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Research Article

IoT-SIWM: IoT Enabled Smart Irrigation System Based on Water Meter Using Mathematical Models

Nauman Riaz[1], Arbab Waseem Abbas[1*], Khalid Saeed[2], Waseem Ullah Khan[1*], Nisar Ali[3] and Kashif Ali[1]

[1]Institute of Computer Sciences and Information Technology, Faculty of Management and Computer Sciences, The University of Agriculture, Peshawar, Pakistan; [2]Department of Computer Science, Shaheed Benazir Bhutto University, Sheringal, Dir Upper, Pakistan; [3]Department of Computing, Abasyn University Peshawar, Pakistan.

Abstract: Internet of Things (IoT) is a revolutionary technology by creating smart surroundings that make it easier for humans to do their work. The IoT applications can be found in many fields such as logistics, transportation, healthcare, industries, supply chain and agriculture. In the agriculture sector, farmers use the traditional method for irrigation purposes. The farmers have no special idea about when and how much water is required for crops due to which the crops production is reduced. However, the low intensity of light also reduces the crops production. Also, water scarcity is now a widespread issue that affects many nations, particularly in rural and arid regions. Therefore, this necessitates the need for fabricating IoT based smart irrigation system to optimize water usage and monitor agriculture. This paper proposes a robust framework for smart irrigation systems. It is based on water meter using mathematical models to estimate the required water rate and effectively control it. The mathematical model is integrated into the Arduino microcontroller to check the level of soil moisture and light intensity and to compare it with the predefined threshold value. The proposed system enhances the effectiveness of watering systems by increasing crop production and consuming less water by more than 80%.

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***Correspondence:** Arbab Waseem Abbas and Waseem Ullah Khan, Institute of Computer Sciences and Information Technology, Faculty of Management and Computer Sciences, The University of Agriculture, Peshawar, Pakistan; **Email:** aristocratarbab@aup.edu.pk, waseem@uetpeshawar.edu.pk
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Introduction

Due to the food industries recent exponential growth and drastic shifts in consumer dietary habits and lifestyles, there has been a surge in food consciousness among the public (Parfitt *et al*., 2010). These days, people are more concerned about the quality and safety of the food they ingest. Foods that are free of impurities and substances that can foster the growth of tiny organisms harmful to people's health and lives are safe (Abdulkadyrova *et al*., 2016). Due to its importance as a major source of food, agriculture systems have a big impact on a nation's economic development. In a report released by the Food and Agriculture Organization of the United Nations, a sizable portion of food waste occurs

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because of different factors during the pre-harvesting, harvesting, and even post-harvest stages, as well as the extent of its influence on the economy, environment, health, and survival of the human race (Food, 2025). A UN analysis predicts that by the year 2050, there will be more than 9 billion people on the planet, a third more people than there are now (Godfray *et al*., 2010). In Pakistan, Nigeria, India, Indonesia, Ethiopia, the United Republic of Tanzania, Egypt, and the United States, more than half of this growth will take place. So, this increase in population needs a nearly 70% increase in the rate of food production.

This rapidly expanding population brings with it numerous new challenges, such as intensifying competition and excessive usage of land, water, and other natural resources. These challenges underscore the urgent need to reduce the dependency of the food system on the environment. Because of this, an evolutionary agricultural model is necessary to assure long-term development and to meet the growing demand for food and crop production. A smart sensing system is required in an agricultural field to integrate the field's status, its impact on field production, and to decide the activities that must be made on the field for a good result of a good yield. An ecosystem for "smart sensing" consists of a network of interconnected devices that may continuously transmit and receive data. Additionally, it can decide on a user's behalf and act to improve the environment (Vangala *et al*., 2021). This change in the environment calls for more frequent monitoring of the surroundings, which leads to an environment that is constantly changing.

Agriculture is the foundation of the human species and is crucial to a nation's economic development. Farmers continue to adopt conventional agriculture techniques, which lead to low crop and fruit yields. Therefore, incorporating Internet of Things (IoT) technologies can increase crop productivity (Alyahya *et al*., 2022). The smart agriculture architecture must include the Internet of Things. The integration of IoT devices has allowed for round-the-clock monitoring of the agricultural systems. To gather sensed data, these IoT devices detect the physical environment and environmental conditions. Such sensed data is subsequently transmitted to the backend server through the Internet or a sensor gateway, where it is stored for use in the future or even made available to the user. In such a controlled environment, the user can choose what actions to take. Integrating everyday devices with the Internet, however, is difficult undertaking.

