring and analysis are shown in Figure (3). An online application was developed to promote the idea of smart agriculture that would perform fast and high-quality agricultural operations, enhance income, and significantly reduce product expenses. This computer application would allow estimation of the economic cost and feasibility of using combined harvesters to harvest grains, as the results showed that the economic feasibility estimated by the web-based application provides more relevant data. The web-based application is a useful tool for farmers and businessmen to estimate the economic feasibility and feasibility of harvesters, allowing better decision-making and improved management processes (Akter et al., 2024).

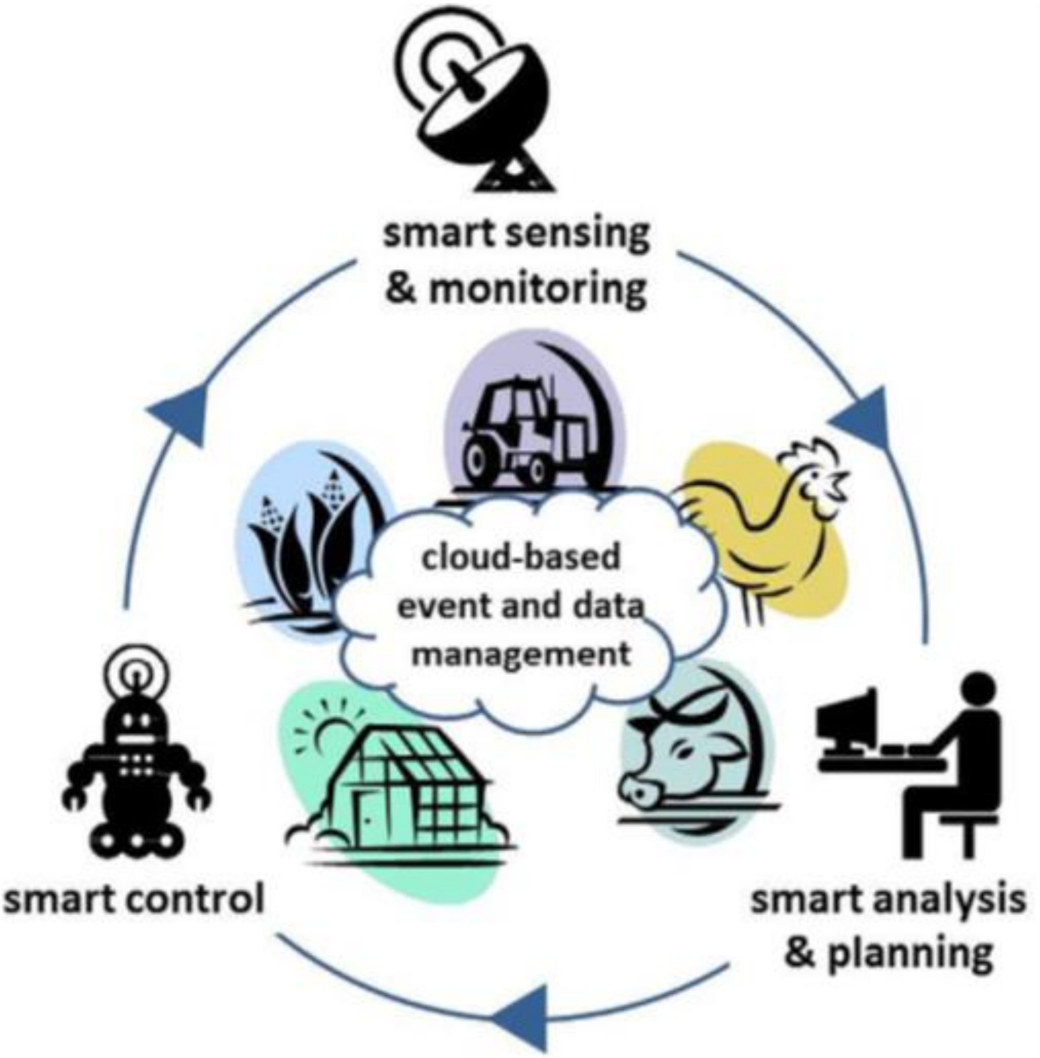


**Figure (2). A framework for a smart farm (Wolfert et al., 2017)**

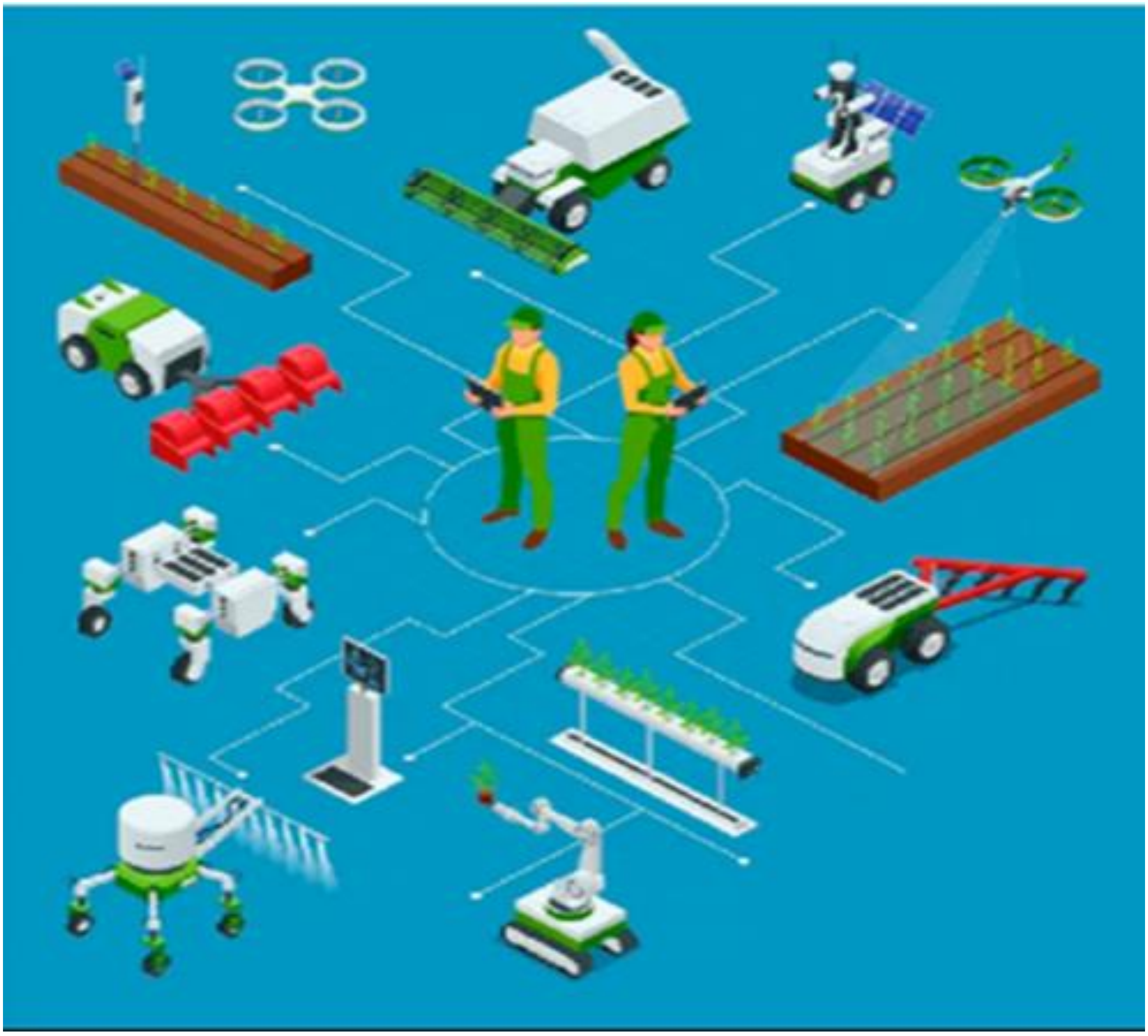

**Figure (3). Smart agriculture tools (Hu et al., 2023)**

**3. Modern and smart farms and their requirements**

Over the past decade, the increasing use of information and communications technology (ICT) in agricultural applications has defined the concept of precision agriculture or its equivalent smart agriculture. In this regard, recent advances in the field of connectivity, automation, image analysis, and artificial intelligence allow farmers to monitor all stages of production and, with the help of automatic procedures, identify better treatments for their farms. One of the main goals of the smart farming system is to improve field productivity. From this point of view, the (IoT) model plays a key role in precision agriculture applications since the use of IoT sensors provides accurate information about the health of production Gagliardi et al., 2021), (Figure 4). The general model of smart agriculture is shown in Figure (5). The components of smart agriculture that facilitate the integration, processing, and use of farm data are shown in Figure (6).

