ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, *Vol 9(48), DOI: 10.17485/ijst/2016/v9i48/108006, December 2016* ISSN (Online) : 0974-5645

A Review of Wireless Sensor Networks in Automated Irrigation

V. Gokul[1], R. Ezhilarasie[2]* and A. Umamakeswari[2]

[1]SASTRA University, Thanjavur - 613401, Tamil Nadu, India; gokul.rasven@gmail.com
[2]School of Computing, SASTRA University, Thanjavur - 613401, Tamil Nadu, India; ezhil@cse.sastra.edu, aum@cse.sastra.edu

Abstract

Objectives: The objective of making the irrigation system automated is not only to decrease the human intervention but also to irrigate optimal water to the crop without affecting its growth. The aim of this paper is to focus on existing technologies for making the irrigation process autonomous and effective use of wireless sensor networks. **Method:** Many existing methodologies use threshold based algorithm and fuzzy logic which lead to imprecise output. **Findings:** For the effective automated irrigation, the factors such as the algorithm for finding reference evapo-transpiration and the sensor node capabilities in terms of processing and communication unit and possible exceptions during the irrigation process all have to be considered to have a precise agriculture. **Applications:** Agriculture is an important area where sensors are deployed for providing abundant benefits like determining the water requirement of the crop, fertility of the soil, index of the leaf area, temperature of the leaf, data about local climate, water quality, water overflow, water continuity etc.

Keywords: Automated Irrigation, Fertility, Optimal Water, Wireless Sensor Networks

1. Introduction

Agriculture plays a vital role in Indian economy. Irrigation plays a main role in the entire agriculture process. The process of providing water to the crops artificially by means of dripper lines, pipes or sprayers is called irrigation[1]. Irrigating water more or lesser than the required level will affect plants growth and also the final yield. There are many types of irrigation techniques, each having its own advantages and disadvantages. Rahat is a traditional method found 1300 years old before which uses Persian wheel to take the surface water. It needs more laborious to operate[2]. Then surface irrigation is done effective by using submersible pumps and centrifugal pumps. This method also needs more laborious to operate and the land should be uniform[3]. Then sprinkler based irrigation developed where water is sprayed with heavy pressure like a rain using sprinklers[4]. By this method the crop get affected by increases in worms like sap beetles. Drip irrigation is an ongoing successful project for providing good yield and more water conservation without affecting the growth of the crop. In drip irrigation, water is irrigated directly to the root of the crop using emitters[5].

The objective of automated irrigation system is to reduce the human interaction and also to irrigate optimal amount of water to the crop without affecting its growth to attain water conservation[6]. Wireless Sensor Networks (WSN) is very much worthwhile for monitoring and controlling application ensuring low cost, low power and high reliability. WSN comprises of more sensor nodes equipped with processing, sensing and communication functionalities. These nodes differ with different infrastructures and make the irrigation system autonomous[7]. Irrigation depends not only on soil moisture but also depends on air humidity, wind speed, bright sunshine hours and air temperature. For the effective reference evapo-transpiration, these all parameter have to be sensed in the automated irrigation system. Evapo-transpiration is the combined nature of evaporation and transpiration. The phenomenon of water getting evaporated from the land called evaporation. The process of evaporating water from the plant called

* *Author for correspondence*

transpiration[8]. There are many models available for finding reference evapo-transpiration like Penman-Monteith FAO-56, Blaney Criddle, Mahringer, Priestley Taylor etc., among these, PM FAO-56 mostly recommended by food and agricultural organization because of its accurate determination of reference evapotranspiration[9]. Product of reference evapo-transpiration with corresponding crop coefficient gives the crop evapotranspiration[10]. Optimal irrigation is the process of irrigating water exactly equal to crop evapo-transpiration. Manually, it is very difficult to provide optimal irrigation. It is necessary to integrate the irrigation methods with technology to make it very effective and autonomous.