Numerous challenges in agriculture can be solved by using cutting-edge IoT technologies, which can also boost agricultural production's quality, quantity, sustainability, and cost efficiency (Priyadharsnee *et al*., 2017). Smart irrigation systems powered by the IoT may also keep an eye on the field's temperature, humidity, rainfall, soil moisture and other field variables (Laksiri *et al*., 2019). These data can be kept on a distant server and used for additional processing, such as in disease diagnosis, soil condition analysis, and weather prediction. Some major environmental parameters that affect the plant productivity include temperature, light, water, nutrients, atmosphere and so on. Automating crop watering is a significant benefit to maximize water efficiency and boost productivity. Water stress can affect plants and slow their rate of growth due to both a lack of water and an abundance of it. The productivity of plants would be increased by determining the rate of water evaporation and supplying water to keep the soil moisture level at the ideal level (Harun *et al*., 2019). Similarly, water scarcity is becoming a major issue that affects many nations, particularly in rural and arid regions. Giving the plants the appropriate amount of water will ensure perfect growth, which is the goal of watering. To achieve the greatest efficacy, optimal irrigation management seeks to ascertain the timing and volume of water appropriate for irrigation. Therefore, this necessitates the need for fabricating IoT based smart irrigation system to optimize water usage and monitor agriculture, which leads to better crop production. So, to improve farming systems' productivity and lower the amount of discharged water, many researchers have debated the need to create a self-watering mechanism. This paper proposes a robust framework for smart irrigation system based on water meter using mathematical models to estimate the required water rate and effectively control it. The mathematical model is integrated into the Arduino microcontroller to check the level of soil moisture and light intensity and to compare it with the predefined threshold value. The proposed system enhances the effectiveness of watering system and can automate, and control water supply based on soil moisture levels.

Literature review

In this section the related literature is discussed about smart irrigation, agriculture, Internet of Things and microcontroller.

IoT is a new revolution of Information Technology (IT). The IoT devices are used in smart logistics, smart industries, smart health and smart homes. Authors in (Imteaj *et al*., 2016) developed automated water supply in farmland using raspberry pi 3. The sensors ensure overall scalable and spirited implementation. The system depends upon the soil moisture level of the field. To communicate with the system, text messages are used. Kumar in (Kumar *et al*., 2019) presented the Effective dampness monitor and control based on modern irrigation system (MIS) with Arduino Nano microcontroller. The proposed system can control the irrigation system automatically and provide water to the fields when required. In (Monica *et al*., 2017), Monica presented a model automation of smart irrigation system based on GSM module, Wi-Fi module, soil moisture sensor, humidity sensor, temperature sensor and arduino Uno to manage the whole system. The GSM module is used to determine the status of the field through messages by mobile phone. The humidity sensor is used to determine the humidity in the field and then send it to the arduino microcontroller. The temperature sensor is used to detect the temperature in the field then send data to arduino Uno. Soil moisture sensor is used to determine the level of soil moisture in the field and send it to the arduino microcontroller.

In (Kaewmard *et al*., 2014), the authors suggested a low-cost intelligent irrigation system utilizing a neural network method to determine the sensor input based on the irrigation schedule for optimal irrigation. The suggested devices provided numerous features, including calculation of irrigation schedules, decision-making, and remote data monitoring. Srbinovska (Srbinovska *et al*., 2019) developed an additional method of real-time monitoring in agricultural areas utilizing wireless sensor network architecture to raise the calibre of output. They concentrate on the insufficient tolerance and energy efficiency of the sensors used for sensing agriculturally related parameters. An automation agricultural strategy built on long-term sustainability was also put up (Mahajan, 2021). In the vegetable fields, the connected sensors can be relocated to capture any potential changes in the environmental factors. A smartphone application-based method for sensing and tracking soil moisture and temperature parameters was created by (Hashim *et al*., 2015). The benefits of small- and large-scale agriculture-related structures were contrasted. It was asserted that small-scale systems are less expensive than large-scale systems that call for pricey components.