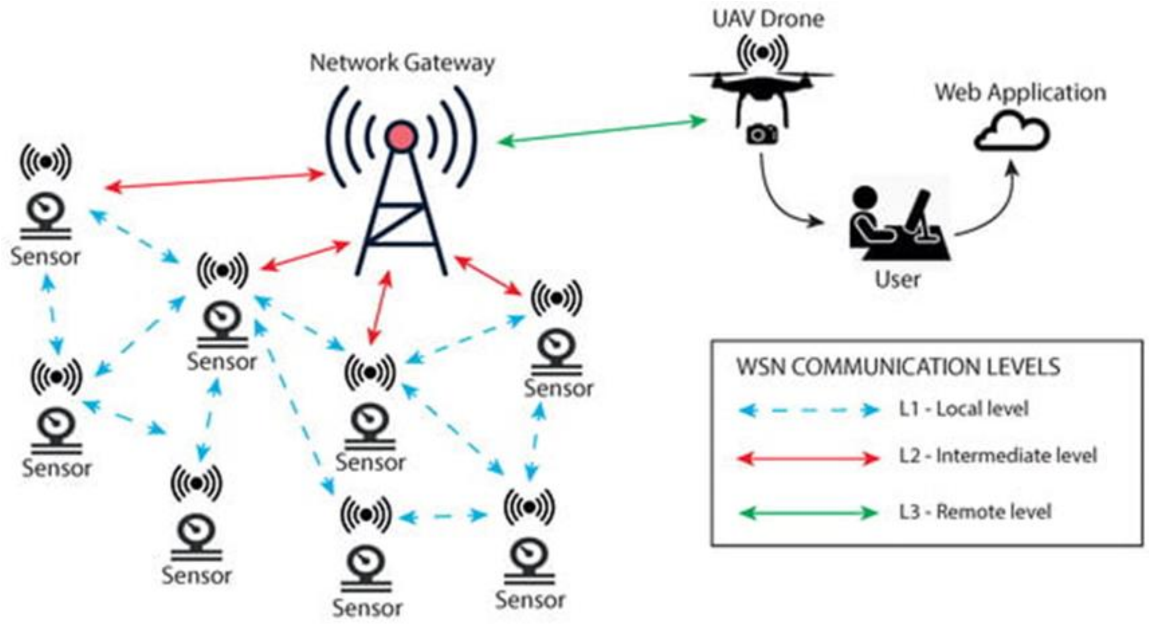


**Figure (4). Smart framework concept - system architecture (Gagliardi et al., 2021)**

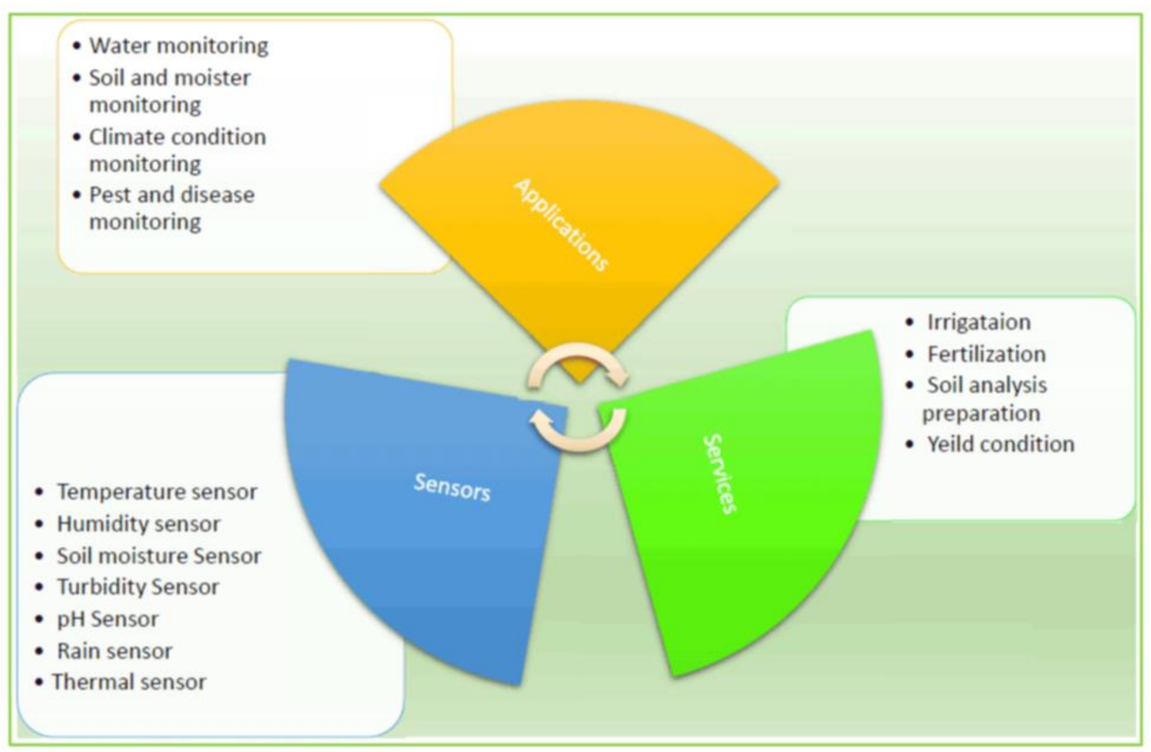


**Figure (5). General paradigm of smart agriculture (Rehman et al., 2022)**

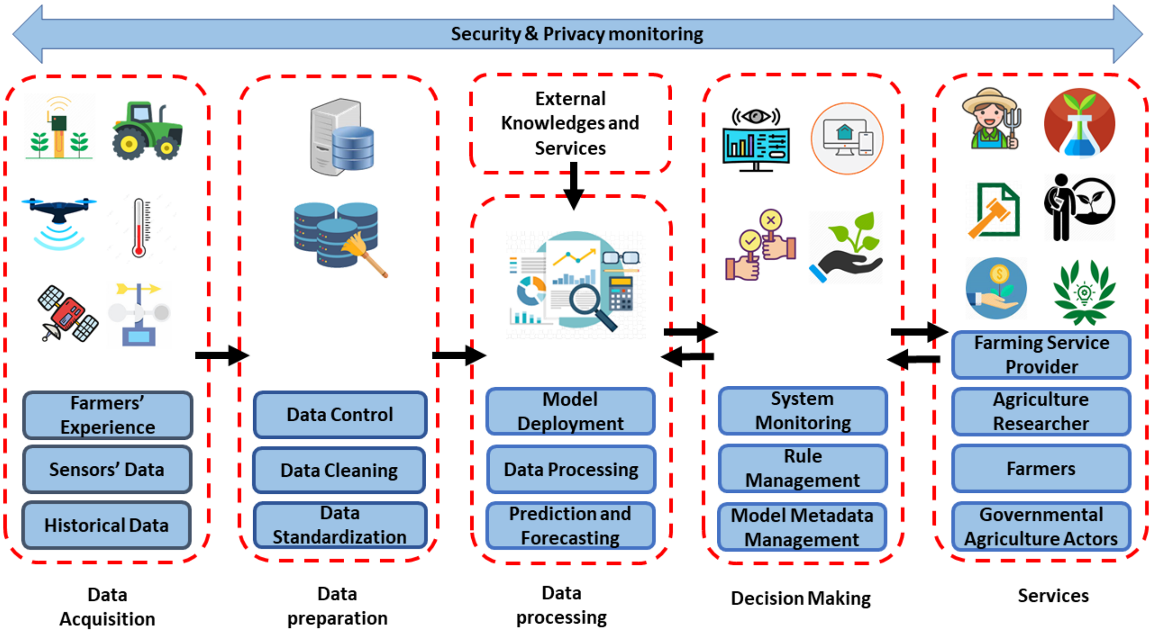


**Figure (6). Smart farming components that facilitate integration, processing, and use of farm data (Amiri-Zarandi et al., 2022)**

### 4. Smart irrigation systems

There are many smart irrigation tools that control irrigation operations that have been manufactured by interested parties are available and have been used for a long time (El Marazky, 2015). Riley (2005) explained that standalone controllers use sensors to sense and measure the weather condition, and then evapotranspiration (ETo) values are calculated based on the real time used to collect the data. These sensors collect readings daily according to the adjustment method to be used at intervals in any location. Therefore, it is clear that the concept of using weather information based on irrigation scheduling for various plants is not new, but transferring this technology to farmers is considered relatively recent (Devitt et al., 2008).