2. Literature Survey

The final yield of any crop fully depends on various environmental calamities like sunlight, wind speed, air temperature and soil moisture. Today's world technology is improving minute by minute. These technologies must be integrated with the agricultural process to achieve not only autonomous and effective operations but also to attain the maximum water conservation without affecting the crops growth.

In[11] focuses on providing optimal water for the crop growth and showed results that this methodology required only 10% of the water needed for traditional irrigation methods. This system provides irrigation when soil moisture values reached below the threshold value or when the soil temperature value exceeds the threshold value. This system also provides fixed duration irrigation by switching manually and irrigation at a particular date and time exactly through a web application. Date and time details are downloaded to the end nodes sensing unit, whereas sensor values and irrigation results are uploaded to a web application using the GPRS. The advantages of this system includes low cost irrigation system and also when received signal strength is low, all the data will be stored in solid state memory and the system tries to reestablish the connection for each hour to increase the data reliability. The issues with this system includes automatic irrigation based on soil temperature and soil moisture as a result the irrigation efficiency will get affected because the irrigation also depends on other parameters like air humidity, wind speed and bright sunshine and the coverage area is less since Xbee is limited to 120 meters[11].

In[12] focuses on an automatic irrigation approach based on the smart phone irrigation sensor. To start the Process, the app request the user defined time to begin the periodic process which includes turn on the active mode, LCD screen, and camera and Wi-Fi connectivity. Once the app activated all the above things, the illumination circuit will turned on and the app will take a photo of the soil. After that the illumination circuit will get turned off for saving the power. The RGB image of the soil is converted to grayscale image where white pixel represents dry region, and dark pixel represents wet region. Then the pixel differentiation process is carried out by subtracting the gray image from a light field matrix to find the number of wet pixels. From that relative wet soil value is computed and transmitted to the gateway via router node. The duration of irrigation process is controlled by the gateway node. Finally, the app turns on the sleep mode until for the next iteration for energy saving. The advantage of this system includes minimized hardware complexity, larger network coverage with the help of Wi-Fi and high energy efficiency by tapping the smart phone into sleep mode. To determine cumulative relative wet soil value more smart phone irrigation sensors has to be deployed that increases the cost of the system is considered as the drawback of the system[12].

In[13] focuses on automated valve control as well as a manual valve control using wireless sensor networks. All the nodes send the soil moisture values to the base station for every 16 minutes. Based on the moisture value, the base station sends the command to the node containing valve actuator to open and close the valves. The node containing valve actuator has equipped with boost regulator to generate 12V for the relay operation. All these operations are updated to the web interface using the gateway. Through the web interface, the user can view all the past and present information like sensor data, time at which valve gets opened and closed and battery life. In addition to that, the user can manually do time based irrigation and schedule based irrigation through the web interface. The advantages of this system include by means of web interface the user can see the irrigation details and manually do time based irrigation and schedule based irrigation irrespective of their location. The major issues with this system include not considering air humidity, wind speed and bright sunshine values truncates the irrigation efficiency[13].

In[14] focuses on automated irrigation system with an efficient routing protocol called ECHERP (Equalized

Cluster Head Election Routing Protocol). All the readings, estimated by the sensor nodes will be transmitted to the base station. The base station also acts as a gateway to send that information to the server. The user can access directly through the web interfaces from their laptop, PC and smart phones. This system uses Priestley-Taylor method for finding the reference evapo-transpiration value. This system also considers historical data to make the automated irrigation process very effective. E.g., Less water will be required if the past temperature value decreased. ECHERP uses Gaussian elimination algorithm to elect a sensor node as a cluster head. The advantages of this system includes increased energy efficiency when compared to other routing protocols like TEEN, LEACH and PEGASIS and consideration of historical data produces great impact in optimal irrigation. The major problems with this system includes sunshine duration and humidity has not taken into account for calculating reference evapo-transpiration that reduces the irrigation efficiency and the overall coverage range is low since only 400 feet can be covered by Xbee devices[14].

