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Application of wireless sensor networks in the field of irrigation: A review

Loubna Hamami*, Bouchaib Nassereddine

Computer, Networks, Mobility and Modeling Laboratory, Department of Mathematics and Computer, Faculty of Sciences and Technology, Hassan 1st University, Settat, Morocco

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ABSTRACT

Due to a series of issues raised in recent years, such as global water crisis, drought, and shortage of freshwater resources, researchers seek solutions to these problems by rationalizing water consumption in the agricultural sector as one of the most water-consuming sectors in the world. Wireless sensor networks (WSN) represent an exciting and important technology that has experienced significant development in recent years and can be applied in different areas of life; agricultural applications are one of the applications in which WSN is widely used and implemented successfully. The purpose of this paper is to review the application of wireless sensor networks in the field of irrigation. The use of WSN technology to control and manage irrigation systems is an ideal solution to ensure the efficient and rational use of water and thus contribute to reducing the severity of the global water crisis.

1. Introduction

The industrial revolution and recent advances in electronic technologies and wireless communications have led to the development of very smart small sensors with low-power and low-cost solutions. Sensor nodes appear as miniaturized autonomous systems, characterized by a lower price, a smaller size, and a wireless communication medium but with few resources. These nodes consist of a sensing unit, a processing unit, a transmission unit, and a limited power source (Akyildiz et al., 2002b; Tan and Panda, 2010; Matin and Islam, 2012). This fusion of integrated systems and wireless communications has also led to a particular type of ad hoc network, i.e., wireless sensor network, which helps us to change our lifestyle, work, and interact with our environment. WSN is often considered as a successor to ad hoc networks. It defines as a network of wireless devices, called nodes, which integrate processing, communication, and acquisition capabilities and communicate via wireless links. WSN collects a set of physical or environmental conditions in order to transmit them cooperatively and autonomously for treatment points to control a particular phenomenon (Akyildiz et al., 2002a; Tubaishat and Madria, 2003; Yick et al., 2008; Akyildiz and Vuran, 2010). Sensor network carries out three fundamental functions including: communication, detection and sensation, and computation and analysis (ur Rehman et al., 2014; Hamami and Nassereddine, 2018a), making it actively in the creation of smart environments (Tubaishat and Madria, 2003).

Agriculture is considered as the backbone of the economy in the world and is often the main source of income for many farmers around the world. Irrigation is a key factor for the agricultural sector, which is one of the most vital services in this sector. It is an important practice for most crops in areas with insufficient rainfall to meet the water needs of crops, as insufficient irrigation generally leads to a reduction in crop quality and yield (Baggio, 2005). Despite the important role played by the agricultural sector but some reasons seriously affect this sector, especially irrigation. The global water crisis (Hanjra and Qureshi, 2010; Damania et al., 2019) is a critical issue in the world that causes a severe decline in water resources and poses growing threats in recent years. It is noteworthy that freshwater supplies have been declining (Gleick, 2003; Brown and Matlock, 2017), which represents only about 2.5% of the total water on Earth where most of the water is stored as deep groundwater or glaciers and only a small amount of it is available for human use (Vörösmarty et al., 2000). Besides, among these reasons: climate change (Kalra et al., 2007; Ghosh, 2018), drought (Mishra and Singh, 2010), salinity risks, and water pollution. Furthermore, the agricultural sector is the most water-consuming activity in the world, especially for irrigation, with 70% of global water withdrawals (FAO, 2019). Globally, it is estimated that about 70% of the global water withdrawals and nearly 90% of the water consumed is used for irrigation service (Haddeland et al., 2014).

Wireless sensor networks have intrinsic characteristics at the level of sensor nodes and at the level of the network formed by these nodes (Tilak et al., 2002; Mishra and Thakkar, 2012; Manshahia, 2016; Hamami and Nassereddine, 2019), such as the possibility to apply WSN

* Corresponding author.
E-mail addresses: l.hamami@uhp.ac.ma (L. Hamami), nassereddine_bouchaib@yahoo.com (B. Nassereddine).

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in almost all types of environments whether in urban environments (Rashid and Rehmani, 2016) or rural environments (Lloret et al., 2009), WSN's dynamic topology, flexibility, self-monitoring, scalability, accuracy, and collaboration of sensor nodes with each other, which allows wireless sensor networks to involve in several application areas including agriculture, military, industry, home, and health (Chong and Kumar, 2003; Arampatzis et al., 2005; Stankovic et al., 2011; Mohamed et al., 2018). One of the promising application areas of WSN is agriculture where WSN technology offers significant support that will drive agriculture, thus irrigation, to a very positive direction and will offer efficient and economical solutions, as well as management and planning of an accurate and automated irrigation system with a high level of efficiency, automation, and precision (Wang et al., 2006; Ruiz-Garcia et al., 2009; ur Rehman et al., 2014; Kumar and Ilango, 2018).

The purpose of this paper is to provide a comprehensive review of the application and deployment of wireless sensor networks in the field of irrigation. The paper is structured as follows. Section 1 provides an introduction. Section 2 presents and explains the various aspects of sensors and wireless sensor networks. Section 3 provides an overview of the literature, followed by a synthesis of the survey on the WSN's various applications in the field of irrigation in Section 4. Section 5 discusses the application and use of wireless sensor networks in the field of irrigation. In Section 6, we present and discuss a methodology for implementing a smart irrigation system using wireless sensor networks. Finally, the paper concludes in Section 7.

2. Wireless sensor network technology

2.1. Wireless sensor networks

The proliferation of MEM systems (i.e., Micro-Electro-Mechanical) technology and the tremendous developments in wireless technologies in recent decades have provided and developed low-cost and energy-efficient smart sensors. These sensor nodes are autonomous, inexpensive nodes characterized by processing and computing capacities and miniature size.

The wireless sensor network is made up of numerous sensor nodes connected to each other through a wireless connection module. These nodes have a variety of abilities (e.g., processing, transmission, and sensation) so that they can be self-organizing and can be deployed precisely or randomly.

In a WSN, the sensor nodes are spread over the field (i.e., sensor field). Each node employs its capabilities to gather and route data in order to create a global view of the controlled field. The collected data is routed directly or via other sensors using a multi-step architecture to a collection point, known as a base station, for subsequent treatment. The base station can also serve as a gateway node whenever there is a need to communicate and connect with the external network for data analysis and decision-making (Akyildiz et al., 2002a; Tubaishat and Madria, 2003; Yick et al., 2008; Akyildiz and Vuran, 2010), as shown in Fig. 1.

2.2. WSN characteristics

Wireless sensor network is a particular kind of ad-hoc network, which achieves three fundamental functions:

- Sensing: The nodes gather the necessary data.
- Communication: The nodes communicate with each other and with the base station, and the base station can communicate with the console.
- Computing using algorithm, hardware, microcontroller, and programs.

Some of the main characteristics of the wireless sensor network (Mishra and Thakkar, 2012; Manshahia, 2016; Hamami and Nassereddine, 2019) are:

- A large number of sensor nodes (i.e., a few tens to thousands).
- Scalability: Regardless of the size of the network and the number of nodes deployed, the design of WSN protocols has been engineered to allow good implementation under different circumstances, whether with increased workload or with network growth (Zhao and Raychaudhuri, 2009), expanding WSN's potential for many applications.
- Property of adapting to different environments: WSN can adapt to a variety of environments so that it is often deployed in hostile environments where human intervention cannot be sustained continuously (Martinez et al., 2004).
- Heterogeneity of nodes deployed in WSNs.
- Advantages of detection and wireless communication.
- Dynamic topology: The topology of WSN is a dynamic topology with frequent changes, which causes many problems in the whole network (Li and Yang, 2006; Hamami and Nassereddine, 2019). Techniques for topology management and control (Ren and Meng, 2009; Li et al., 2013) allow better configuration of dynamic network topology so that good communication and collaboration between network sensors are established, as well as achieving improved communication topology (Hamami and Nassereddine, 2019).
- The WSN nodes cooperate among themselves to achieve a targeted objective, i.e., to make a final decision collectively (Wu et al., 2012; Yao et al., 2013; Hamami and Nassereddine, 2019).
- Little or no infrastructure.
- Ability to deal with node failures: The wireless sensor network is often subject to various environmental conditions due to its application in hostile or inaccessible environments (Hamami and Nassereddine, 2019). To overcome this, the WSN protocol stack incorporates techniques to manage and handle node failures under harsh environmental conditions.
- Ability to operate autonomously without supervision in remote or hostile areas.
- Simple to utilize.
- Limited power and storage capacity of sensor nodes.
- Fault tolerance: The wireless sensor network is subject to a range of sensor node failures such as environmental interference, battery depletion, and hardware component failure (Younis et al., 2014; Hamami and Nassereddine, 2019). By using fault tolerance strategies in WSN (Kakamanshadi et al., 2015), the fault tolerance feature aims to enhance the reliability and availability of WSNs.

2.3. Sensor nodes

The sensor node emerges as a miniature autonomous system with advanced sensation abilities, which constitutes the core unit of a WSN. A sensor node is considered a micro-electromechanical system that measures or detects physical or environmental attributes (e.g., emissions, pressure, humidity, and temperature) and converts them into signals for surveillance and control purposes (Hamami and Nassereddine, 2019).

A sensor node is composed basically of four basic units, a transmission unit, a sensing unit, a processing unit, and a power source (Akyildiz et al., 2002b; Matin and Islam, 2012), as shown in Fig. 2.

The sensing unit is the principal element of a sensor node. It generally comprises two sub-units: a sensor and an analog-to-digital converter (ADC) for measuring and converting data. The power unit supplies the power to all node components, which is a vital element of the sensor node. The processing unit offers cooperation with other nodes to perform appropriate tasks. It consists of a computer unit (processor) and a storage unit (memory). Moreover, the transmission unit establishes a connection between the sensor node and the WSN. It handles data transmission and reception in the network through a wireless medium.

