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## A complete study in smart environmental monitoring and irrigation system using Arduino

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### Abstract

In response to rising water shortages and the growing need for sustainable agriculture methods, this study describes the creation of a smart environmental monitoring and automated irrigation system based on Arduino technology. The system uses a number of sensors, including a soil moisture sensor, a DHT11 temperature and humidity sensor, a rain sensor, and a water level sensor, to monitor environmental conditions in real time. Sensor data are shown on an LCD screen and on the Serial Monitor for debugging and monitoring. A relay-controlled water pump is started based on certain conditions, such as dry soil, no rain observed, and a sufficient reservoir water level. Arduino IDE is used for programming, and Tinkercad for simulation and testing before physical implementation, which enhances the development process and reduces errors. The proposed system improves water management, decreases manual intervention, and promotes sustainable agriculture. The suggested approach is low-cost, flexible, and scalable, making it appropriate for small-sized agricultural applications, as well as for both educational and practical agricultural applications. The findings show that smart irrigation not only conserves resources but also improves farming production efficiency.

**Keywords:** - Smart Irrigation System, Environmental Monitoring, Arduino, Soil Moisture Sensor, DHT11 Sensor, Water Level Monitoring, Rain Sensor.

### I. Introduction

Water is a scarce resource that is essential for life and agricultural productivity. Water shortage is a serious issue impacting countries all over the world, particularly in arid and semi-arid areas, with far-reaching consequences for global food security and the economic and environmental sustainability of human activities. Population growth and climate change have increased the demand for water, aggravating the situation [1]. Water and energy are wasted by using the traditional way of irrigation due to the wrong

time of irrigation which resulting in uneven or excessive watering. The technological advances in agriculture have fundamentally affected our vision and approach to food production. These developments, which include the use of smart sensors and advanced data processing techniques, have made agricultural operations more productive, efficient, and sustainable. These technologies have the potential to improve food production efficiency, save resources, and promote long-term economic growth. Integration by using technology is becoming increasingly important in addressing these issues. Water management is an essential component of agricultural activity [2].

Due to their affordability, ease of use, and versatility in connecting a multitude of sensors and actuators, microcontroller-based systems like Arduino have become more popular in academic and research environments [3]. Arduino IDE serves as the primary programming interface, this toolkit provides a complete environment for designing, programming, and simulating embedded systems. While Tinkercad is a cloud-based platform that allows users to digitally simulate electronic circuits and Arduino code, assist to speed up the development process, allowing developers and students to confirm their concepts before physically implementing them. [4].

This work aims to design and develop a smart irrigation system that automates water provision in response to environmental conditions, resulting in decreased water waste and aiding in precision agriculture by combining Arduino-based hardware with sensor inputs and relay control for water pumping, as well as evaluating the concept using Tinkercad simulation.

## II. Literature Review:

Various articles have looked into the use of irrigation systems with smart technology to reduce human involvement and improve water consumption. Table 1 illustrate some of these articles: -

**Table 1:** Literature review of some articles

Ref no	Year	Control Method	Sensors Used	Automation	System Validation + User Interface	Best Use Case	Advantages	Disadvantages	Future Work
[5]	2018	Moisture threshold	Soil moisture	Basic	- Conceptual and practical testing. - Serial monitor of Arduino IDE.	Small-scale gardens, home gardens	- Simple and low-cost - Easy to build and implement	- Limited automation - Not suitable for large-scale use	-
[6]	2018	Threshold + GSM	Moisture, temperature	Remote monitoring	- Prototype tested. - GSM-	Remote fields with	- Remote access - Real-time	- GSM cost - Moderate complexity	Include mobile app