In[15] focuses on automatic region specified irrigation in greenhouses using wireless sensor and actuator networks. This system uses Tyndall25 mote. Based on the existing knowledge of the plant growth and environmental parameters, a decision will be made for irrigation. Ontology based decision support system does this work. Hierarchy based decision trees can be done with the help of classification algorithms. This system uses machine learning process to enhance plant state diagnosis. Machine learning experimentation fully depends on logging data and it is used to derive new rules for the accurate determination of threshold for irrigation. To derive the irrigation rule, this system uses rule editor tool. This tool also provides the visualization of measured constraints and evaluated states. Quality indicators are used for handling the uncertainty of data. The advantages of this system includes fast configuration of sensor nodes with Tiny OS, integration of plant based method with soil-moisture sensor method increases the accuracy of irrigation on time and off time. The major contention with this system includes less coverage area of about 120 meters because of Xbee devices[15].

In[16] focuses on closed loop distant observing of precise irrigation by means ofCitect configuration software. All the end nodes will transmit the soil temperature, humidity and soil moisture values to the sink node for every 30 minutes. Once the sink node received the data, it compares the received data with predefined value. Based on that, sink node gives command to open as well as to close the valve. Information like soil moisture value, soil temperature value, humidity and valve status at various time intervals will be transmitted to the web server using GPRS module. The end user can remotely monitor from their PC, laptops and mobile phones via web interfaces. The advantages of this system include real time collection and transmission of data and conservation of water up to 25% when compared to normal irrigation systems. The major issues with this system include tapered irrigation efficiency by reason of not utilizing bright sunshine duration and wind speed values for reference evapotranspiration[16].

In[17] focuses on dynamic automatic irrigation and pesticide avoidance using wireless sensor networks. As soon the wireless sensor nodes measures the soil moisture and soil fertility, the on stream camera compares the measured value with reference values. Based on this, the valve gets actuated for irrigation. The valve keeps close when soil is wet and no pesticide found and gets open when soil is dry and pesticide found. When there is no need of irrigation the microcontroller will be in sleep mode and when needed the microcontroller will be in active mode for power consumption. The advantages of this system include improved energy efficiency using power saving modes, dynamic irrigation and pesticide avoidance. Reduced irrigation efficiency because of not considering bright sunshine duration, air temperature and wind speed values for reference evapo-transpiration are considered as the main issues with this system[17].

In[18] focuses on solar powered, economical, robust and automated irrigation management system using wireless sensor networks. The soil moisture values and soil temperature values sensed by the end devices are forwarded to the coordinator node. Based on the sensor data, the coordinator node gives the decision for the irrigation valve to open or to close. The coordinator node sends details like soil moisture value, soil temperature value, valve status, wireless link performance and battery level to the gateway node using Xbee device. The gateway node forwards all this information to the remote station through a cellular network. The alarms will horns when the battery voltage or the GPRS signal quality reaches below the minimum threshold. The user can monitor the irrigation system remotely through the web interfaces.

Economical for small scale farmers and reduced bytes of transmission of data due to the sampling interval of 15 minutes are considered as advantages of this system. The major contention with this system includes reduced irrigation efficiency by reason of ignoring air humidity, bright sunshine duration and wind speed values when finding reference evapo-transpiration and the coverage area is unsubstantial by cause of Xbee devices[18].

In[19] focuses on fuzzy logic based irrigation control using the Penman-Monteith model. In this system, the evapo-transpiration value is found by using environmental parameters like air temperature, air humidity, net solar radiation and wind speed value. The comparator compares the estimated evapo-transpiration value and the desired evapo-transpiration value and the output is given as one of the input and the length of the sowing period of the crop is given as the second input to the fuzzy logic controller. Fuzzification converts those two crisp input values to fuzzy sets. That fuzzy set is given to the fuzzy inference engine where fuzzy rule base consists of conditions using If Then for the irrigation duration. Once the fuzzy set compared with the fuzzy rule, fuzzy set output will be generated. It is then fed to the defuzzification unit that converts fuzzy set output into crisp output that tells the corresponding irrigation valve opening duration. The implementation of this system was done in MATLAB 7.8.0.347. The advantage of this system includes improved irrigation efficiency because of Penman-Monteith model. The major issues with this system includes fuzzy logic delivers surmised output that affects the closeness of irrigation duration[19].