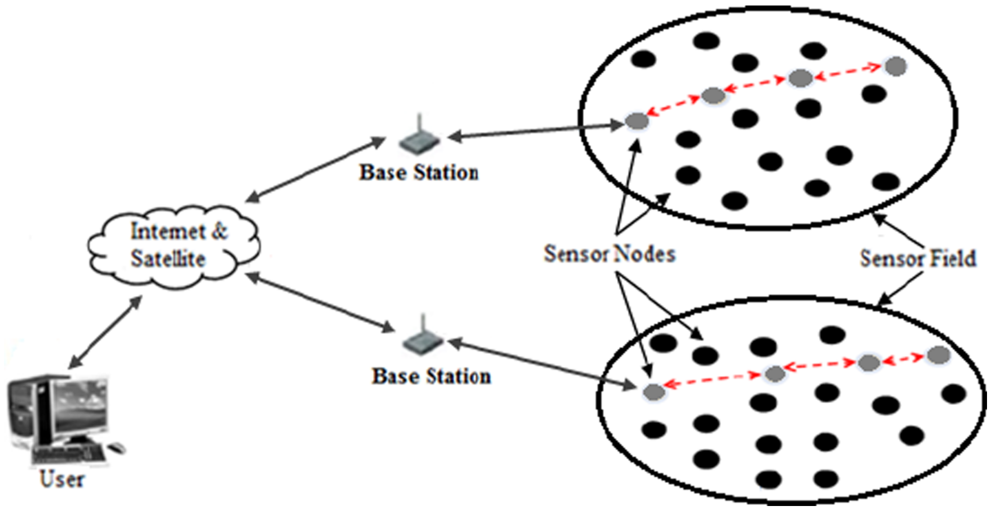


Fig. 1. Structure of wireless sensor network.

Optional modules can be attached to the sensor node, such as external memory, localization system, and mobilizer, as well as its main components.

2.4. Wireless communication technology

Several wireless communication technologies are utilized in the wireless sensor network to effectively communicate data for improving irrigation systems. There are numerous technologies such as Wi-Fi, ZigBee, and Bluetooth, which are the most widely applied.

- Wireless Fidelity: or WiFi (Kaushik, 2012) is a wireless local area network technology introduced by the Wi-Fi Alliance (Wi-Fi Alliance Organization, 2020), which is based on the institute of electrical and electronics engineers' 802.11 standards (i.e., IEEE 802.11, 802.11 a/b/g/n) (IEEE Standard for Information technology, 2012). It provides a wireless exchange of information or wireless connection to the Internet based on these standards (i.e., IEEE 802.11). WiFi has a communication range of about 20 m indoors and up to 100 m outdoors. It can operate in both the 2.4 GHz UHF and 5 GHz SHF ISM (i.e., Industrial, Scientific, and Medical) frequency bands.
- Bluetooth: Bluetooth (Bisdikian, 2001; Bluetooth Special Interest Group, 2020) is a wireless personal area network technology, which is based on the IEEE 802.15.1 standard (IEEE Standard for Information technology, 2005). It enables proximity connections between multiple electronic devices with short-range such as tablets and cell phones. Furthermore, Bluetooth operates at 2.4 GHz ISM, allowing transmission and exchange of data over short distances with very few devices.
- ZigBee: ZigBee (Baronti et al., 2007; Wang et al., 2016) is a wireless communication technology introduced by the ZigBee Alliance (ZigBee Specifications, 2020). It is based on the IEEE 802.15.4 standard (IEEE Standard for Information technology, 2006), specifies the number of communication protocols employed in the design and the establishment of a personal wireless local area network with low power radio signals and low data rate (IEEE Std, 2011). Besides, Zigbee works at frequencies of 915 MHz, 868 MHz, and 2.4 GHz and its data rate are 250 kbps making it best suited for periodic and intermediate data transmissions from an input device or sensor. ZigBee is specified to be low-cost, simpler, easier to use and install, consumes less energy, and uses unlicensed radio bands and low flow (Hamami and Nassereddine, 2018a).
- GPRS: GPRS (Ghribi and Logrippo, 2000; General Packet Radio Service, 2020) (i.e., General Packet Radio Service) is a wireless communication service that operates on the mobile network (i.e., the 2G, 3G, and 4G cellular communications network) using IP transmissions. It is used to transmit data packets over cellular networks (i.e., cellular phones based on GSM) and to offer Internet services on the mobile. GPRS is an integral part of the switching subsystem of the GSM network. GPRS operates in the 2.4 GHz frequency band and its range is extended up to a few kilometers.

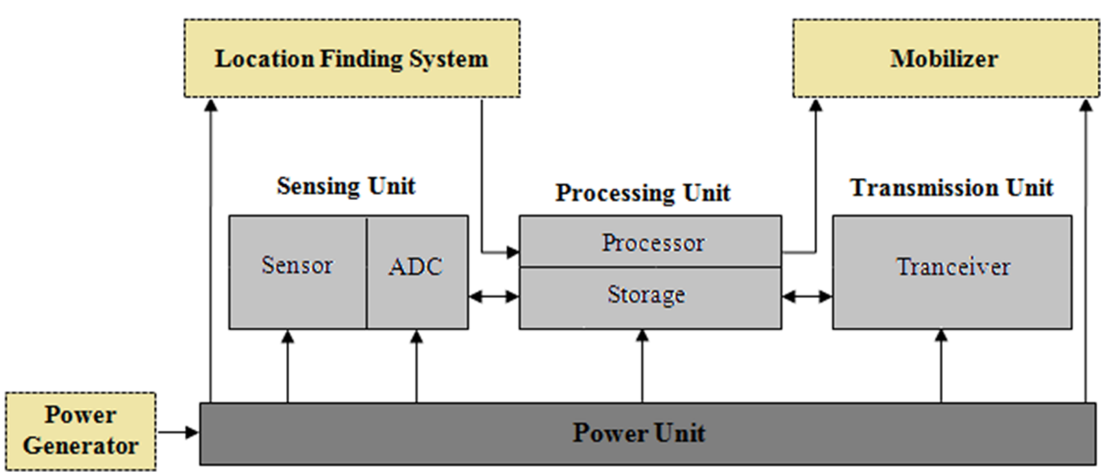


Fig. 2. Sensor node architecture.

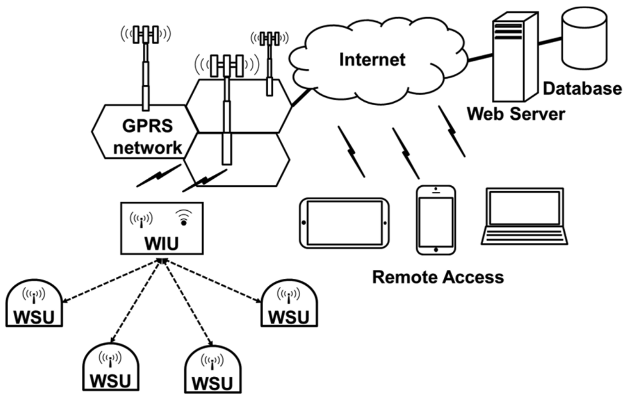


Fig. 3. Automated irrigation system (configuration of a wireless information unit and wireless sensor units) using WSN, ZigBee, and GPRS (Gutiérrez et al., 2014).

3. Survey of the literature

The application of wireless sensor networks in the field of irrigation has been widely utilized, and this use has been greatly appreciated in recent years. This literature review highlights a variety of works and research involving the use and application of WSN technology to manage and control irrigation systems.

Avatade and Dhanure (2015) developed an automated irrigation system using a wireless sensor network and GPRS technology. The developed system is based on an embedded platform using an ARM microcontroller for the water irrigation system. This system allows the measuring and monitoring of the temperature and moisture level of the soil using numerous wireless sensor nodes based on an ARM microcontroller. It controls the water flow in the field using the measured values to reduce the water consumption of irrigation. This embedded project also allows monitoring and controlling the status of the sensors used on a remote PC via a web page by entering an IP address specified for the system.

Kim and Evans (2009) developed a software system for irrigation control using WSNs. They presented the design of decision support software and the integration of this software with an in-field WSN for the control and monitoring of sprinkler irrigation techniques. The authors developed wireless in-field sensing and control (WISC) software for remote access to information, decision-making, and real-time monitoring and control of site-specific sprinkler irrigation via WSN and Bluetooth.

The authors of Navarro-Hellín et al. (2015) proposed and developed wireless sensor architecture for efficient management of irrigation water; this proposed irrigation architecture is based on the use of WSN and GPRS technology. Navarro-Hellín et al. (2015) described the development, optimization, and design of practical applications aimed at optimizing water resources in irrigated agriculture through monitoring of the state of soil water and irrigation water. The suggested system consists of autonomous wireless sensor nodes fitted with GPRS connectivity. These nodes measure and monitor the soil parameters to be transmitted to a remote server through GPRS/GSM for further processing to achieve effective management of water resources in irrigation. Various realistic scenarios for irrigation management were performed in this work using the proposed wireless sensor architecture to evaluate this device's behavior.

According to Nikolidakis et al. (2015), Nikolidakis et al. (2015) proposed and developed an automated irrigation system using wireless sensor networks to efficiently control and manage irrigation by identifying suitable schemes for rational utilization of irrigation water. In this work, the researchers have integrated an automated irrigation technique with a new advanced routing protocol, i.e., ECHERP (Equalized Cluster Head Election Routing Protocol), which achieves high-energy efficiency.

A system for remote sensing and control of irrigation system using a distributed wireless sensor network, Global Positioning System (GPS), and Bluetooth technology has been developed and presented in Kim et al. (2008). The proposed system consists of a distributed wireless sensor network that includes a set of sensor nodes deployed in farmland for monitoring and controlling weather and soil conditions. It also allows for the detection of sprinkler positions. The authors have also developed software for real-time field detection and monitoring of a site-specific precision linear move irrigation system. In this work, Kim et al. (2008) have sought better water management to control irrigation efficiently in order to improve agricultural productivity and conserve water.

Spatio-temporal modeling based on high temporal and spatial resolution electromagnetic survey data has been developed and approved to predict and model the depth of the water table and the state of the soil water in Hedley et al. (2013), with the aim to have accurate planning and management of the irrigation system. Hedley et al. (2013) utilized the DEM (i.e., Digital Elevation Map) and EM (i.e., Electro-Magnetic) data layers at high spatial resolution in this modeling. Further, to model the dynamic nature of moisture in the soil, they utilized various high temporal resolution WSN dataset from a WSN deployed in the irrigated land. In this work, the proposed model aims to achieve better implementation of an irrigation system with a variable rate.