Using the IoT, which offered a facility for sensing, processing, and evaluating environmental data, (Nawandar *et al*., 2019) proposed the connecting method between various sensors. To communicate with one another, these devices frequently use accepted network protocols. The goal of Ashton's strategy was to create tools that automatically created reports in real-time, increasing efficiency and gathering pertinent data. A remote-controlled irrigation system for water was suggested by (Damas *et al*., 2001) for use in various agricultural locations. To automate the irrigation operation, computer networks were employed to connect each area to the central controller. The actual findings demonstrated that the suggested approach might save up to 30–60% of the water used. Additionally, the authors in (Evans *et al*., 2003) technique managed irrigation by utilizing wireless sensors to gather environmental data from the surrounding area and aid in the creation of an irrigation schedule. To manage irrigation timing and watering requirements in various soil moisture conditions, (Ofrim *et al*., 2010) developed an automatic irrigation system using the ZigBee wireless sensor network. One of the most important concerns in agriculture is the irrigation process, where various irrigation strategies are employed to reduce water waste in traditional irrigation techniques (Sarwar *et al*., 2022).

Materials and Methods

The proposed system is used for continues monitoring the fields. The soil moisture sensor senses the moisture level of the field soil then supplies water on the requirement. Soil moisture sensor, temperature sensor, humidity sensor and light dependent resistor are connected to the input pins of Arduino Uno microcontroller. These sensors get data from the environment and send to the Arduino microcontroller then the microcontroller takes decision based on received data. The GSM/GPRS module, Bluetooth module, water motor, water flow meter and artificial lights are connected to the output pins of Arduino Uno microcontroller as shown in Figure 1.

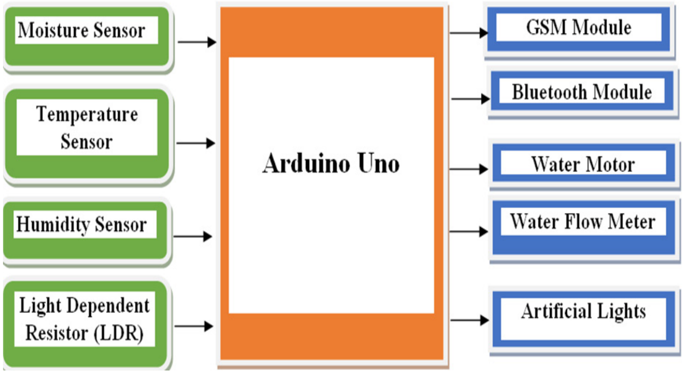

Figure 1: *Proposed system architecture.*

Flow chart of proposed system

The main part of the whole system is Arduino micro-controller which is also known as the brain of the whole system. The micro-controller manages all the processes of irrigation like water motor turn ON/OFF, artificial lights turn ON/OFF. The model can control or manage the irrigation process automatically. Also, water motors, water meter and artificial lights are turned ON/OFF automatically through specific algorithms for each. The flow chart of the proposed system is shown in Figure 2.