In[20] focuses on fuzzy logic based irrigation system with wireless data logging in the state of Qatar. Some of the existing methods fed evapotranspiration value as an input to fuzzy controller. But here, direct sensor data like air temperature, soil-moisture, solar radiation and water flow are fed directly as the inputs to fuzzy logic controller. So, fuzzy rule base requires more number of conditions for determining the time and duration of irrigation. Here, fuzzy set of crisp input is done by using trapezoidal and triangular membership function. Max-Min Inference engine and Mamdani type rule base are used for the accurate determination of fuzzy set output. Crisp output of time and duration of irrigation is done by using centroid based defuzzification. Computed irrigation data will be sent to the radio station via the GPRS module. For the purpose of improvement and analysis, this system creates a database in the remote system. The advantage of this system includes improved tracking system performance. The major problems with this system include lowered exactness of irrigation duration due to imprecise output remitted by fuzzy logic[20].

In[21] focuses on automated irrigation system using Medium Access Control (MAC) protocol based on Time Division Multiple Access (TDMA) through wireless sensor networks. All the end nodes are homogenous, constrained in energy and equipped with soil moisture and temperature sensors to monitor the real time environment data. All the end nodes send the environmental data to the base station. Based on the threshold value, the base station informs the processing unit to actuate the motor for irrigation. Based on the TDMA scheduler time slot, on time and off time for the communication unit of all the end nodes will be decided to conserve energy. This system uses two energy conservation methods in TDMA scheduling process. The first method is, all the end nodes send the measured environmental data directly to the sink node. The second method is, data aggregation in which group of end nodes forms clusters, then the head of the cluster sends the aggregated form of data towards the sink node. The simulated results shown that, the aggregation method increases the residual energy and throughput by 10% and 13% respectively than the first method. The advantages of this system include achieved eminent energy efficiency because of using energy conservation methods[21].

In[22] focuses on determining the soil moisture values one hour in advance for getting the effective irrigation recommendations using neural network pattern classification technique in addition to fuzzy logic. The pattern classification methods used in this system includes Broyden Fletcher Goldfarb Shanno (BFGS) quasi-newton method and scaled conjugate gradient method. This pattern classification method uses input parameters like soil moisture, soil temperature, type of soil, present time and temperature of the environment, air humidity, UV index and intensity of sunlight, sun rising time, flow rate of air and CO_2 in air. This system analyzed Root Mean Square Error (RMSE) and Mean Square Error (MSE) estimated from the above two pattern classification methods. Scaled conjugate gradient method produces much lesser MSE and RMSE as well as estimates accurate soil moisture content than the BFGS quasi-newton method. The estimated soil moisture content is fed as an input to fuzzy logic controller for getting the irrigation suggestions. The advantages of this system include attaining the sensor data in real time manner from farm locations. The main issues with this system included based peculiarity of irrigation suggestions by virtue of uncertain output from the fuzzy logic controller[22].

In[23] focuses on wireless underground sensor networks based autonomous center pivot irrigation system. The soil moisture sensor in the sensing unit of the end nodes measures the soil conditions in real time manner. Based on the soil moisture value, the hydraulic valve will get actuated for the irrigation process. With the help of carefully designed antenna, this system improved the underground communication range up to 400% than conventional methods. This system evaluated the performance of the underground communication in a corn field. From the result, it is found that, the soil-air wireless communication gets affected significantly, since the sensors are buried into the soil as well as due to the texture of the soil. The advantage of this system includes improved energy efficiency by probabilistic transmission of data. The main issue with this system includes variation of signal quality time by time due to the soil moisture dynamics[23].