Gutiérrez et al. (2014) proposed and developed an automated irrigation system based on the use of the wireless sensor network and other technologies to manage and optimize the use of water for crops (see Fig. 3). The proposed system consists of a distributed wireless network with many soil moisture and temperature sensors to monitor and control soil parameters. It also consists of a control unit that allows identifying, evaluating, and storing the collected data, as well as automatic irrigation activation management with the help of a developed program containing threshold values of measured information. The authors tested this automated system in a greenhouse for organic sage cultivation for 136 days, in which test results demonstrated significant water savings, i.e., up to 90%, compared to traditional irrigation techniques.

Sawant et al. (2017) proposed and developed an agro-meteorological monitoring and management system for precision farming. The suggested system is based on a sensor framework with a sensor web enablement architecture integrated the OGC (Open Geospatial Consortium) sensor web enablement standards. In which this system is considered as a standardized heterogeneous sensing system that comprises tools for monitoring crop water needs, remote control, and plug-n-play sensors. In this work, the authors aim to achieve data sharing and access over diverse distributed sensor networks and standardization of data discovery. Fig. 4 shows the real deployment Deployment of the SenseTube sensing system in the field.

Another solution to automate the irrigation system using the WSN was presented in Afolabi et al. (2019). This solution allows the development and evaluation of the performance of an automated irrigation system. The developed system is composed of a wireless sensor network with numerous humidity sensors to monitor and control conditions of the soil. Furthermore, it allows users to remotely interrogate the system to obtain information about soil conditions. In this work, the authors aim to use this system in different types of agricultural land, in which the evaluation of the performance of this system was made in three soil types: clay, loamy, and sandy soil.

Viani et al. (2017) developed a low-cost decision support system to manage the irrigation system efficiency and thus save water in agriculture. The suggested system is based on the integration of an innovative decision support methodology and a low-cost wireless sensor and actuation network (WSAN). The innovative methodology helps decision support using fuzzy logic (FL); this methodology was calibrated and designed based on the indications given by farmers to understand the state of the crop and reproduce the human experience. The

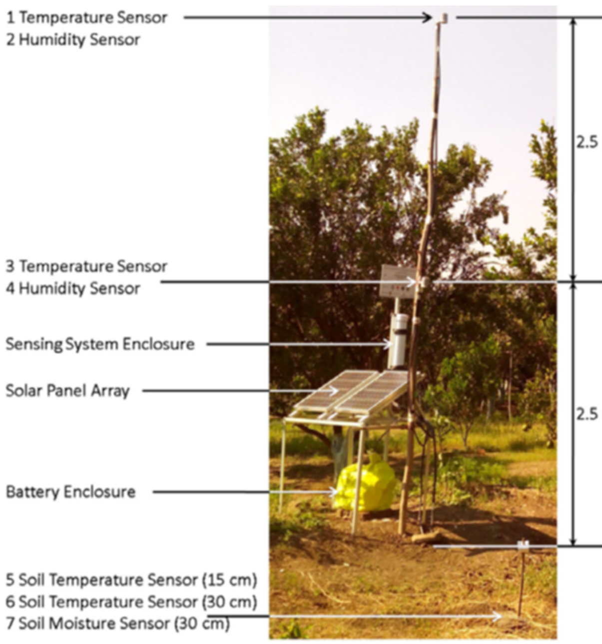


Fig. 4. Deployment of the SenseTube sensing system in the field (Sawant et al., 2017).

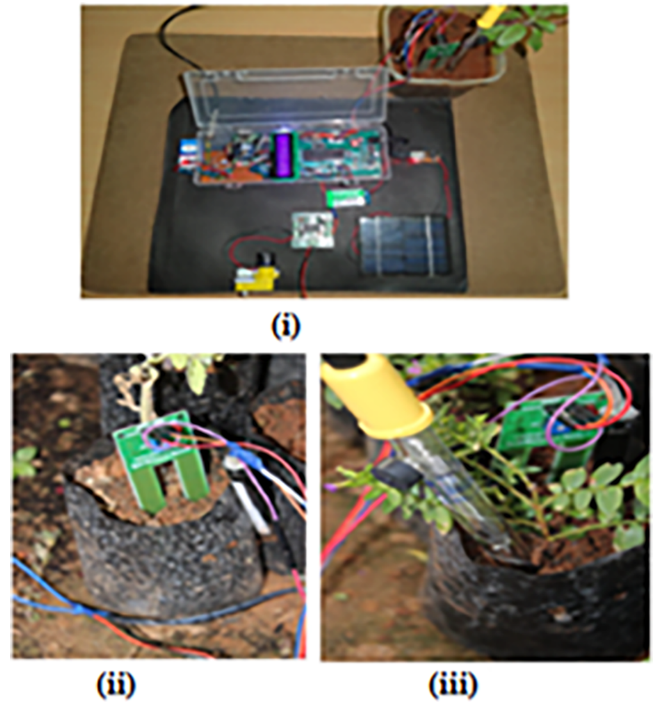


Fig. 5. Equipment used in Nagarajan and Minu (2018). (i) an overview of the equipment used; (ii) Moisture sensor used in the field; (iii) pH sensor used in the field.

WSAN consists of a set of sensor nodes and is used to measure and monitor environmental conditions and to manage the irrigation system. The suggested smart irrigation system aims to achieve many benefits, including a fully autonomous wireless system, a low level of water stress, increased water conservation, and increased crop productivity.

Another decision support system based on WSN has been presented by Khan et al. (2018) for efficient use of water. Khan et al. (2018) developed a system for irrigation management and outlier sensing using a wireless sensor network, which helps farmers to manage crop irrigation processes.

Cambra et al. (2018) proposed and developed an intelligent system based on the use of a wireless sensor network to monitor bicarbonate in the irrigation system to enhance hydroponic precision farming in greenhouses. The authors propose using an auto-calibrated pH sensor that is connected to a wireless node, for detecting and adjusting the pH imbalances detected in nutrient solutions utilized for hydroponic agriculture. The developed system based on a WSN that was made up of a set of auto-calibrated pH sensor nodes for better management and control of hydroponic precision farming in greenhouses.

A system for identifying placement criteria for moisture sensors based on the analysis of temporal stability of the soil water content has been presented and developed by Zhao et al. (2018); the system aims to enhance the management of a variable rate irrigation technique. By identifying the criteria for placement of soil moisture sensors, the authors assessed the temporal stability of water content in the soil regularly and compared this model of temporal stability between uniform rate irrigation and variable rate irrigation. In this work, tests of the suggested variable rate irrigation technique demonstrate that there is a change in the overall similarity of the spatial pattern of soil moisture and that there is a significant water saving.

Imteaj et al. (2016) proposed an automatic water supply system to manage properly the irrigation system that used mainly Arduino, a Wi-Fi module, Raspberry Pi, and GSM. A set of sensors is utilized to establish a WSN for detecting and monitoring the intensity of daylight, the water level in the soil, and the soil moisture and this data is sent to the Raspberry Pi through Wi-Fi. The system alerts the administrator through GSM by SMS in case of water supply problems (e.g., lack of water). Note that the present system aims to identify the appropriate time for the supply of irrigation water by analyzing the measured data.

Besides, the authors of Difallah et al. (2017) proposed a linear programming model for optimizing the use of water according to soil and weather parameters for irrigation. In this work, Difallah et al. (2017) integrated a decisional form of the "knapsack" problem with a linear programming model to identify the quantity of water needed for irrigation. Tests of this proposed system indicate that it can reduce water usage by 28.51%.

Nagarajan and Minu (2018) proposed and designed an automation system for sprinkler irrigation using a WSN. The proposed system is also utilized GPRS technology for data storage and analysis and ZigBee technology for data transmission. This system monitors soil conditions (e.g., humidity, pH, and temperature of the soil) using a set of different sensors (see Fig. 5), and send the detected data to a controller for monitoring purposes (e.g., soil water content control and soil temperature control). The proposed system also allows the control and optimization of the water supply.

Hamami and Nassereddine (2020) proposed an automated irrigation system to conserve water and improve the efficiency and performance of irrigation systems. The proposed system is based on a WSN that consists of a set of soil and weather sensor nodes to control and manage the irrigation system by monitoring soil parameters and weather conditions (e.g., humidity, soil moisture, pH, and temperature). The authors presented a visual representation of the proposed system by illustrating the various connections and interplays between the system components. They also explained the steps, procedures, and the workflow of the proposed solution. The schematic diagram of the design for an automated irrigation system is illustrated in Fig. 6.

Moreover, Katyara et al. (2017) implemented a wireless sensor network as a remote terminal unit (RTU) for remote monitoring and smart control of irrigation systems in Pakistan. Various data, such as soil moisture and temperature, were measured by these RTUs and these data are sent to estimate and control the amount of water needed during irrigation activity. The results of tests showed positive results in terms of reducing water used in irrigation and increase the productivity of agricultural land, increased by almost 20–25%.

A precision irrigation system employing a sensor network integrated

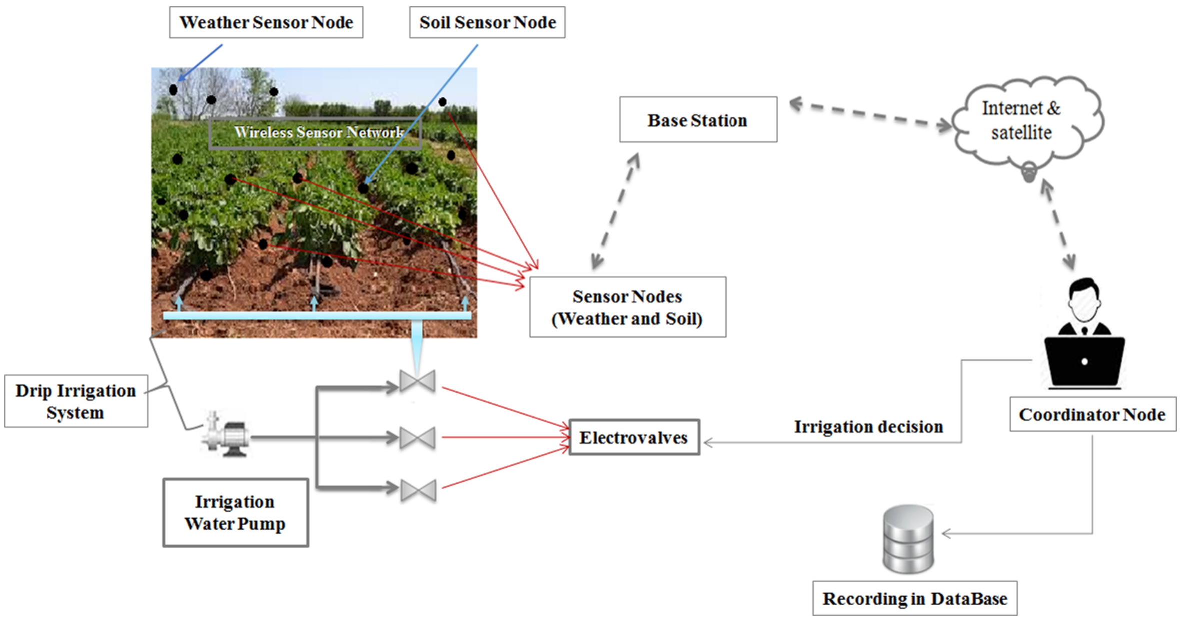


Fig. 6. Schematic diagram of the design for an automated irrigation system (Hamami and Nassereddine, 2020).

with the IOS/Android application to monitor and manage the different phases of plant growth has been proposed in Işik et al. (2017). The developed system consists mainly of a solar panel, valves, filter, water booster, and water tank. It is also composed of a set of DS200 humidity sensors that allow measuring the quantity of water in the soil. In this system, the measured data was sent in real-time through Wi-Fi to a mobile phone-based on IOS/Android.