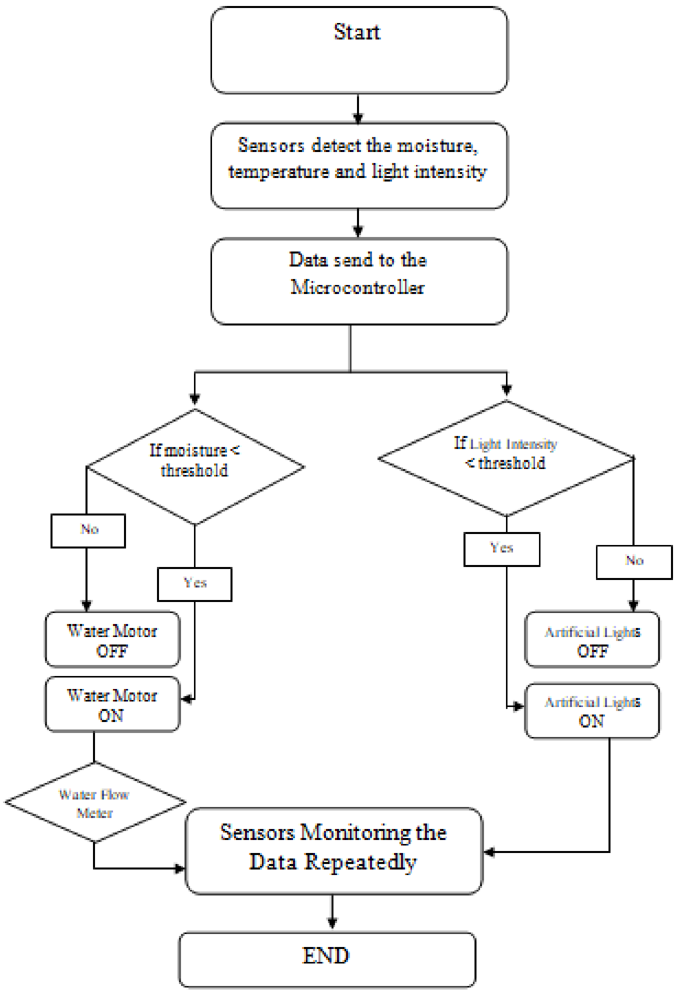

Figure 2: *Block diagram of proposed system.*

Alogrithm 1: For water meter and water motor ON/OFF.
if System Mode = AMON
(Auto Mode ON) then
Soil Moisture Check
Get the sensor data
if SML < threshold
(Soil Moisture Level) then
Auto Water Motor ON
Auto Water Meter ON
end
SML > threshold
(Soil Moisture Level)
Auto Water Motor is OFF
end
Mode = AMOFF
(Auto Mode OFF)
Read Message
if Message =WMOTORON then
Water Motor ON
Water Meter ON
end
Message = WMOTOROFF
Water Motor OFF

Algorithm 2: For Artificial lights ON/OFF
if Mode = AMON
(Auto Mode ON) then
Intensity of Light Check
Get sensor data
if Light Intensity < threshold then
Lights ON
end
Light Intensity > threshold
Lights OFF
end
Mode = AMOFF
(Auto Mode OFF)
Read Message
if Message = LIGHTSON then
Lights ON
end
Message = LIGHTSOFF
Lights OFF

Blocked diagram of the system

The flow of smart irrigation model is defined in the blocked diagram as shown in Figure 3. This includes all the steps of the model from getting the data and its processing to the last step of output result.

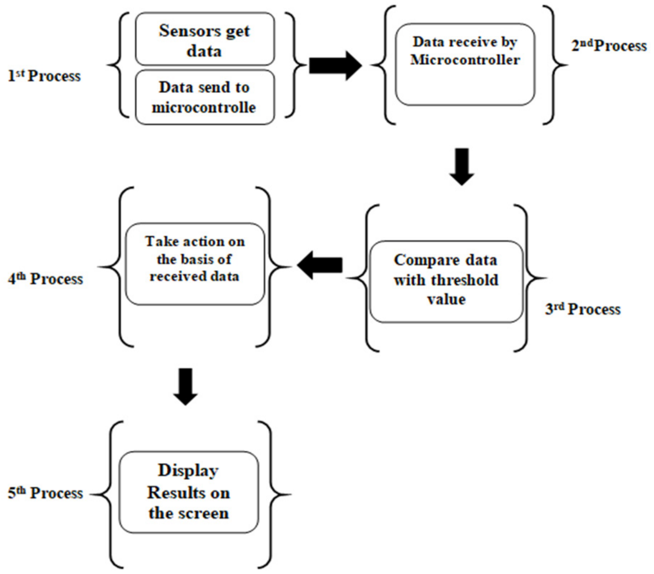

Figure 3: Block diagram of proposed system.

Stepwise approach to proposed system

The proposed system is defined in stepwise approach as shown in Figure 4. The first step is to find the problem. In this step, problem investigation is done in the smart irrigation system. The next step is to design and develop a model which includes all the functionalities. In the last step testing and performance evaluation is done.