In a study evaluating two smart irrigation technologies, it was found that the highest value associated with saving added water was achieved with the use of ground humidity sensors, followed in terms of saving the amount of water used using irrigation controlled by evaporation and then treatment using seasonal meteorological data (Nautial, et al., 2010). El Marazky (2015) explained that using two types of automatic control technologies [SmartLine, SL-1600 (SL) and Hunter Pro-C (H)] with surface and subsurface drip irrigation systems compared to irrigation with the traditional irrigation system (control) on the basis calculated evapotranspiration (ETo) values using climate data from the weather station located at the study site. The results showed that there were significant differences in the amount of water added and crop productivity for the three irrigation scheduling methods. The results from the two-season analysis revealed that the smart irrigation technique using Hunter Pro-C (H) gave the highest percentage of water savings and an increase in tomato crop productivity with the highest water use efficiency compared to other irrigation scheduling methods. The results also showed that plant growth characteristics and irrigation water availability were significantly affected by the automatic control unit (Hunter) with the subsurface irrigation system. Thus, as a result of using the Hunter automatic control unit technology with the subsurface irrigation system, it provides significant advantages both in terms of yield and water use efficiency. In addition, the results indicated that the subsurface drip irrigation system gave the highest yield and highest water use efficiency compared to the surface drip irrigation system. Generally, these technologies can be recommended for automated irrigation systems, and the Hunter automatic control unit can contribute to maintaining water planning and irrigation scheduling for tomato crops, which is usable for other similar agricultural crops. There are also a variety of techniques to reduce irrigation water use that can be used by those interested in smart irrigation (McCready et al., 2009). These smart technologies include evapotranspiration control devices as well as soil moisture control using ground moisture sensors.

Muangprathu et al. (2019) developed an optimal irrigation system for agricultural crops based on a wireless sensor network with data management via smartphone and web application. The three components are hardware, web application, and mobile application (Figure 7). The first component is designed and implemented in connected control box devices to collect data on crops. Soil moisture sensors were used to monitor the field irrigation process and communicate with the control box. The second component is a web-based application designed and implemented to process details of crop data and field information. The application extracts data to analyze the data for predicting the appropriate temperature, humidity and soil moisture for optimal future management of crop growth. Irrigation is controlled manually or automatically. The results showed that work is beneficial in agriculture. The soil moisture content was maintained appropriately for vegetable growth, reducing costs and increasing agricultural productivity. Moreover, this work represents one of the methods of digital farming.