Dursun and Ozden (2011) presented another work in the WSN application in the field of irrigation intending to control and monitor a drip irrigation system for a dwarf cherry farm site (see Fig. 7). The developed system is composed of three essential components: a sensor unit, a valve unit, and a base station unit. With this system, the irrigation technology can be controlled wirelessly and the soil moisture content can be monitored in real-time through soil moisture sensors. In this work, many benefits have been achieved including prevention of water stress on trees, salification, and efficient use of freshwater resources.

Another validation of the use of WSN in greenhouses was made in Shaker and Imran (2013). Shaker and Imran developed a system that enables to monitor climate parameters and control irrigation water to optimize the production process within the greenhouse based on the utilization of the wireless sensor network. The developed system includes the Atmeag328P microcontroller, controlled by the Arduino platform, which allows the treatment of the measured data, the presentation of the measured values on the LCD screen, and the monitoring of the valve. It also includes the XBee module, which is operated as a transceiver module. For the measurement of climate parameters, the authors employed EC-5 sensors to measure soil moisture and DHT22 sensors to measure humidity and temperature.

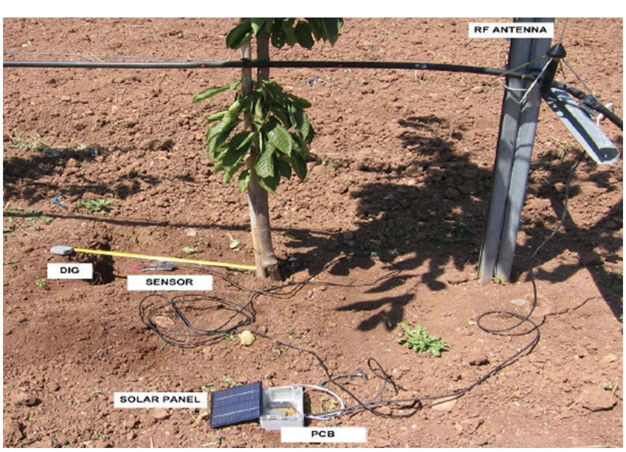


Fig. 7. Application of automated drip irrigation on a dwarf cherry tree (Dursun and Ozden, 2011).

There are also different types of applications combining wireless sensor networks and multi-agent systems in irrigation. One of them an innovative multi-agent system has been developed by González-Briones et al. (2018) to handle WSN information for knowledge discovery and decision making in rural areas. The proposed system was tested in a case study of a localized irrigation system with a pivot for a corn crop. The developed system includes a WSN, which is composed of a set of sensors for height, wind, humidity, and temperature measurements. The measured data allows making efficient decisions on maize irrigation for optimizing the consumption of irrigation water. Another one has been proposed by González-Briones et al. (2019) where they developed an intelligent multi-agent system to reduce water usage in automotive irrigation. The authors developed a new multi-agent system according to the cloud-computing model. The developed system aims to automate the collection and management of potato crop information. Data are collected using WSNs to support decision making and knowledge discovery for precision irrigation.

Rahim Khan et al. (2013) developed an irrigation control system for container crops using WSN. The system developed includes a wireless sensor network that allows continuous monitoring of environmental and soil conditions using a set of sensors (e.g., soil moisture sensors and temperature sensors). The measured data are processed and evaluated to determine water-deficient areas and then notifies the farmer by sending a text message or via an alarm unit.

Chikankar et al. (2015) developed an automatic irrigation system based on the control of a set of parameters (e.g., air humidity, soil moisture, and temperature) using WSN and ZigBee. The developed system used ZigBee technology for data communications. The system included a WSN, which is composed of the soil moisture, SY-HS-220, and LM-35 sensors for measurements of air humidity, soil moisture, and temperature.

A review on the utilization of wireless sensor networks in different services of the agricultural sector such as irrigation was presented and discussed in Ruiz-Garcia et al. (2009) and ur Rehman et al. (2014). In

Table 1
Summary of the survey on the WSN's various applications in the field of irrigation.

Author	Description	Technologies/Tools	Specifics	Types of sensors	Crop/Labo
Avatade and Dhanure (2015)	Develop an automated irrigation system based on an embedded platform using a wireless sensor network, ARM microcontroller, and GPRS technology.	ZigBee wireless communication. GPRS/GSM. ARM microcontroller. Web page.	° ZigBee wireless communication technology is used for data transmission. ° GPRS/GSM is used to ensure data transmission to a web page where status of all sensors is display graphically. ° ARM microcontroller is used to program some threshold values of soil moisture and temperature.	Soil-moisture sensor. Temperature sensor. Water level sensor.	Laboratory
Kim and Evans (2009)	Develop a software design for decision support and monitoring of wireless sensor based site-specific irrigation system	Bluetooth wireless communication. Bluetooth transmitter SD202. Bluetooth receiver MSP-101a. Data logger CR200. The WISC software. Battery YUASA NP7-12. Solar panel SX5.	° Bluetooth wireless communication technology is used to send and receive data. ° The data are wirelessly transmitted via a Bluetooth radio transmitter SD202 and are received by Bluetooth receiver MSP-102a. ° The data logger CR200 is used to record the data. ° WISC software is composed of four main designs, including a control panel for hardware interface, nozzle sequencing, irrigation monitoring and control, and graphical monitoring for in-field WSN.	Soil moisture sensor CS625. Soil temperature sensor 109-L.	A field planted to maltingbarley (Five different soil zones)
Dursun and Ozden (2011)	Develop an application of a wireless sensor network to automate drip irrigation system using soil moisture sensors.	Model UFM-M11. MCU. Power panel.	° UFM-M11 is a wireless module. ° MCU is a low power micro controller chip.	10SH sensor.	Dwarf cherry trees
Navarro-Hellín et al. (2015)	Design wireless sensor architecture for efficient management of irrigation water, this proposed irrigation architecture is based on the use of WSN and GPRS technology.	ZigBee wireless communication. SIM900 GSM/GPRS. SDI-12 interface. Remote server. Web application. Relational database. GPRS.	° ZigBee wireless communication technology is used for data transmission. ° Communication module is based on the SIM900 GSM/GPRS chip. ° SDI-12 interface is one of the most important and standardized interfaces in the field of precision agriculture. ° Remote server lets the user access the files ° Web application was developed using PHP, JavaScript, and HTML5, it ensures verification of information from sensors. ° Relational database ensures storing of data.	ES-2 sensor. HP II sensor. LMK sensor. 10HS sensor. MPS-2 sensor. GS3 sensor.	Four experimental sites: woody crop (Fino lemon trees), vegetable crop, greenhouse soilless culture, and water reservoir
Nagarajan and Minu (2018)	Develop an automated soil properties monitoring system using WSN to automate sprinkler irrigation system	Wireless sensor network actuator controller (WSN-AC). ZigBee. GPRS system. Solar panels. Microcontroller PIC 16F877.	° The whole system is powered by Solar panels. ° ZigBee wireless communication technology is used for data transmission. ° GPRS system is used for data storage and analysis.	Soil moisture sensor SEN-13322. pH sensor (SEN10972 pH Sensor kit). Temperature sensor LM35 IC.	Farm field
Sawant et al. (2017)	Develop an interoperable agro-meteorological observation and analysis platform for precision farming.	SenseTube. Serial peripheral interface (SPI). Low powered System on Chip (SoC). Wi-Fi wireless communication. The Open Geospatial Consortium (OGC) sensor web enablement standards.	° SenseTube is an interoperable wireless sensing system. ° SPI is used to collect data. ° SoC single board computer is used as a data collection and dissemination platform. ° Wi-Fi communication protocol is used for wireless communication.	Humidity sensor. Temperature sensor.	Citrus crop
Zhao et al. (2018)	Develop an application of a wireless sensor network to automate drip irrigation system using soil moisture sensors.	Uniform rate irrigation (URI). Variable rate irrigation (VRI).	° The model of temporal stability of soil water content compared between URI and VRI treatments to determine the criteria for placement of soil moisture sensors.	Decagon soil moisture sensors EM50.	Summer maize and Winter wheat

(*continued on next page*)

Table 1 (*continued*)