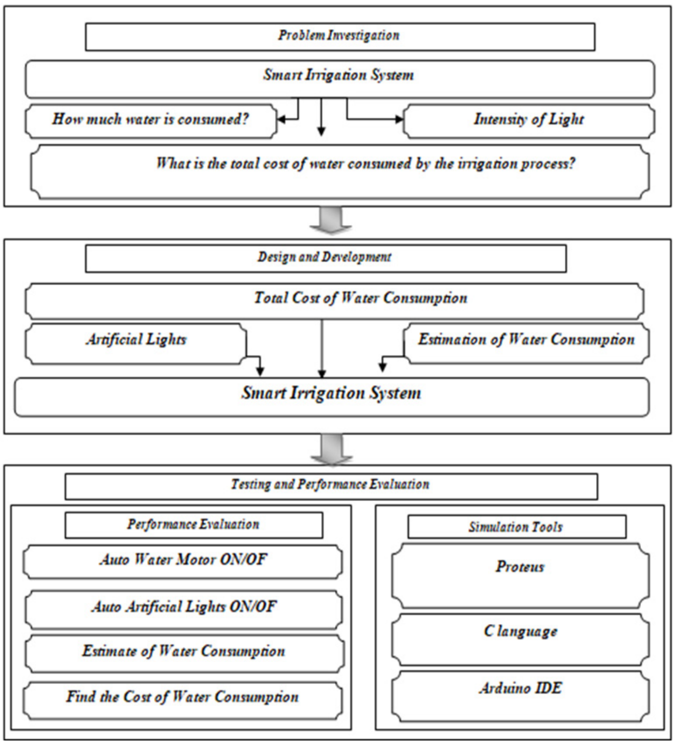

Figure 4: *Stepwise approach to proposed system.*

Mathematical model

Mathematical modeling is the ability to translate problems from a physical area into well-mannered mathematical formulations whose theoretical and numerical analysis provides answers and guidance which is useful for originating application.

Equation 1 is used to determine the total consumption of water by the fields. Where TM stands for total minutes that how much time the water motor is ON. Time is calculating in term of minutes. GPM stands for gallons per minute. That is how many gallons of water are pumping by water motor in one minute Arduino microcontroller estimate total water consumption by using this formula. Total water consumption is equal to total minutes multiply by gallons per minute.

$$TWC = [TM * GPM] \quad \dots. (1)$$

Where TWC is total water consumption, TM is total minutes and GPM is gallons per minute.

Equation 2 is used to determine the total cost of water consumption. TCWC stands for total cost of water consumption. TG stands for total gallons that how many gallons of water are consumed during the irrigation process. POG stands for the price of one gallon. It means how much it costs for one gallon of water. The microcontroller estimates the total cost of water consumed by the irrigation process.

$$TCWC = [TG * POG] \quad \dots. (2)$$

Where TCWC is the total cost of water consumption, TG is total gallons and POG is price of one gallon.

Equation 3 is used to find the total consumption of water by the fields with variable 'x'. Variable 'x' is an amount of extra water which totally depends on humans. According to this formula the usage of water is always grater with human interference.

$$TWC = [TM * GPM] + x \quad \dots. (3)$$

Where TWC is total water consumption, TM is total minutes, GPM is gallons per minute and x is variable.

Equation 4 is used to determine the total cost of water consumption with variable 'x'. Variable 'x' depends on human interference. According to this formula the cost of total consumption of water is always high with variable 'x'. Variable 'x' is an amount of extra cost of water which totally depends on humans.

$$TCWC = [TG * POG] + x \quad \dots(4)$$

Where TCWC is the total cost of water consumption, TG is total gallons, POG is price of one gallons and x is variable.

Results and Discussions

The result of water motors and water meters are totally based on the condition of soil moisture and its threshold. Artificial lights turn ON/OFF also depend on the light intensity and its threshold. The threshold is a specific value given to the micro-controller.

Water motor ON/OFF

The soil moisture sensor gets data from the soil and sends it to the microcontroller. Microcontroller compares the receive data with the given threshold. For testing purposes, the soil moisture threshold is 55% to 60%. If soil moisture level is below 55% then the micro-controller turns ON, the water motor automatically. If the soil moisture level is high from 60% the micro-controller turns OFF water motor automatically as illustrated in Figure 5. Table 1 describes the water motor status based on soil moisture level.

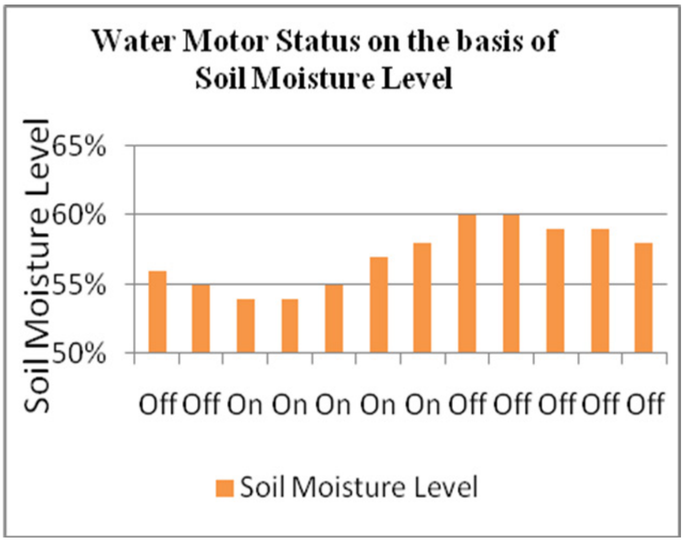

Figure 5: *Automatic water motor on/off*

Estimation of water consumption

The proposed system estimates the consumption of water during irrigation process as shown in Figure 6. It determines how much water is consumed by irrigation. To determine the water consumption, the proposed system uses a water consumption formula as shown in Equation 1. 3.78 litters are equal to 1 gallon. The estimation of water consumption is given in Table 2.