In[24] focuses on automated irrigation system based on neural network using wireless sensor network. The slave unit equipped with soil moisture sensor measures the soil characteristics in real time manner. The slave unit forwards the measured soil moisture value to the master unit via the Bluetooth module. Based on the soil moisture value, the irrigation valve gets actuated by the master unit. Soil moisture values and status of the irrigation valve are sent to personal computer via serial communication for maintaining the database for future purposes. From the results, this system provided accurate water and soil ratio and higher Peak Signal to Noise Ratio (PSNR) using neural network. The advantage of this system includes improved performance for controlling irrigation using neural network. The major issues with this system includes lower coverage area on account of Bluetooth being a communication medium between master and slave unit and deciding irrigation without employing bright sunshine duration and wind speed impoverishes irrigation efficiency[24].

In[25] focuses on automated irrigation system using wireless sensor network and fuzzy logic to preserve the water resource and to avoid the soil fertility loss. All the end nodes equipped with soil humidity sensor to measure the soil moisture. The end node forwards the measured soil moisture value and different crop growth information in different periods to the coordinator node via router node. This system uses Zigbee as a communication medium between coordinator node and end nodes. All the data from the coordinator node will be transmitted to the monitoring station using RS232. The deviation of soil moisture value and the time at which the deviation occurs are fed as input to the fuzzy logic controller. From that, opening and closing of the irrigation valve will be computed. The advantage of this system includes real time monitoring of crop growth and soil. The main issue with this system includes fuzzy logic gives imprecise output that slashes the irrigation efficiency and lesser bandwidth coverage forasmuch as Xbee is confined to 120 meters[25].

In[26] focuses on the automated irrigation system ensuring lower cost and higher power efficiency. The Wireless Sensing Unit (WSU) contains humidity sensor and soil temperature sensor. For the accurate measurement of soil temperature and humidity the WSU is buried into the soil. Once the WSU reads the soil temperature and humidity, it sends those values to Wireless Interface Unit (WIU). Then WIU actuates the solenoid valve for the irrigation process based on the threshold based algorithm. All the irrigation details will be intimated via Short Message Service (SMS) and also forwarded as an email to the farmer using General Packet Radio Service (GPRS) module. The advantage of this system includes lower cost and higher power efficiency. The major issues with this system includes the signal quality of the wireless sensing unit differs time by time due to soil moisture dynamics and other environmental parameters like sunshine duration, wind speed have not been used for the irrigation decision which significantly affects the irrigation efficiency[26,27] focuses on determining the water level of the irrigation process using wireless data acquisition system. In the transmitter section once the ultrasonic sensor reads the water level, it will forward the data to the receiver section via the Radio Frequency (RF) transmitter. On the receiver side once the RF receiver receives the data, it will display that in the LCD screen. The advantage of this system includes high energy efficiency and data reliability. The major issue with this system is lesser coverage area since RF transmitter and receiver can able to cover upto 100 meters only[27].