Author	Description	Technologies/Tools	Specifics	Types of sensors	Crop/Labo
		TDR trime-tube system.	◦ TDR trime-tube is a moisture meter utilized to measure soil moisture.		
Kim et al. (2008)	Develop a remote sensing and control system of irrigation system based on a distributed wireless sensor network, Bluetooth and GPS technologies.	Bluetooth wireless communication. GPS technology. The WISC software. Irrigation control station. Weather station. In-field sensing station.	◦ Bluetooth wireless communication technology is used to send and receive data. The global positioning system is used to determine the georeferenced location of sprinklers. ◦ WISC software ensures real-time remote control and monitoring of the variable rate irrigation system. ◦ Irrigation control station updates and transmits georeferenced machine locations from a differential GPS to the base station. ◦ Weather station is used to monitor micrometeorological conditions (solar radiation, wind speed, precipitation, air temperature, and relative humidity). ◦ In-field sensing station monitors the field conditions (soil temperature and soil moisture).	Water content reflectometes CS616. Temperature probe 107. Humidity probe HMP35C. Pyranometer LI200X.	A small field at the Eastern Agricultural Research Center, Montana
Nikolidakis et al. (2015)	Develop an energy-efficient automated control of irrigation depending on wireless sensor networks to efficiently control and manage irrigation.	ZigBee ECHERP. Automated system.	◦ ZigBee wireless communication technology is used to transmit data. ◦ ECHERP is a new advanced routing protocol, which achieves high-energy efficiency.	A set of sensors that monitor the humidity and the temperature of soil, the humidity, the temperature and the speed of air, and the duration of sunshine.	Laboratory (Simulation)
Hedley et al. (2013)	Develop a spatio-temporal modeling based on high temporal and spatial resolution electromagnetic surveys to predict and model the depth of the water table and the state of the soil water for Precision irrigation scheduling.	Method for real-time variable rate irrigation scheduling. Electromagnetic surveys. Modeling water table depth and soil moisture. Random Forest (RF) model.	◦ Electromagnetic surveys are used to quantify soil variability. ◦ RF model is used to better predict water table depth and soil moisture, being more interrogation of the data via classification trees with subsequent regression.	DELTA-T SM300 sensor. Geonics EM38Mk2/EM31 sensors.	Field of maize
Chikankar et al. (2015)	Develop an automatic irrigation system based on the control of a set of parameters using WSN and ZigBee.	ZigBee wireless communication. Microcontroller PIC 18F458. Display LCD.	◦ ZigBee wireless communication technology is used for data transmission. ◦ LCD screen display the average values measured.	LM-35. Soil moisture sensor SY-HS-220.	Agriculture field
Gutiérrez et al. (2014)	Develop an automated irrigation system based on the use of wireless sensor network and GPRS module to optimize the use of water for agricultural crops.	ZigBee wireless communication. GPRS/GSM. Web application. Triggers actuators.	◦ ZigBee wireless communication technology is used for communication between the sensor nodes and the data receiver. ◦ GPRS/GSM is used to ensure data transmission to a web server. ◦ Web application ensures real-time programming and monitoring of irrigation depending on the data of temperature and soil moisture.	Temperature sensor DS1822. Soil-moisture sensor VH400.	Greenhouse for organic sage
Viani et al. (2017)	Develop a low-cost decision support and wireless monitoring to efficiently manage the irrigation system and save water in agriculture.	Fuzzy logic (FL) and fuzzy rules. Decision support system (DSS). Wireless sensor and actuation network (WSAN). Wireless actuation node. Wireless anchor node. Wireless sensor node.	◦ Innovative decision support methodology using fuzzy logic (FL) helps decision support. ◦ WSAN consists of a set of sensor nodes and is used to measure and monitor environmental conditions and to monitor and manage the irrigation system.	Sensirion SHT11. Watermark 200SS probe. DS18B20 probe.	Irrigated vineyard
Angelopoulos et al. (2011)	Develop a smart system based on WSN for watering a domestic garden.	ZigBee wireless communication. Telosb mote. IRIS mote. MDA100CB. Java software.	◦ TelosB motes equipped with SHT11 and EC-5 sensors monitor environmental conditions. ◦ IRIS motes are used for controlling electro-valves. ◦ Java software for data collection and recording these data in MySQL database.	EC-5. SHT11.	Geranium, lavender, and mint

(*continued on next page*)

Table 1 (*continued*)

Author	Description	Technologies/Tools	Specifics	Types of sensors	Crop/Labo
		MySQL database.			
Işik et al. (2017)	Develop a precision irrigation system employing a sensor network integrated with the IOS/Android application.	Wi-Fi wireless communication. IOS/Android. Filter. Solar Panel. Software.	° Wi-Fi (IEEE 108.11) communication protocol is used for wireless communication. ° Filter is used to eliminate bottlenecks that can occur in the pipe. ° Solar Panel to provide energy system requirements. ° Software operates in IOS/Android based systems.	DS200.	Walnut land
Shaker and Imran (2013)	Develop a system to monitor climate parameters and control irrigation water based on the wireless sensor network for optimizing the production process within the greenhouse.	Amega382P microcontroller. XBee module. ZigBee wireless communication. LCD screen.	° Amega382P treats data from the communication subsystem or sensor subsystem. ° XBee for transceiver module. ° LCD screen display the average values measured.	DHT22. EC-5.	Greenhouse
Katyara et al. (2017)	Implement wireless sensor network as a remote terminal unit (RTU) for remote monitoring and smart control of irrigation system in Pakistan using SCADA applications.	CC2530 IC system-on-chip. CN3063 IC. SCADA monitoring center.	° The nodes of WSN are made of CC2530 IC. ° CN3063 IC module collects and manages the solar power. ° SCADA control panel is extended to provide coverage to all sensor and coordinating nodes.	Soil moisture sensor TDR-3A.	Rice Canal

the same vein, Ojha et al. (2015) examined a range of potential applications of wireless sensor networks, as well as the challenges and issues related to the deployment of a wireless sensor network in the agricultural sector (e.g., irrigation). The authors analyzed these different problems via case studies and scenarios to explore different solutions to enhance agricultural productivity. Kodali et al. (2014) also presented an in-depth study of the different types of sensors usable in the field of precision agriculture.

Angelopoulos et al. (2011) suggested another application of the wireless sensor network in irrigation. In this work, home irrigation (i.e., watering a domestic garden) was highlighted. The system is composed of two types of sensor motes. TelosB motes equipped with SHT11 and EC-5 sensors, which allow monitoring a set of environmental conditions. IRIS motes used for controlling electro-valves. The system also utilizes a Java application for data collection and recording.

A prototype of an intelligent irrigation system using a wireless sensor network has also been presented in Hamami and Nassereddine (2018a). The authors presented the architecture and design of an irrigation system. Besides, they showed the different actors of this system with the different existing interactions.

A service of ambient crop field monitoring using a mobile sink in the WSN has been presented and developed by Khan and Kumar (2020) to enhance context-dependent agriculture. In this work, Kumar and Khan designed an algorithm to find a better path employing a sensor node to a mobile sink in WSN and another algorithm for a mobile sink displacement path. Wireless sensor networks are deployed to monitor ambient crop fields. The authors seek to achieve improved performance of the ambient sensor network and increased crop yields while decreasing delay and energy consumption in ambient context-dependent agricultural wireless sensor networks.

The smartphone with WSN in the field of irrigation has been used by Bartlett et al. (2015) and Jagüey et al. (2015). Bartlett et al. (2015) developed a smartphone application to expand the usage of cloud-based scheduling for irrigation. The developed application allows rapid visualization of measurements of weather and soil moisture scarcity, as well as the input of applied irrigation quantities into an online irrigation-planning tool based on evapotranspiration. Jagüey et al. (2015) developed an automated irrigation sensor. This sensor enables the capture and processing of digital images of the soil based on smartphone use. Besides, it allows the visual estimation of water content using captured images.

4. WSN's applications in the field of irrigation: Synthesis

The wireless sensor network is one of the best options for precise monitoring and control of the environment. The fast evolution of communication technologies and sensor technology over the past decades has led to a major shift in the WSN, allowing wireless sensor network technology to be successfully applied in the field of irrigation.

Numerous advantages have been enabled the WSNs to contribute and provide economical and effective strategies to support, improve, and strengthen irrigation systems. Such as the dynamic network topology, the large number of sensor nodes deployed, the self-organization and heterogeneity of the deployed nodes, the collaboration between nodes to reach a focused aim, the sensing, control, and wireless communication functionalities, the adaptability to different environments, and the transfer of gathered data through intermediate nodes with no increase in energy or cost (Mishra and Thakkar, 2012; Manshahia, 2016; Hamami and Nassereddine, 2018b).

After an extensive literature review, we can conclude that the majority of the work and research undertaken in this context is focused on improving the efficiency and performance of irrigation to ensure the efficient and rational utilization of water for irrigation systems. Thus, wireless sensor networks can be utilized in different scenarios to smartly control and manage irrigation systems for precision irrigation, and thus achieving precision agriculture. In which, a group of

Table 2
Summary of the most captured data in the field of irrigation for precision agriculture.

Captured data	Sensor type	Reference
Soil moisture	Ground sensors	(Kim and Evans, 2009; Navarro-Hellín et al., 2015; Hedley et al., 2013; Gutiérrez et al., 2014a, 2014b; Afolabi et al., 2019; Viani et al., 2017; Nagarajan and Minu, 2018; Zhao et al., 2018; Dursun and Ozden, 2011; Işik et al., 2017; Shaker and Imran, 2013; Angelopoulos et al., 2011; Kassim et al., 2014; Katyara et al., 2017; Hedley and Yule, 2009; Sawant et al., 2017; Avatade and Dhanure, 2015; Imteaj et al., 2016; Rahim Khan et al., 2013; Chikankar et al., 2015; Nikolidakis et al., 2015; Khan et al., 2018)
Soil temperature	Ground sensors	(Kim et al., 2008; Kim and Evans, 2009; Gutiérrez et al., 2014; Navarro-Hellín et al., 2015; Viani et al., 2017; Katyara et al., 2017; Kassim et al., 2014; Sawant et al., 2017; Avatade and Dhanure, 2015; Nagarajan and Minu, 2018; Nikolidakis et al., 2015; González-Briones et al., 2019; Khan et al., 2018)
Air temperature	Unmanned Aerial Vehicles (Popescu et al., 2019) sensors or weather sensors	(Kim et al., 2008; Rahim Khan et al., 2013; Nagarajan and Minu, 2018; Chikankar et al., 2015; Kassim et al., 2014; Angelopoulos et al., 2011; Viani et al., 2017; Shaker and Imran, 2013; Sawant et al., 2017; González-Briones et al., 2018; Nikolidakis et al., 2015; Khan and Kumar, 2020; Khan et al., 2018)
Air humidity	Unmanned Aerial Vehicles (Popescu et al., 2019) sensors or weather sensors	(Kim et al., 2008; Shaker and Imran, 2013; Kassim et al., 2014; Rahim Khan et al., 2013; Chikankar et al., 2015; Viani et al., 2017; Sawant et al., 2017; González-Briones et al., 2018, 2019; Nikolidakis et al., 2015; Khan and Kumar, 2020; Khan et al., 2018)
Electrical conductivity	Electrochemical sensors	(Hedley and Yule, 2009; Hedley et al., 2013; Navarro-Hellín et al., 2015)
Wind speed and direction	Weather stations	(Kim et al., 2008; González-Briones et al., 2018, 2019; Nikolidakis et al., 2015)
ph value	Electrochemical sensors	(Kassim et al., 2014; Nagarajan and Minu, 2018; Cambra et al., 2018)

researchers has used WSNs to optimize the use of water in irrigation. Other researchers have attempted to monitor and control soil and weather conditions using WSN to properly manage the irrigation systems. Moreover, others have sought to automate the irrigation process using WSN and other technologies. Some works have developed systems based on dynamic thresholds, while others rely on the use of linear programming models to improve water resources for irrigation. On the other hand, many authors have also used the WSN either to develop a decision support system, or real-time detection and control software, or an automatic water supply system, or a system for determining sensor placement criteria, and others; all for efficient management of irrigation systems.