Table 1: *Water motor status based on soil moisture level.*

Soil moisture level	Water motor status
SML 46%	Water Motor OFF
SML 45%	Water Motor OFF
SML 44%	Water Motor ON
SML 44%	Water Motor ON
SML 45%	Water Motor ON
SML 47%	Water Motor ON
SML 48%	Water Motor ON
SML 50%	Water Motor OFF
SML 50%	Water Motor OFF
SML 49%	Water Motor OFF
SML 49%	Water Motor OFF
SML 48%	Water Motor OFF

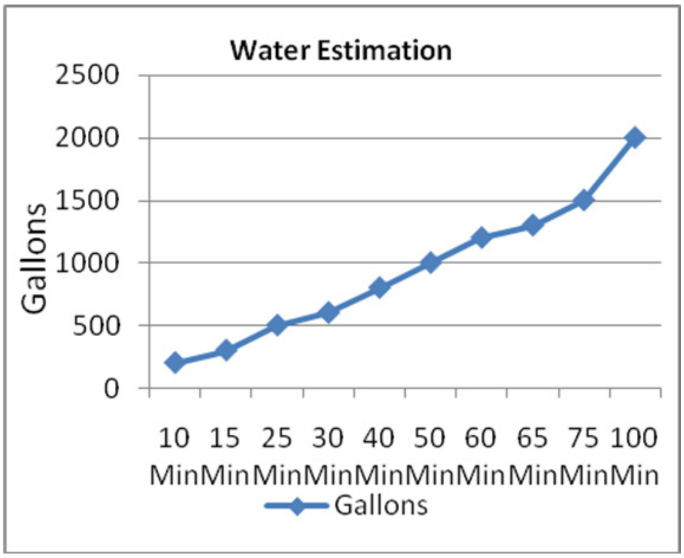

Figure 6: *Estimation of water consumption*

Table 2: *Estimation of water consumption.*

Minutes	Gallons
10 Minutes	200 Gallons
15 Minutes	300 Gallons
25 Minutes	500 Gallons
30 Minutes	600 Gallons
40 Minutes	800 Gallons
50 Minutes	1000 Gallons
60 Minutes	1200 Gallons
65 Minutes	1300 Gallons
75 Minutes	1500 Gallons
100 Minutes	2000 Gallons

Cost estimation of consumed water

The proposed system offers the cost estimation of the consumed water during irrigation process as shown in Figure 7. It calculates the cost of water which is consumed by the irrigation process. To determine the cost of water consumption the model uses a formula of cost estimation as shown in Equation 2. For testing the cost of one gallon is PKR 0.5. **Table 3** is based on the cost estimation of water consumption.

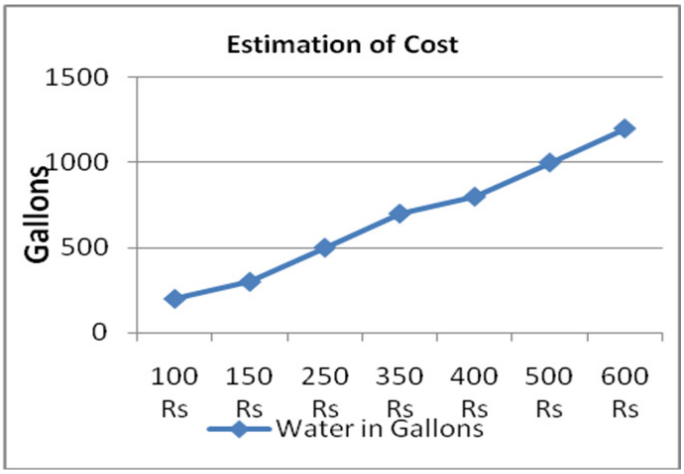

Figure 7: *Cost estimation for water consumption.*

Table 3: *Cost estimation of water consumption.*

Water in Gallons	of water in PKR
200 Gallons	100 Rs
300 Gallons	150 Rs
500 Gallons	250 Rs
700 Gallons	350 Rs
800 Gallons	400 Rs
1000 Gallons	500 Rs
1200 Gallons	600 Rs