Table 1. Hardware components and methodology used in the existing systems

Reference	Sensing element	Processing element	Communication element	Power unit	Methodology used
11	Soil sensor array	PIC24FJ64GB00	IEEE 802.15.4	MPT 4.8-7.5 Solar panel	Threshold based
12	Smart phone	Smart phone	IEEE 802.11	MPT 4.8-7.5 Solar panel	Pixel differentiation process to find relative wet soil value
13	Soil moisture sensor	Atmega 16L	IEEE 802.15.4	Solar panel	Threshold based
14	Temperature sensor, humidity sensor, soil moisture sensor	Microcontroller	IEEE 802.15.4	Battery	Priestley-Taylor method to find reference evapotranspiration
15	Soil moisture sensor, humidity sensor, thermistors	Atmega 128L	IEEE 802.15.4	25mm lithium ion battery	Ontology based decision support system
16	Soil temperature sensor, humidity sensor, soil moisture sensor	STC89C52	IEEE 802.15.4	Power adapter	Threshold based
17	Soil moisture sensor, soil fertility sensor	Atmega 128	IEEE 802.15.4	PV cell array	Threshold based
18	Moisture sensor, temperature sensor	Wasp motes	IEEE 802.15.4	Solar panel	Threshold based
19	Air temperature sensor, air humidity sensor	---	---	---	Fuzzy logic based
20	LDR sensor, soil moisture sensor, temperature sensor	Atmega 32	IEEE 802.15.4, GPRS module	100 watts photo voltaic solar cell	Fuzzy logic based
21	Soil moisture sensor, temperature sensor	PIC microcontroller	On board transceiver	PA2460 Power amplifier	Threshold based
22	Soil moisture sensor, humidity sensor, soil temperature sensor, LDR sensor, CO2 sensor	Raspberry Pi	IEEE 802.15.4, IEEE 802.11	Power adapter	Neural network pattern classification technique in addition with fuzzy logic based
23	Soil moisture sensor	Mica 2 (Atmel Atmega 128L)	Full wave dipole antenna and Single ended elliptical antenna (433MHz)	Battery	Threshold based
24	Soil moisture sensor	AT89C51	IEEE 802.15.4	Power adapter	Threshold based
25	Humidity sensor	8051	IEEE 802.15.4	Solar panel with lithium battery	Fuzzy logic based
26	Humidity sensor, soil temperature sensor	Arduino, Raspberry Pi	GPRS	Solar panel	Threshold based 28

3. Conclusion

In this paper, a review about the existing technologies for the automated irrigation process using wireless sensor networks is described. Mostly, the present methodologies use wireless LAN, Bluetooth and Xbee for the communication medium between end nodes and sink node that result in less coverage area. Some of the existing methodologies have taken only soil moisture value and humidity value for the irrigation decision. But irrigation also depends on wind speed, period of bright sunshine and air temperature which lead to imperfect determination of irrigation time requirement. Further, many existing methodologies use threshold based algorithm and fuzzy logic which lead to less precise output. For the effective automated irrigation, the factors such as the algorithm for finding reference evapo-transpiration and the sensor node capabilities in terms of processing and communication unit and possible exceptions during the irrigation process all have to be considered to have a precise agriculture.

4. Acknowledgements

The author wish to express sincere thanks to the Department of Science & Technology, New Delhi, India (Project ID: SR/FST/ETI-371/2014). We also thank SASTRA University, Thanjavur, India for extending the infrastructural support to carry out this work.