			ure, humidity		based SMS	low labor	monitoring		and cloud data storage . using Wireles s sensors .
[7]	2018	Thresho ld + GSM alerts	Soil moisture	Enhanced with alerts	- Field prototype. - SMS alert + LCD.	Farm irrigati on, larger fields	- Water- saving - SMS alerts - very easy to Implement . - cost- effective	- GSM reliance	Switch to cloud- based automa tion with a mobile dashbo ard.
[8]	2019	SMS- based moistur e & manual	3x Soil Moisture , Rain Sensor	Semi- automated + SMS	- Prototype tested. - Basic SMS alerts.	Garden s, remote farms with GSM access	- Remote SMS control - Water conservati on - Easy SMS interface	- Requires manual SMS intervention - GSM-only control	-
[9]	2020	IoT- based automat ion	Soil moisture , temperat ure, pH, ultrasoni c	Advanced	- Prototype tested. - Android app, web interface	Smart agricul ture in remote areas	- Real-time monitoring . - Fertilizer suggestion s. - Automated water flow control. - time saving, cost effectivene ss	- Requires stable internet. - Initial setup complexity	-
[10]	2020	Fuzzy logic	FC-28 soil moisture	Smart decision- making	- Field tested.	Control led precisi on farmin g	- Adaptive control - Efficient water usage. - Use a low-cost soil moisture sensor	- Requires tuning - Complex fuzzy rules	include a water tank, networ k sensors , cloud/I oT monito ring, and deep learnin g.
[11]	2021	IOT & Machin e learning -based	Tempera ture, humidity , pH, pressure, Soil moisture	AI-driven automatio n	Prototype tested. LCD display + IoT dashboard	Smart agricul ture with AI integra tion	- Predictive analytics - Soil health monitoring .	- Requires ML model training. - Higher initial complexity	-

							- Water conservati on		
[12]	2022	Automa ted seeding & irrigatio n	Soil moisture , DHT22, ultrasoni c	Semi- autonomou s	Practical and Prototype tested Android app + SMS alerts	Small to mediu m farms with row crops	- Combined seeding and irrigation. - Obstacle avoidance. - Real-time monitoring	- Limited seed size compatibilit y. - Basic obstacle detection.	Integra tion of image process ing and robotic arm for weed remova l
[13]	2023	IoT-based automat ion	temperat ure, Rain, Water Level, Light Sensor	Advanced	- Prototype tested. - Remote access via IoT.	Smart agricul ture in remote areas	- Real-time monitoring . - Remote access. - automate and Efficient water usage	- Requires stable internet. - Initial setup complexity	-
[14]	2024	IoT-based monitor ing	Air quality, temperat ure, humidity , atmosph eric pressure, rainfall	Monitorin g system	- Prototype tested. - Web and mobile application	Enviro nmenta l monitor ing in agricul ture and urban plannin g	- simple or less expensive Platform. - Real-time environme ntal data. - Remote access. - User-friendly interface	- Not directly controlling irrigation. - Requires stable internet	Optimi zing energy Utilizat ion by combin ing sun-oriente d control or energy-efficient compo nents.
[15]	2024	Multi-sensor threshol d	Moisture , Tempera ture , Humidit y DHT11, pressure BMP180, photores istor LDR, Gas MQ135	Advanced	- Tested on Proteus software + Arduino IDE. - LCD screen + Serial Monitor.	Resear ch project s & academi a	- High automatio n. - This technique is both practical and affordable.	- High complexity - Needs frequent calibration	Resear ch, environ mental studies
[16]	2025	Multi-functio nal automat ion	Soil moisture , humidity & temperat ure, ultrasoni c sensors	Advanced	- Prototype tested. - Bluetooth mobile app	Small to mediu m-scale farms	Multipurp ose functions (plowing, seeding, irrigation, weeding). - Solar-powered. - cost effective (Reduces	- Complex mechanical design. - Higher initial cost - Limited scalability, energy efficiency, and connectivity. - Bluetooth	- Improv e scalabil ity to handle larger fields using GPS. - integra

							manual labor)	range limitations	tion of Solar power. - use advanced communication technologies like Wi-Fi or LoRa and IOT. Integration of AI-algorithms
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### III. System Design:

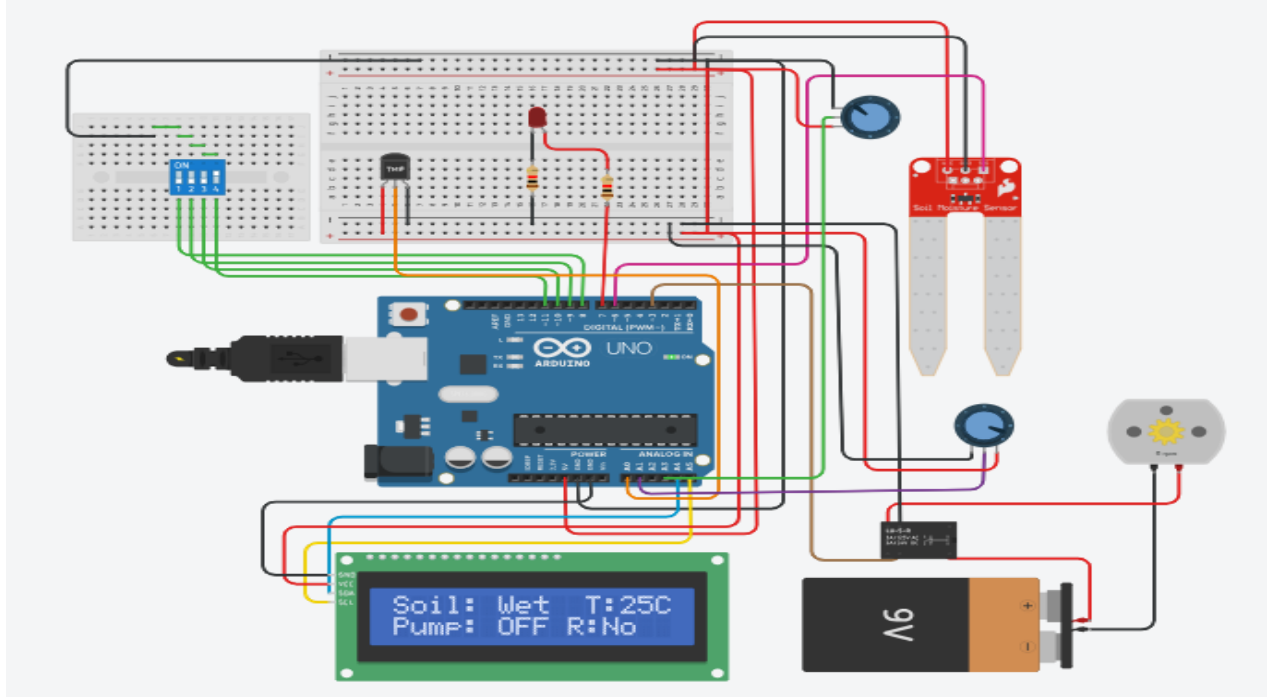
The suggested technology is intended to automate watering by constantly monitoring critical environmental parameters that affect plant development. It was created with open-source tools and readily available hardware to ensure cost and ease of replication. The design uses many sensors and an Arduino Uno microcontroller to make real-time choices depending on soil conditions, the status of weather, and water availability. The system flow is as follows:

1. **Data Collection:** Sensors like (Soil moisture, Rain, Water level, and DHT11) collect data from the environment.
2. **Decision Making:** The Arduino processes the data and applies logical conditions (if the soil is dry, no rain is detected, and water is available), the system will activate the pump.
3. **Output and Monitoring:** The pump is activated or deactivated via a relay based on the logic output. the live environmental data will display in a 16x2 I2C LCD screen and also in a Serial monitor of Arduino IDE.

Figure 1 displays the system circuit diagram by using Tinkercad simulation. Some parts have been replaced due to their absence in the simulation program with the following parts:

- a) **Potentiometer:** - two of potentiometer applied. one used as an as an indicator of rain status if it's raining or not by measuring changes in resistance when exposed to water. The second one use as an indicator for humidity.
- b) **DIP switch SPST × 4:** - It used as an indicator of the water level in the tank. The water level is detected according to the status of the four DIP switches. Each switch represents a specific percentage (0%, 25%, 50%, 75%). If all switches are inactive, the system displays "Water Level: 100%".

c) **Temperature sensor [TMP36]:** - It used instead of DHT-11 sensor for measuring temperature.



**Figure 1: - Circuit diagram.**

#### IV. Hardware Components:

The system has the following major hardware components:

##### a) **Arduino Uno**

It is an open-source microcontroller board. The board includes 14 digital input/output pins. To use the microcontroller, connect it to a computer via a USB connection or battery. All necessary components are included. It can be programmed using Arduino IDE [8] [9].



**Figure 2: - System's block diagram [9].**

##### b) **Soil Moisture Sensor**

It measures the water content (moisture) of soil. The sensor is linked to an Arduino and implanted in the soil. It sends a signal to the Arduino whether the soil is wet or dry, triggering irrigation to start or stop [8] [9].