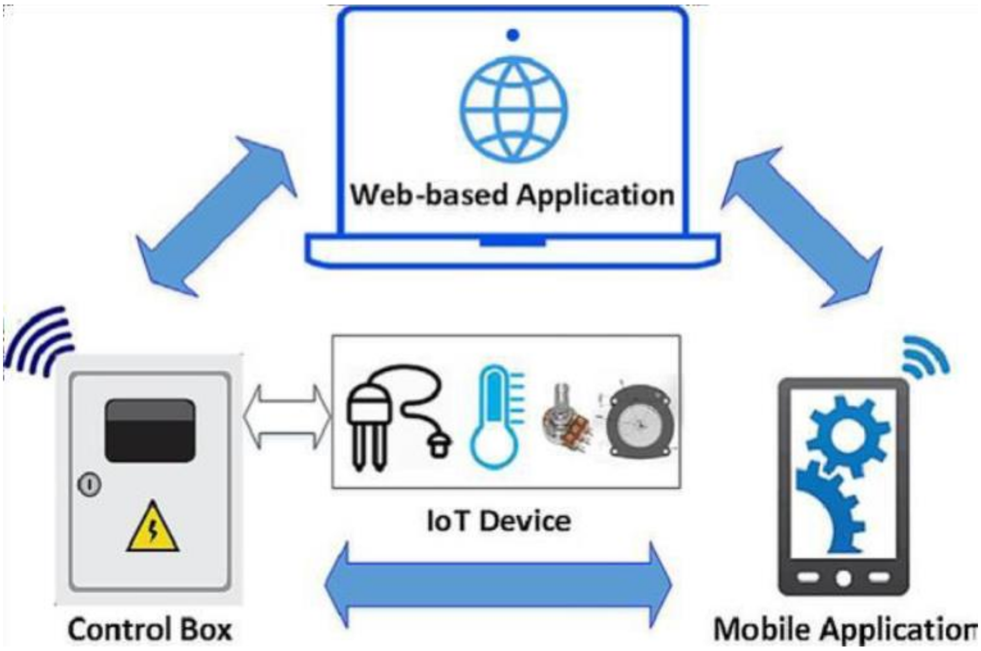


**Figure (7). A system for optimal irrigation of agricultural crops based on a wireless sensor network with data management via smartphone and web application (Muangprathu et al., 2019)**

Ndunagu et al. (2022) proposed a smart irrigation system using the drip method, which was designed and implemented using wireless communication technology, sensor networks, and an open source IoT cloud computing platform for data collection, storage, data analysis, and visualization (Figure 8). The electronic methodology involves the integration of hardware and software components and making irrigation decisions based on web resources such as weather forecasts and sensor values from the soil. The collected data is then analyzed on a dedicated server and updated every 15 minutes. Based on the threshold value, the system starts pumping water or stops irrigation according to the irrigation schedule. A web application has been developed to display the result so that we can monitor and control the system using the Android application or web browser.

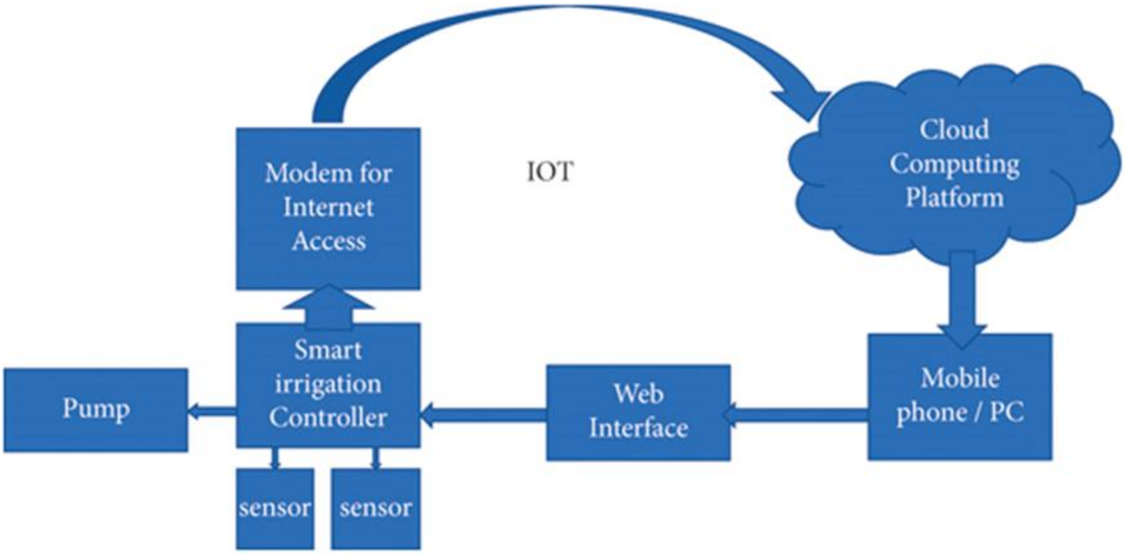


**Figure (8). IoT architecture designed for smart irrigation (Ndunagu et al., 2022)**

**5. Data series**

The term agricultural production refers to the production process by which a set of available agricultural production elements are transformed into agricultural commodities that can be directly consumed by their final consumers and other transformational operations are carried out for the produced goods by adding new productive elements in order for them to become suitable for consumption. The farm is considered the productive unit within the agricultural economic structure that produces various agricultural commodities, whether animal or vegetable, as a result of the decisions taken at the level of this unit related to the use of available resources to produce various agricultural commodities. In contrast, for farm management, data management activities are required to manage the farm, and they are shown in Figure (9), where the sequence of activities starts from data capture to decision making and data marketing (Miller and Mork, 2013; Chen et al., 2014).