Summarizing the above, Table 1 summarizes the various work and research related to the use and application of WSN technology in the field of irrigation to achieve precision agriculture.

Table 2 presents the most captured data by sensors, among the articles reviewed, in the field of irrigation to achieve precision agriculture.

And Table 3 shows the application efficiency of some articles reviewed in the field of irrigation to achieve precision agriculture.

5. Discussion

5.1. Sensors used in the field of irrigation

In the field of irrigation, performance and efficiency improvement of the irrigation system depends on several conditions, which are related to different weather and soil parameters. To achieve this objective, various sensors can be used to measure and monitor soil (e.g., salinity, moisture, pH, and temperature) and weather conditions (e.g., humidity, temperature, wind speed, and barometric pressure).

Many sensors can be utilized in the field of irrigation; we can classify them into two main categories: sensors related to the soil and sensors related to the weather. Table 4 gives several sensors used in the field of irrigation to measure soil parameters. Table 5 also provides a set of sensors used to measure the weather parameters used in the field of irrigation. Besides, many sensors mentioned in the literature to obtain precision irrigation are presented in Table 6.

We notice that sensors make a significant contribution to the improvement of irrigation systems so that they play a crucial role in promoting measurement techniques for different agricultural factors. A set of soil and weather parameters are measured and collected using sensor nodes scattered in the area to be irrigated. These data are then processed and utilized for control and supervision purposes. From Tables 4 and 5, various sensors such as the DS1822 sensor (Datasheet of DS1822, 2020) used to sense the temperature, the VH400 sensor used to determine the amount of moisture in the soil, the EC-5 sensor (Operator's Manual of EC-5, 2020) to provide soil moisture measurement, the LMK sensor (Datasheet of LMK331, 2020) that measures pressure and others, are helping to advance the field of irrigation. Fig. 8 provides a visual depiction of some examples of sensors used in the field of irrigation.

We also find that works such as Shaker and Imran (2013), Rahim Khan et al. (2013), Navarro-Hellín et al. (2015), Viani et al. (2017) and

Table 3
Application efficiency of some articles reviewed in the field of irrigation for precision agriculture.

Irrigation method/Model/Technology	Application efficiency	Reference
Drip hole spacing	Water savings of up to 90% compared to traditional irrigation practices	(Gutiérrez et al., 2014)
Linear programming Model	Reduction of water consumption by 28.5%	(Difallah et al., 2017)
SCADA based Wireless Sensing Irrigation system	Conservation of about 2150 cusecs of water annually and increasing lands productivity by almost 20 to 25%	(Katyara et al., 2017)
Individual sprinkler control/Variable-rate irrigation	Average annual water savings from 21.8 to 26.3%	(Hedley and Yule, 2009)
Equalized Cluster Head Election Routing Protocol (ECHERP)	Network lifetime improvement using ECHERP up to 1825 min	(Nikolidakis et al., 2015)
WSAN-based DSS	An improved water saving	(Viani et al., 2017)
Drip irrigation/IOS/Android	Adjustment of the quantity of water required at the growth stages of plants and significant energy cost savings	(Işik et al., 2017)
Ambient crop field monitoring using a mobile sink	Reduction of energy consumption 0.0115 J in the network	(Khan and Kumar, 2020)
Automotive irrigation/Multi-agent system	15.06% reduction in water consumption compared to traditional automotive irrigation	(González-Briones et al., 2019)

Table 4
Sensors used in the field of irrigation for soil parameters.

Sensor	Moisture	Temperature	Water level	pH	Salinity	Conductivity	References
EC-5	√	—	—	—	—	—	http://www.decagon.com
VH 400	√	—	√	—	—	—	http://www.vegetronix.com
EC 250	√	√	—	—	√	√	http://www.stevenswater.com
TDR-3A	√	√	—	—	—	—	www.ictinternational.com
HydraProbe II Soil Sensor	√	√	√	—	√	√	www.stevenswater.com
DS1822	—	√	—	—	—	—	www.maximintegrated.com
Sensor S8000 pH	—	—	—	√	—	—	www.sensorex.com
MP406 Moisture Sensor	√	√	—	—	—	—	www.ictinternational.com
WATERMARK Soil Moisture Sensor	√	—	—	—	—	—	www.irrometer.com
107-L temperature	—	√	—	—	—	—	www.campbellsci.com
AquaTrak 5000	—	—	√	—	—	—	http://www.stevenswater.com
Pogo portable soil sensor	√	√	—	—	—	√	(Datasheet of Pogo, 2020)
pH 3000	—	—	—	√	—	—	(Technical Data of pH 3000, 2020)
CS625	√	—	—	—	—	—	www.campbellsci.com
109-L temperature	—	√	—	—	—	—	www.campbellsci.com
SEN10972 pH Sensor kit	—	—	—	√	—	—	www.generationrobots.com

Katyara et al. (2017) have employed multiparameter sensors. These sensors, such as GS3 (Navarro-Hellín et al., 2015), SHT11 (Viani et al., 2017), TDR-3A (Katyara et al., 2017), and SHT75 (Rahim Khan et al., 2013), have the advantage of measuring several parameters simultaneously, thus reducing the number of nodes needed in the wireless sensor network to control the irrigation system. For example, SHT75 (Datasheet of SHT75, 2020) for air humidity and temperature measurements, GS3 (Operator's Manual of GS3, 2020) for moisture, conductivity, and temperature measurements, CM-Compact Weather Sensor 100 (Datasheet of CM-100, 2020) for humidity, temperature, wind speed, wind direction, and air pressure measurements, and TDR-3A for soil humidity and temperature measurements. However, the use of this type of sensor may negatively impact the control system of the irrigation system in case of dysfunction or failure in any of the used nodes, given that each node is in charge of a set of measurements simultaneously

5.2. Crops, soil types and irrigation strategies to study the role of WSN in the field of irrigation

5.2.1. Type of crop cultivated

By this work, we realize that the researchers have taken into account different crops to study and test the role of the wireless sensor network in the field of irrigation. Many crops such as maize, tomato, rice, vegetable crop, citrus crop, and many others are mentioned in the literature to demonstrate the effectiveness of using the wireless sensor network in irrigation systems. Other researchers have also shown the efficiency of using the wireless sensor network in the field of irrigation for greenhouse crops.

Table 7 presents many cultures mentioned in the literature to study and evaluate the role of the wireless sensor network in the field of irrigation.

5.2.2. Type of soil used

In the same context, we note that the researchers have also evaluated the performance and the role of the wireless sensor network in the field of irrigation for different types of soil such as red sandy, clay, and motuiti sands.

Table 8 presents the different soil types referred to in the literature to study and evaluate the role of the wireless sensor network in the field of irrigation.

5.2.3. Irrigation strategies

Besides, we notice that researchers have used many existing irrigation systems such as surface irrigation, sprinkler irrigation, sub-irrigation, and drip irrigation to adapt them to a precision irrigation system.

Table 9 presents the irrigation strategies most referred to in the literature to study and evaluate the role of wireless sensor networks in the field of irrigation.

From Table 9, we confirm that the irrigation techniques most used by researchers are sprinkler irrigation and drip irrigation. Sprinkler irrigation is more water-intensive compared to drip irrigation, whereas drip irrigation can be automated, which saves large amounts of water, and reduces soil erosion. Of these two irrigation systems, drip irrigation is arguably the most effective and adaptable technique for making the irrigation system precise if it is managed correctly and carefully (Hamami and Nassereddine, 2018b, 2020).

5.2.4. Synthesis and discussion

Each type of soil requires a different irrigation technique. For example, drip irrigation is more suitable for soils with good water

Table 5
Sensors used in the field of irrigation for weather parameters.

Sensor	Humidity	Temperature	Wind speed	Wind direction	Solar radiation	Air pressure	References
SHT85	√	√	—	—	—	—	www.sensirion.com
DS18B20	—	√	—	—	—	—	(Datasheet of DS18B20, 2020)
EE181	√	√	—	—	—	—	www.campbellsci.com
Wind Monitor Model 05103	—	—	√	√	—	—	(Datasheet of 05103, 2020)
CM-100 Compact Weather Sensor	√	√	√	√	—	√	http://www.stevenswater.com
Pyranometer LI-200X	—	—	—	—	√	—	www.campbellsci.com
HMP35C	√	√	—	—	—	—	www.campbellsci.com
Temperature Sensor STS3x	—	√	—	—	—	—	www.sensirion.com
WS500-UMB Smart Weather Sensor	√	√	√	√	—	√	www.lufft.com
Pyranometer CS320	—	—	—	—	√	—	www.campbellsci.com
LM35	—	√	—	—	—	—	www.ti.com
SHT75	√	√	—	—	—	—	www.sensirion.com

Table 6
The numerous sensors mentioned in the literature for obtaining precision irrigation.