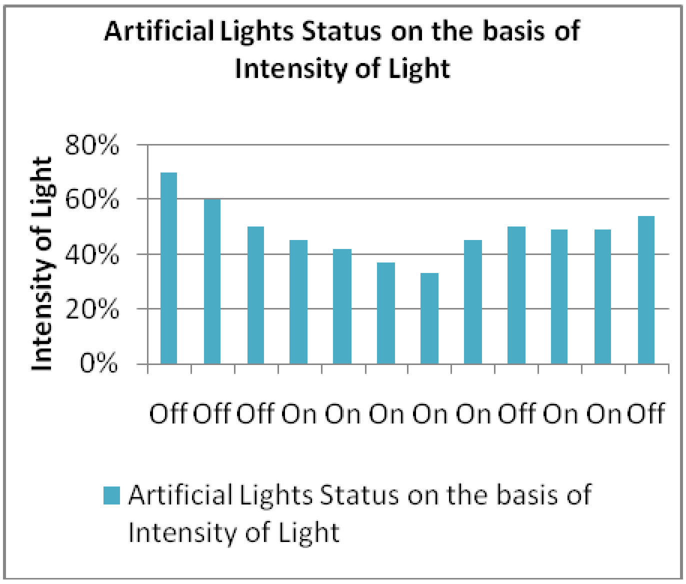

Figure 8: *Automatic artificial lights on/off.*

Artificial lights ON/OFF

In the proposed system artificial lights are used to solve the problem of low intensity of light. Low intensity of light affects the photosynthesis process of crops especially during rainy days. For testing purposes, the threshold value for intensity of light is 50%. If the light intensity is low from the desire level the artificial turns ON automatically and if the light intensity is high from the threshold value, the lights turn OFF as shown in Figure 8. The status of artificial lights on the basis of light intensity is shown in Table 4.

Table 4: *Artificial lights status on the basis of light intensity.*

Light Intensity	Status of Lights
LI 70%	Lights OFF
LI 60%	Lights OFF
LI 50%	Lights OFF
LI 45%	Lights ON
LI 42%	ON
LI 37%	Lights ON
LI 33%	Lights ON
LI 45%	Lights ON
LI 50%	Lights OFF
LI 49%	Lights ON
LI 49%	Lights ON
LI 54%	Lights OFF

Conclusions and Recommendations

The proposed system aim is to facilitate the farmers and automate the whole irrigation process, i.e. automatic water motor ON/OFF on the basis of soil dampness level, calculate the consumption of water in irrigation process, estimate the total cost of the consumed water during irrigation and provide light source during low intensity of light without any human interaction. The result of Table 1 shows that the proposed system performs perfectly by automatically turning ON and turning OFF water motors according to the given threshold. Moreover, Table 2 describes the estimation of consumed water by irrigation process. Table 3 shows the cost of water which is consumed by irrigation process. Table 4 shows the result of artificial lights which automatically turn ON when the intensity of light is low then the given threshold and turn OFF when the intensity of light is high. For future work the suggestion for improving it using a solar panel for the power consumption of the system. Hence, the system is going to be eco-friendly.

Novelty Statement

This paper proposes a novel IoT-based smart irrigation system that integrates mathematical modelling and sensor data (soil moisture and light intensity) using an Arduino microcontroller to automate and optimize water usage. The system reduces water consumption by over 80% while enhancing crop productivity, addressing critical challenges in traditional irrigation methods.

Author's Contribution

Nauman Riaz: Methodology, data management, Writing-original draft.
Arbab Waseem Abbas: Conceptualization, methodology, formal analysis, writing original manuscript., project administration.
Khalid Saeed: Conceptualization, formal analysis, project administration.
Waseem Ullah Khan: Conceptualization, methodology, formal analysis, data management, writing original manuscript.
Nisar Ali: Conceptualization, formal analysis, methodology, formal analysis.
Kashif Ali: Formal analysis, data management, project administration.

Data availability
The data that support the findings of this research study are available on request from the corresponding author.

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Conflict of interest
The authors declare no conflict of interest.

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