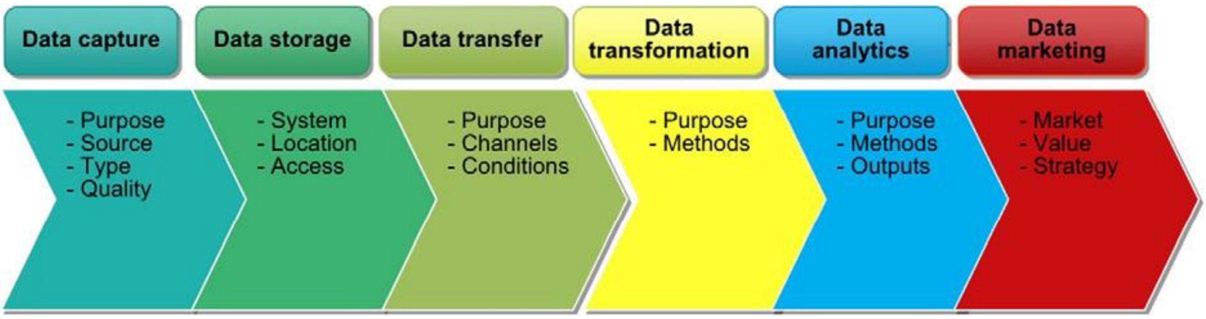


**Figure (9). The data chain of big data applications (Chen et al., 2014)**

**6. Analysis of agricultural data**

In light of the rapid development of computer and information technology, the amount of data that can be stored is increasing significantly, and the ability to store this data does not end there. This is where the most important step comes, which is how to invest in these huge amounts of data (Al-Jana'i et al., 2011). It can be said that this data represents real wealth that can be neglected, and it can also be invested in analyzing past events, and then policies and plans can be clearly drawn, which allows predicting opportunities for future improvement of the plans drawn up by an organization. With these huge amounts of data, traditional methods of data analysis, which are a combination of statistical methods and some computer systems designed to manage databases, are suffering from many problems in dealing with this type of data. In addition, these traditional methods are based in a way that relies entirely on the mental and technical capabilities of those responsible for it and then on the experience of the data analyst in directing the analysis to extract useful and profound indicators for decision makers. Where the analyst assumes previous hypotheses about the relationships that exist between the various variables of the data, and all he does after that is use the analysis to prove or refute these hypotheses (Al-Jana'i et al., 2011).

Artificial intelligence technologies have great potential when used in future prediction, serving as key elements within the framework of precision agriculture. These models and tools make use of different methodologies, including linear regression techniques, nonlinear simulation, specialized systems, pattern recognition, data analysis, decision making, automation, and artificial neural networks to predict various agricultural components. Data mining is the process of analyzing data from a different perspective, extracting relationships between them, and summarizing them into useful information through the use of a set of complex tools, and some of these tools include regular statistics tools and artificial intelligence (Ali, 2018). Data mining tools can be divided into direct and indirect data mining tools; The goal of direct data mining is to use available data to create a model with a description of the variables. The goal of indirect data mining is that there is no choice of a specific variable, in order to build a relationship between all variables. Classification, estimation, and prediction tools fall within direct data mining tools. As for the tools of association, clustering, description, and display, they fall within indirect data mining (Sayed, 2015). That is, the use of data mining is considered one of the important methods for extracting important and useful knowledge from big data in the agricultural field. This data can be obtained in real time or through previous data, and the process of extracting data with this method takes place in 4 steps as follows (Muangprathu et al., 2019):

**The first step** is pre-processing the data. This is an important step in the knowledge discovery process because the quality of knowledge depends on the quality of the data. In the real world, data tends to be inconsistent and incomplete. Therefore, this step can help improve the accuracy and efficiency of the information extraction process later. This step includes data cleaning, data integration, and data transformation.

**The second step** is data reduction. This step can encode data into a reduced representation with small numbers. So that the integrity of the original data is preserved so that mining the downsized data is more efficient while obtaining the same (or almost the same) analysis results.

**The third step** is data modeling/discovery, which extracts knowledge from previously prepared data. Mostly, data modeling/discovery applications use intelligent methods to identify patterns in data. Analysis tools can include classification, grouping, correlation, etc.