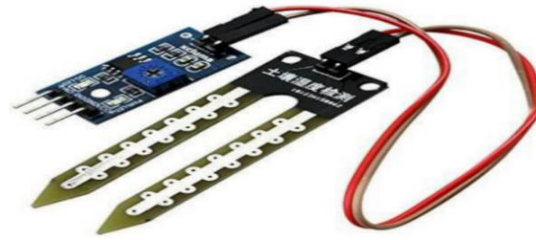


Figure 3: - Soil Moisture Sensor [17].

c) DHT-11 Temperature and Humidity Sensor

a DHT11 sensor used to determine the temperature and humidity levels and outputs digital signals [18].

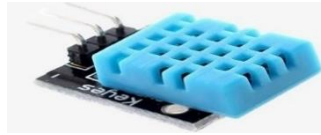


Figure 4: - DHT-11 Temperature and Humidity Sensor [18].

d) Water Level Sensor

The water level sensor measures the tank water level, shutting off the engine if below the specified level, and activating the water motor when the water level is reached [18].



Figure 5: - Water Level Sensor [18].

e) Rain Drop Sensor

The rain sensor is a crucial component in reducing water waste by stopping the pump from working when it detects rain [19].

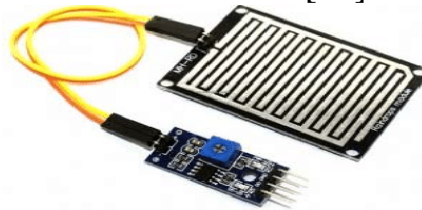


Figure 6: - Rain Drop Sensor [19].

f) Relay Module

A relay regulates the flow of electricity inside a circuit, which allows controlling the opening or closing of the water pump [17].

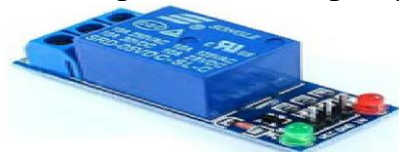


Figure 7: - Relay Module [17].

### g) Water Pump

The water pump motor is connected to Arduino via the relay module, transfers water via pipes, and supplies soil [20].



Figure 8: - Water Pump [20]

### h) LCD (Liquid Crystal Display)

It is an electronic display module. it can show 16 letters per line [21]. The LCD displays the sensor's data.

### i) Breadboard

It is a building block for electronic prototypes [22].

### j) Jumper wires

It is commonly used to link the components of an Arduino UNO with sensors.

### k) USB cable

It is used to link the Arduino UNO to PC.

Each sensor of the system is connected to an Arduino Pin as shown in Table 2.

Table 2: Connection Table for the Proposed System

Component	Arduino Pin	Connection Description
Soil Moisture Sensor	D6	Reads soil dryness (1 = dry, 0 = wet)
Relay for Water Pump	D3	Turns pump ON/OFF based on conditions
DHT11 (Temp & Humidity)	D7	Reads temperature and humidity
Rain Sensor	D8	Detects rain (0 = rain, 1 = no rain)
Water Level Sensor	D9	Checks water availability in tank (1= high level, 0= low level)
LCD I2C Display	A4 (SDA), A5 (SCL)	Displays real-time data
Power Supply	5V / GND	Powers sensors, LCD, DHT11, and logic devices

## V. System Operation and Software Implementation

The smart irrigation system was operated and evaluated in a controlled environment using Arduino UNO to determine its efficacy in monitoring environmental variables and automating water distribution. Arduino IDE 2.3.6 is used to develop code for the Arduino UNO. Figure 9 shows a flow chart of the system operation, which can also be illustrated as follows: -

1) First, initial components and set pins; then read the sensors' responsiveness values (Temperature and humidity, Soil Moisture, Rain, Water Level sensors).

2) Display sensor values on the serial monitor and LCD.

3) Apply Pump Control Logic as below: -

if (soilMoisture == HIGH && waterLevel == HIGH && rainDetected == HIGH)