5. References

1. CDC - Types of Agricultural Water Use - Agricultural Water - Other Uses of Water - Healthy Water [Internet]. Cdc.gov. Available from: http://www.cdc.gov/healthywater/other/agricultural/types.html
2. Rehat – Traditional Irrigation [Internet]. Available from: https://www.youtube.com/watch?v=VpLuCWB7siA
3. Google Search [Internet]. Available from: Books.google.co.in. Available from: https://books.google.co.in/books?isbn=8132100182
4. Chapter 5. Sprinkler Irrigation [Internet]. Fao.org. Available from: http://www.fao.org/docrep/s8684e/s8684e06.htm
5. Chapter 6. Drip Irrigation [Internet]. Fao.org. Available from: http://www.fao.org/docrep/s8684e/s8684e07.htm
6. Kuzhalvaimozh CS. Irrigation and internet of things platform. IRJET. 2016; 3(3):1643-6.
7. Wireless Sensor Networks for Agricultural Applications [Internet]. Fraunhofer Food Chain Management Alliance. Available from: http://www.fcm.fraunhofer.de/en/beispiele11/drahtlose_sensornetzeinderland-undforstwirtschaft.html
8. on o evapotranspiration [Internet]. Fao.org. Available from: http://www.fao.org/docrep/x0490e/x0490e04.htm
9. Pandey S, Kumar M, Chakraborty S, Mahanti NC. A statistical comparison of reference evapotranspiration methods: A case study from Jharkhand state of India. International Journal of Innovative Research in Science, Engineering and Technology. 2014; 3(1):8765-77.
10. Bausch WC. Crop coefficients for use in irrigation scheduling. Water Conservation Factsheet, Ministry of Agriculture, Food and Fisheries. 2001 Oct; 27(1):55-68.
11. Gutierrez J, Villa-Medina J, Nieto-Garibay A, Porta-Gandara M. Automated irrigation system using a Wireless Sensor Network and GPRS module. IEEE Transaction on Instrumentation and Measurements. 2014; 63(1):166-76.
12. Gutierrez Jaguey J, Villa-Medina J, Lopez-Guzman A, Porta-Gandara M. Smartphone Irrigation Sensor. IEEE Sensors Journal. 2015; 15(9):5122-7.
13. Coates R, Delwiche M, Broad A, Holler M. Wireless sensor network with irrigation valve control. Computers and Electronics in Agriculture. 2013; 96:13-22.
14. Nikolidakis S, Kandris D, Vergados D, Douligeris C. Energy efficient automated control of irrigation in agriculture by using wireless sensor network. Computers and Electronics in Agriculture. 2015; 113:154-63.
15. Goumopoulos C, O'Flynn B, Kameas A. Automated zone-specific irrigation with wireless sensor/actuator network and adaptable decision support. Computers and Electronics in Agriculture. 2014; 105:20-33.
16. Yu X, Han W, Zhang Z. Remote monitoring system for intelligent irrigation in hybrid wireless sensor networks. International Journal of Control and Automation. 2015; 8(3):185-96.
17. Merlin Suba G, Jagadeesh YM, Karthik S, Sampath ER. Smart irrigation system through wireless sensor networks. ARPN Journal of Engineering and Applied Sciences. 2015; 10(17):7452-5.
18. Mafuta M, Zennaro M, Bagula A, Ault G, Gombachika H, Chadza T. Successful deployment of a wireless sensor network for precision agriculture in Malawi. International Journal of Distributed Sensor Networks. 2013: 1-13.
19. Rahangadale VS, Choudhary DS. On fuzzy logic based model for irrigation controller using Penman-Monteith equation. 2nd National Conference on Information and Communication Technology, NCICT; 2011. p. 22-5.
20. Touati F, Al-Hitmi M, Benhmed K, Tabish R. A fuzzy logic based irrigation system enhanced with wireless data logging applied to the state of Qatar. Computers and Electronics in Agriculture. 2013; 98:233-41.
21. Nesa Sudha M, Valarmathi M, Babu A. Energy efficient data transmission in automatic irrigation system using wireless sensor networks. Computers and Electronics in Agriculture. 2011; 78(2):215-21.

22. Mohapatra A, Lenka S. Neural network pattern classification and weather dependent fuzzy logic model for irrigation control in WSN based precision agriculture. Procedia Computer Science. 2016; 78:499-506.
23. Dong X, Vuran M, Irmak S. Autonomous precision agriculture through integration of wireless underground sensor networks with center pivot irrigation systems. Ad Hoc Networks. 2013; 11(7):1975-87.
24. Salam Al-Ammri, Sherin Ridah. Smart irrigation system using wireless sensor network. International Journal of Engineering Research and Technology. 2014; 11(7):3204-9.
25. Gao L, Zhang M, Chen G. An intelligent irrigation system based on wireless sensor network and fuzzy control. Journal of Networks. 2013; 8(5):1080-7.
26. Nallani S, Berlin Hency V. Low power cost effective automatic irrigation system. Indian Journal of Science and Technology. 2015; 8(23):1-6.
27. Mamun AA, Ahmed N, Ahamed NU, Matiur Rahman SAM, Ahmad B, Sundaraj K. Use of wireless sensor and microcontroller to develop water-level monitoring system. Indian Journal of Science and Technology. 2014; 7(9):1321-6.