Article	Sensor	Measured parameter
Kim and Evans (2009)	CS625	Soil moisture
Kim and Evans (2009)	109-L	Soil temperature
Navarro-Hellín et al. (2015)	ES-2	Water electrical conductivity and temperature
Navarro-Hellín et al. (2015)	HP II	Moisture, conductivity, and temperature
Navarro-Hellín et al. (2015)	LMK	Pressure
Navarro-Hellín et al. (2015)	10HS	Soil moisture
Navarro-Hellín et al. (2015)	MPS-2	Soil metric potential and temperature
Navarro-Hellín et al. (2015)	GS3	Moisture, conductivity, and temperature
Kim et al. (2008)	CS616	Volumetric water content of soil
Kim et al. (2008)	107-L temperature	Air-temperature and soil temperature measurement
Kim et al. (2008)	HMP35C	Relative humidity
Kim et al. (2008)	Pyranometer LI200X	Solar radiation
Hedley et al. (2013)	DELTA-T SM300	Soil moisture
Hedley et al. (2013)	Geonics EM38Mk2/EM31	Weighted mean average value for apparent electrical conductivity (EC)
Gutiérrez et al. (2014)	DS1822	Temperature
Gutiérrez et al. (2014)	VH400	Moisture in the soil
Afolabi et al. (2019)	YL-69	Soil moisture
Viani et al. (2017)	SHT11	Air humidity and temperature
Viani et al. (2017)	Watermark 200SS probe	Soil moisture
Viani et al. (2017)	DS18B20 probe	Soil temperature acquisition
Nagarajan and Minu (2018)	SEN-13322	Soil moisture
Nagarajan and Minu (2018)	SEN10972 pH Sensor kit	ph value of soil
Nagarajan and Minu (2018)	LM35 IC	Temperature
Zhao et al. (2018)	EM50	Soil moisture
Katyara et al. (2017)	TDR-3A	Soil humidity and temperature
Dursun and Ozden (2011)	10SH	Soil moisture
Işik et al. (2017)	DS200	Soil moisture
Shaker and Imran (2013)	DHT22	Humidity and temperature
Shaker and Imran (2013)	EC-5	Soil moisture
Rahim Khan et al. (2013)	SHT75	Temperature and air humidity
Chikankar et al. (2015)	LM-35	Temperature
Chikankar et al. (2015)	SY-HS-220	Air humidity
Angelopoulos et al. (2011)	SHT11	Air temperature
Angelopoulos et al. (2011)	EC-5	Soil moisture

conductivity, while sprinkler irrigation is best for sandy soils with a fairly high infiltration rate. Furthermore, the irrigation technique used varies from one cultivated crop to another. For example, sprinkler irrigation is very suitable for tree and field crops, while drip irrigation is very suitable for vines and row crops, i.e., fruit and vegetables. On the other hand, the type of cultivated crop depends on the type of soil used because there are crops suitable for a particular type of soil and not suitable for another type. For example, sandy soil is well suited for so-called heather earth plants, while loamy soil is suitable for many plants except for heather earth plants.

Therefore, to design an ideal system for precision irrigation, a set of different requirements and needs must be considered. These requirements and needs are determined by three main factors, as discussed above, as follows: the appropriate irrigation system, the type of soil used, and the type of crop grown.

On the basis of the numerous articles reviewed in this work, we notice that many researchers as in Nikolidakis et al. (2015), Bartlett et al. (2015) and Difallah et al. (2017) have proposed a complete precision irrigation system without defining the three main factors mentioned above (i.e., the adapted irrigation system, the type of soil used, and the type of crop grown) so that the proposed system could operate under different conditions. However, when applying any of these systems, these three main factors must be taken into account. While other researchers have offered a complete system for precision irrigation without the imposition of the three main factors mentioned above, although the proposed system does not operate under different conditions. On the other hand, there are other researchers as in Hedley et al. (2013) and Dursun and Ozden (2011) have proposed a complete precision irrigation system with the definition of the three main factors mentioned above.

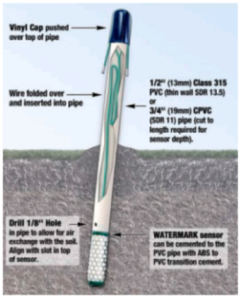
On the contrary, other works have taken into consideration the irrigation system used without taking into account the type of soil used or the type of crop grown as in Nagarajan and Minu (2018), or vice versa as in Navarro-Hellín et al. (2015). While other works have taken into account only one of the three factors without taking into account the other factors. This is practically unacceptable (i.e., when applying the proposed system), as the appropriate irrigation system depends on the type of soil used and the type of crop grown, and the type of crop grown also depends on the type of soil used.

5.3. Communications technologies used

For successful communication and data transmission in the field of irrigation, many wireless communication technologies represent a part of the wireless sensor network. Table 10 shows a comparison of the most commonly utilized wireless communication technologies, highlighting the characteristics of each technology. Besides, the communication technologies mentioned in the literature to achieve precision irrigation are presented in Table 11.

We notice that the wireless communication technologies adopted in wireless sensor networks to improve irrigation systems are Wi-Fi, GPRS, ZigBee, and Bluetooth, as mentioned in Section 2. Whereas, ZigBee technology is more widely used by researchers.

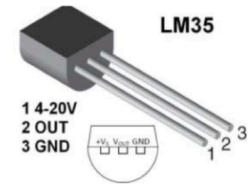
Looking at Tables 10 and 11 as well as in Mihajlov and Bogdanoski (2011) and Lee et al. (2007), we find that Zigbee technology is the most effective technology in applications that require low-power consumption and low data-rate, because Zigbee features low cost and low power consumption, and is hence most appropriate for usage in WSN (Hamami and Nassereddine, 2018a, 2020). Thus, by considering the requirements of irrigation systems, we can deduce that Zigbee's technology is the best selection in the field of irrigation.



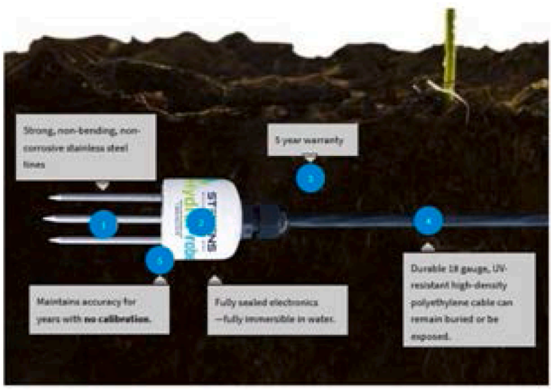
(i) WATERMARK soil moisture sensor (Datasheet of Watermark, 2020)

(ii) pH 3000 sensor (Technical Data of pH 3000, 2020)

(iv) EC-5 soil moisture sensor (Operator's Manual of EC-5, 2020)



(v) LM35 temperature sensor (Datasheet of LM35, 2020)



(iii) HydraProbe II Soil Sensor (Datasheet of HydraProbe II, 2020)

(vi) WS500-UMB Smart Weather Sensor (Technical Data of WS500-UMB, 2020)

Fig. 8. Some examples of sensors used in the field of irrigation.

Table 7
Different crops mentioned in the literature for obtaining precision irrigation.

Article	Type of crop cultivated
Kim and Evans (2009)	A field planted to maltingbarley
Navarro-Hellín et al. (2015)	Fino lemon trees and Vegetable crop
Hedley et al. (2013)	Maize
Gutiérrez et al. (2014)	Greenhouse for organic sage
Viani et al. (2017)	Vineyard
Sawant et al. (2017)	Citrus crop
Zhao et al. (2018)	Summer maize and Winter wheat
Cambra et al. (2018)	Tomato crops and lettuce crops
Katyara et al. (2017)	Rice
Dursun and Ozden (2011)	Dwarf cherry trees
Işik et al. (2017)	Walnut
González-Briones et al. (2018)	Corn Crop
Rahim Khan et al. (2013)	Container crops
Angelopoulos et al. (2011)	Geranium, lavender, and mint

Table 8
Soil types mentioned in the literature for obtaining precision irrigation.

Article	Type of soil used
Navarro-Hellín et al. (2015)	Sandy clay loam texture
Hedley et al. (2013)	Motuiti sands
Afolabi et al. (2019)	Clay, loamy, and sandy soil.
Viani et al. (2017)	Any
Cambra et al. (2018)	Hydroponic Precision Farming
Dursun and Ozden (2011)	Any
Işik et al. (2017)	Red Sandy
Shaker and Imran (2013)	Any

6. Proposed methodology for a smart irrigation system utilizing WSNs:

The integration of wireless sensor network technology with the field of irrigation offers many advantages in comparison to traditional irrigation systems. Therefore, we can note that the use of WSN as a method of monitoring, control, and management in the field of irrigation is an ideal option to improve the performance and efficiency of an irrigation system and thus ensuring rational and efficient utilization of irrigation water.

Several scenarios have been proposed by the researchers in this context in which we note that there are many differences between the proposed scenarios (see Section 3). Due to the rapid technological development and also the existence of many different conditions such as various irrigation systems, different sensors, various soil, and crop types, as well as diverse technologies, it is complicated to suggest and develop a standardized scenario for all conditions and situations in order to use WSN in the field of irrigation. Nevertheless, this does not preclude us from defining a set of basic rules, steps and procedures to be followed in the implementation of a typical automated system to smartly manage irrigation using wireless sensor networks.

To implement an automated system for smartly managing irrigation by using wireless sensor networks, firstly we need to stop at several basic rules, the most important of which are:

(i) It is necessary to develop a simple and comprehensible communication interface for effective communication with the user, who

Table 9
Irrigation strategies mentioned in the literature for obtaining precision irrigation.

Article	Irrigation systems
Kim and Evans (2009)	Sprinkler irrigation
Kim et al. (2008)	Sprinkler irrigation
Hedley et al. (2013)	Sprinkler irrigation (centre pivot irrigator)
Gutiérrez et al. (2014)	Drip hole spacing
Sawant et al. (2017)	Drip irrigation
Cambra et al. (2018)	Hydroponic Precision Farming
Nagarajan and Minu (2018)	Sprinkler irrigation
Dursun and Ozden (2011)	Drip irrigation
Işik et al. (2017)	Drip irrigation
Shaker and Imran (2013)	Pipe irrigation
González-Briones et al. (2018)	Pivot irrigation
Rahim Khan et al. (2013)	Any
Chikankar et al. (2015)	Drip irrigation
Angelopoulos et al. (2011)	Home irrigation

could be the farmer,

(ii) The developed system must not be affected by the various crop growth phases,
(iii) The system must not be affected equally by the different climate changes,
(iv) The system must ensure a rapid response in real-time.

The following is a set of procedures and steps for establishing an automated smart irrigation system based on wireless sensor networks (Hamami and Nassereddine, 2018b, 2020), summarized in Table 12.

In Fig. 9, we show and describe the operating flow of our proposed methodology for a smart irrigation system utilizing WSN.

Determining the structure of a smart irrigation system is one of the most crucial steps that can provide optimal efficiency for irrigation system management. Primarily, an automated system for smartly managing irrigation by using wireless sensor networks should include the components listed below, as follows.