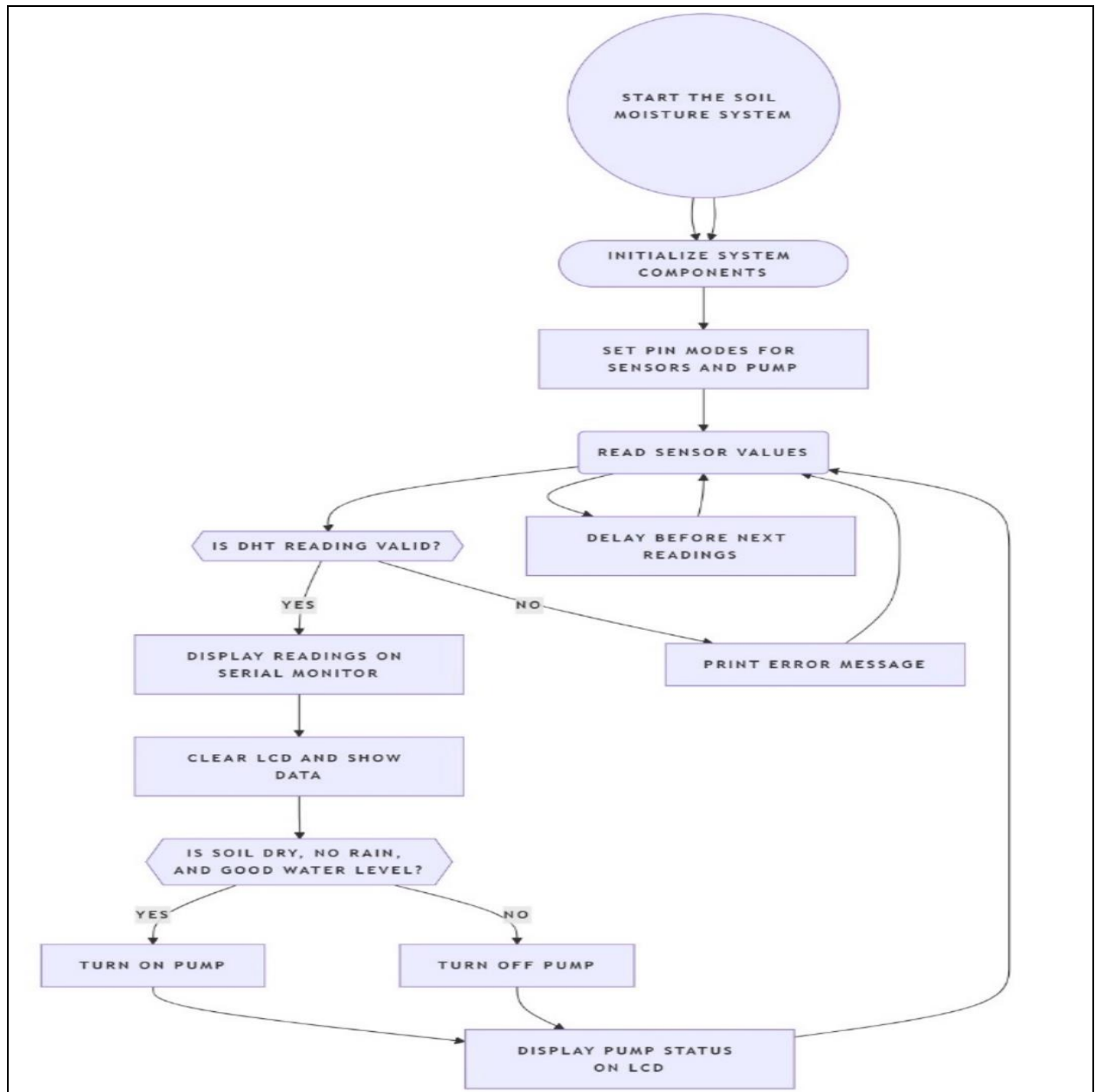
The word High means (1) as an output of the sensor value. the **pump only activated** when:

➤ The **soil was dry** (S = 1 → Soil is **DRY**)

➤ The **tank had sufficient water** (W = 1 → **Water level is HIGH**)

➤ **No rain was detected** (R = 1 → **No Rain detected**)

So if the soil is dry and there is no rain, and the water level in the tank is high, then the water pump will (TURN ON) and display (PUMP ON) on the LCD and serial monitor; else if any condition is not met, then the water pump will (TURN OFF) and display (PUMP OFF). This prevented **over-irrigation**, saving water, especially in rain-prone or already moist conditions.



**Figure 9: - System Operation Flowchart**

System performance in a real environment was shown in Figure 10 .