**The fourth step** is analyzing the results, which depends mainly on the third step.

The data mining process is concerned with two basic processes (Figure 10), which are descriptive mining and predictive mining. In descriptive mining, data analysis depends on reorganizing and mining the data to extract information from it, while predictive mining depends on data analysis using previous information to predict what will happen in the future. Time series analysis, classification, and regression are basic types of predictive mining. Classification is used to predict the discrete or symbolic value (descriptive variable). Classification is widely used in analyzing a set of data and placing it in the form of categories or sections that can be used later to classify the data in the future. Data mining tools can be divided into direct and indirect data mining tools; the goal of direct data mining is to use available data to create a model with a description of the variables; The goal of indirect data mining is that there is no choice of a specific variable, in order to build a relationship between all variables. Data mining tools such as classification, forecasting, and time series analysis fall within direct data mining tools. As for descriptive mining tools, such as correlation, clustering, description, and display, they fall within the tools of indirect data mining (Sayed, 2015)

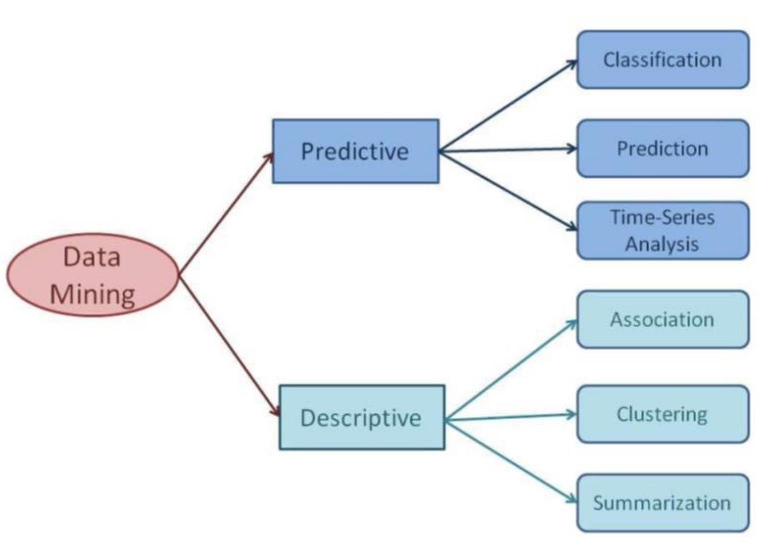


**Figure (10). Data mining tasks (Sayed, 2015)**

The cluster analysis method is considered one of the important statistical methods used in descriptive exploration, which relies on the analysis of specific variables based on points of similarity and difference between the data. Cluster analysis is used to classify and study collections of data, observations, or elements into groups that are homogeneous among themselves and different from the rest of the groups, based on a set of characteristics or variables. The clustering process means placing the elements in groups, that is, it represents obtaining one or more groups that include a number the elements that have a high degree of similarity to each other, and the process of obtaining these groups is done by dividing the total number of elements into groups, or each group includes a number of elements based on the similarity matrices. Among the tools used in descriptive mining are association rules, which are one of the most promising techniques in data mining tools as a tool for exploring knowledge. They have the ability to process huge numbers of data and allow the conclusion of all possible laws that explain some existing characteristics based on others (An et al., 2003), and several data mining tools can be applied in agriculture through different applications (Kodeeshwari and Ilakkiya, 2017).**Conclusion**

Twenty-first- century agriculture must be resource efficient and sustainable to ensure a high level of food security and a reliable supply of energy and renewable materials for a growing global population. Currently, approximately 12% of the global land area is used for crop production, and technological innovations, increasing demand for agricultural products, limited (and in some cases declining) availability of arable land, water scarcity, and climate change have intensified agricultural production. Over the past decade, the increasing use of information and communications technology in agricultural applications has defined the concept of precision agriculture or its equivalent smart agriculture. Advances in connectivity, automation, image analysis, and artificial intelligence allow farmers to monitor all stages of production and, with the help of automatic procedures, select better treatments for their farms. One of the main goals of the smart agriculture system is to improve field productivity. However, smart agriculture requires the use of big data analysis methods, and this requires significantly different skills and deeper knowledge than what many farmers, agricultural engineers, and agricultural college graduates possess, which constitutes an obstacle to using this data effectively in making decisions, etc. The study aimed to summarize and provide insight into smart agriculture tools and modern methods used to analyze data for several agricultural applications, with the aim of applying both smart agriculture methods and modern data analysis depending on the goals set.

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