Sensor nodes: In the field of irrigation, sensor nodes can be either weather sensor nodes and/or soil sensor nodes. The number of sensor nodes scattered in the field differs depending on the wide of the field. Moreover, according to the needs and requirements of the developed irrigation systems, the type of sensor nodes utilized is decided.

Soil sensor nodes are dispersed on the soil within the area to be irrigated. Such nodes are used to measure and process soil conditions, the most important of which are: soil moisture, soil temperature, and soil pH.

Weather sensor nodes are deployed within the area to be irrigated. These nodes are used to measure and process weather conditions, the most important of which are: temperature, wind speed and direction, and humidity.

Many sensors can be employed in irrigation, soil-related sensors such as EC-5, VH 400, Sensor S8000 pH, and TDR-3A (see Table 4) and weather-related sensors such as SHT85, HMP35C, DS18B20, and Wind Monitor Model 05103 (see Table 5).

Table 11
Communication technologies mentioned in the literature for obtaining precision irrigation.

Article	Communication technology used
Kim and Evans (2009)	Bluetooth
Avatade and Dhanure (2015)	Zigbee and GPRS/GSM
Navarro-Hellín et al. (2015)	Zigbee
Nikolidakis et al. (2015)	Zigbee
Kim et al. (2008)	Bluetooth
Gutiérrez et al. (2014)	Zigbee and GPRS/GSM
Sawant et al. (2017)	Wi-Fi
Nagarajan and Minu (2018)	ZigBee
Işik et al. (2017)	Wi-Fi
Shaker and Imran (2013)	Zigbee
Chikankar et al. (2015)	Zigbee
Angelopoulos et al. (2011)	ZigBee

Base Station: The base station acts as the entry point to the wireless sensor network. It is a node with powerful functionalities for collecting and processing the data detected and measured by the sensor nodes. It also allows the transfer of this data to a coordinator node for further analysis.

The network of transmission: The sensor nodes are connected and communicated to the base station and the base station to the coordinator node through a wireless communication technology for transmission of the collected and processed data.

There are many different wireless communication technologies, as mentioned in Section 2. For choosing a wireless communication protocol, it is necessary to take into account many parameters, the most important of which are: the range and size of the area, the defined budget, and the maximum number of nodes deployed.

Most applications using WSNs require low consumption of power and transfer over long distances small data quantities. As we mentioned earlier in Section 5.3, the ZigBee protocol is best suited for usage in the wireless sensor network, and it is, therefore, the best choice for types of monitoring applications in real-time like WSN applications in irrigation.

Coordinator Node: The coordinator node performs further analysis to verify and identify the measured data. It also enables the storage of these data in a database making it easier for farmers to display the irrigated area status and thus help in irrigation decision making. Moreover, this node transmits orders to many other nodes to manage the irrigation correctly using WSN.

Terminal surveillance and exploitation of the processed data: Based on the verification of the processed data and their analysis with threshold values for each measured parameter, the irrigation decision will be made. The status of the area to be irrigated for the farmers is displayed via an application online using for example a smartphone.

Irrigation system: According to the comparison results of the processed data with the threshold values so that if these results are

Table 10
Comparison of wireless communication technologies.

Parameters	Zigbee	Bluetooth	Wi-Fi	GPRS
IEEE Standard	802.15.4	802.15.1	802.11a/b/g/n	–
Application focus	Monitoring, control	Cable replacement	Data network, Internet, monitoring	Control, Internet, monitoring
Power consumption	Low	Medium	High	Medium
Nominal range	10–100 m	10 m	100 m	Coverage area of Entire GSM
Data rate	20–250 kbps	1 Mbps	11–54 Mbps	50–100 kbps/200 kbps/0.1–1 Gbps
Frequency band	868/915 MHz; 2.4 GHz	2.4 GHz	2.4 GHz; 5 GHz	2.4 GHz
Cost	Low	Low	High	Medium
Max number of cell nodes	> 65,000	8	2007	–
Battery life (days)	100–1000 +	1–7	0.5–5	–
Success metrics	• Low power, Low cost, • Scalability, Reliability	• Low cost, • Convenience	• Speed, • Flexibility	• Convenience, • Cost, Range,

Table 12
Procedures and steps for establishing a smart irrigation system using WSNs.

1	Deploying a group of sensor nodes in the area to be irrigated in order to set up a WSN,
2	Monitoring of soil parameters (e.g., temperature and moisture) and weather parameters (e.g., temperature, wind speed, and humidity) at predetermined times depending on the type of soil and crop being used,
3	Processing the measured data and transmitting the obtained data to the coordinator node for further analysis,
4	Exploitation and utilization of the processed data by the coordinator node in such a way that the control unit will make the decision to open or close the electro valve, and thus activate or deactivate the irrigation system,
5	Recording and saving the processed data in a database for future use.
6	Sending alerts to the user via GSM technology if necessary.

lower than the threshold values, the electro valve will open, and thus the irrigation system will be activated, and vice versa.

There are many irrigation systems, which can be classified into three main categories: surface irrigation, sprinkler irrigation, and drip irrigation. As mentioned earlier in Section 5.2.3, the drip irrigation system is best suited for use with the wireless sensor network in the field of irrigation. This is mainly because drip irrigation saves a lot of water compared to other systems and can also be automated.

7. Conclusion

The incorporation of wireless sensor networks with the field of irrigation helps to provide efficient and cost-effective solutions for supporting, improving, and strengthening irrigation systems. This integration is therefore also beneficial to guarantee efficient and rational irrigation water consumption and to alleviate to some extent the severity of the global water crisis. The present paper has provided a comprehensive review of the application and deployment of wireless sensor networks in the field of irrigation. Firstly, we presented and explained the various aspects of sensors and wireless sensor networks. Next, we highlighted different WSN applications in the field of irrigation, and then presented a synthesis of various works and research in this context. After that, we discussed the application and use of wireless sensor networks in the field of irrigation, by presenting various wireless

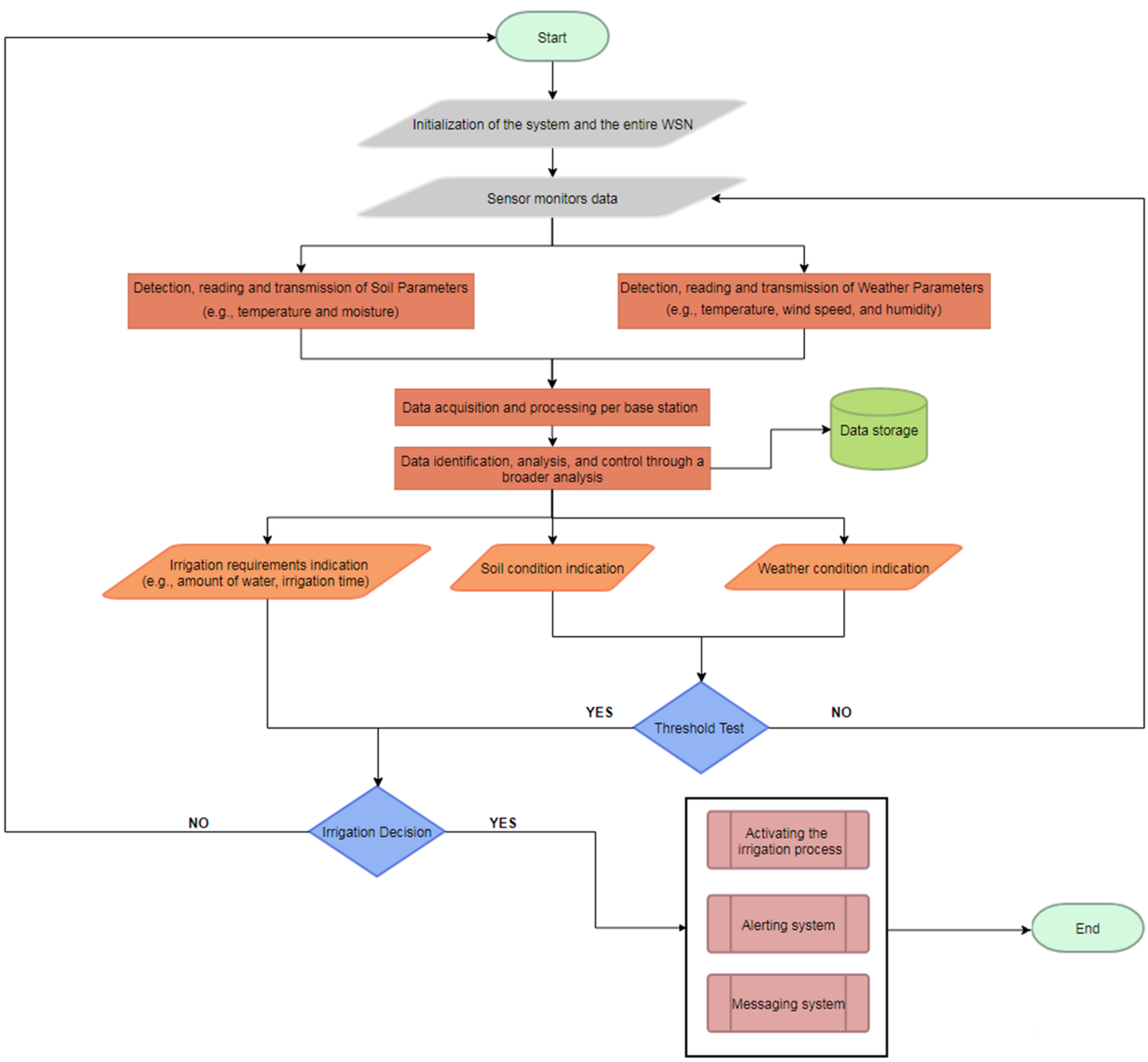


Fig. 9. Workflow algorithm of the proposed methodology.

communication technologies used, various sensors used, and irrigation strategies, soil types, and types of crop grown to study the role of WSN in the field of irrigation. According to this survey, we note that a smart irrigation system can be efficient and offers significant potential to economize irrigation water if it is well and properly planned, managed, and maintained. Finally, a proposed methodology is presented to implement an automated system for smartly managing irrigation using wireless sensor networks.

Declaration of Competing Interest

The authors declare that they have no known competing financialinterestsor personal relationships that could have appeared to influence the work reported in this paper.

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