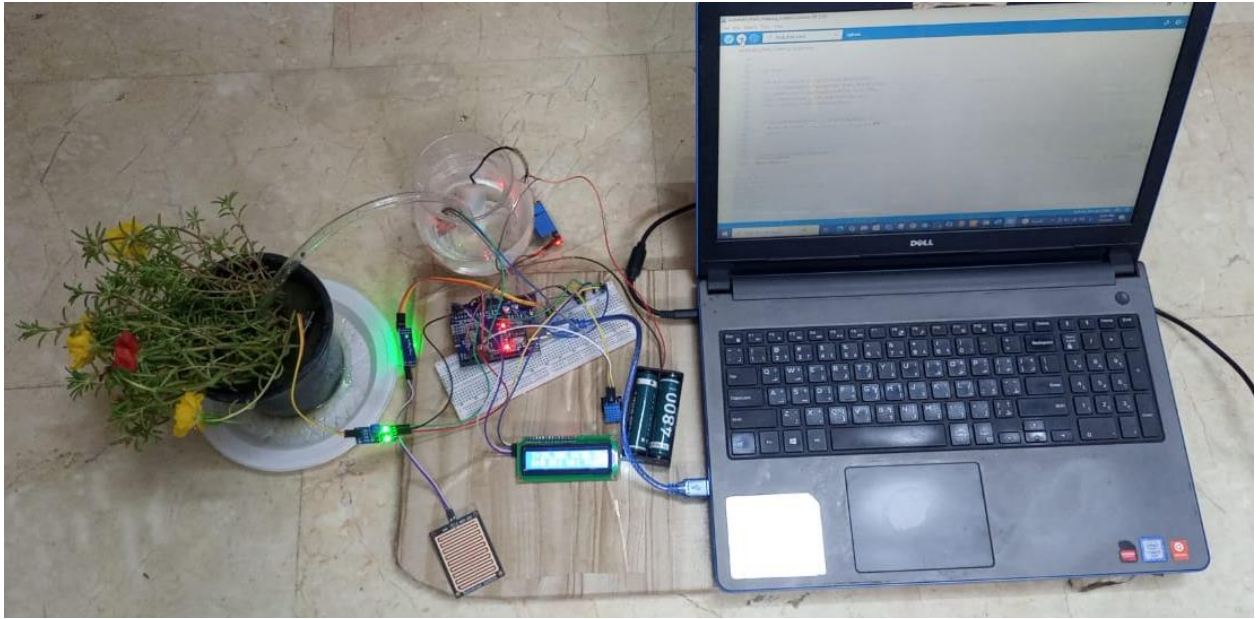


Figure 10:- The system in a real environment.

## VI. Results and Discussion:

The results of operating the smart environmental monitoring and irrigation system were collected over a specific time period, as shown in Table 3.

Table 3: System Results

Time	Soil moisture (S)	Temperature in C <sup>□</sup>	Humidity	Rain (R)	water level (W)	pump status (P)
1:00	1	28.90 C	27.60	1	1	ON
2:00	1	29.40 C	28.90	1	1	ON
2:10	1	29.30 C	28.90	1	1	ON
2:15	0	29.00 C	29.00	1	1	OFF
2:20	0	29.00 C	29.30	1	1	OFF
2:25	0	28.70 C	29.80	1	1	OFF
2:30	1	28.80 C	29.60	0	1	OFF
2:35	1	28.70 C	29.90	0	1	OFF
2:40	1	28.80 C	29.60	1	0	OFF
2:45	1	28.70 C	29.90	1	0	OFF

By analysis of the data showed that the pump was automatically turned **ON** only when all of the following conditions were met: **dry soil (S=1)**, **no rain detected (R=1)**, and **sufficient water level (W=1)**, as shown in Figure 11 (e). And from Table 3, during the time 1:00 to 2:10, the soil was dry, there was no rain, and the water level was high, which triggered the pump to operate. Conversely, the pump remained OFF during periods when the soil

was wet ( $S=0$ ) or water level was low ( $W=0$ ) or rain was detected ( $R=0$ ), as shown in Figure 11 (a, b, c, d). To further evaluate system behavior, three experimental scenarios from Table 3 were conducted:

**1. Water Level Sensor Removed ( $W = 0$ ):**

During both times, 2:40 and 2:45, the water level was intentionally set to LOW by disconnecting to simulate a depleted tank. Despite the soil being dry ( $S=1$ ) and no rain ( $R=1$ ), the pump remained OFF. This confirms the system's ability to prevent pump operation when there is insufficient water, thus protecting the hardware.

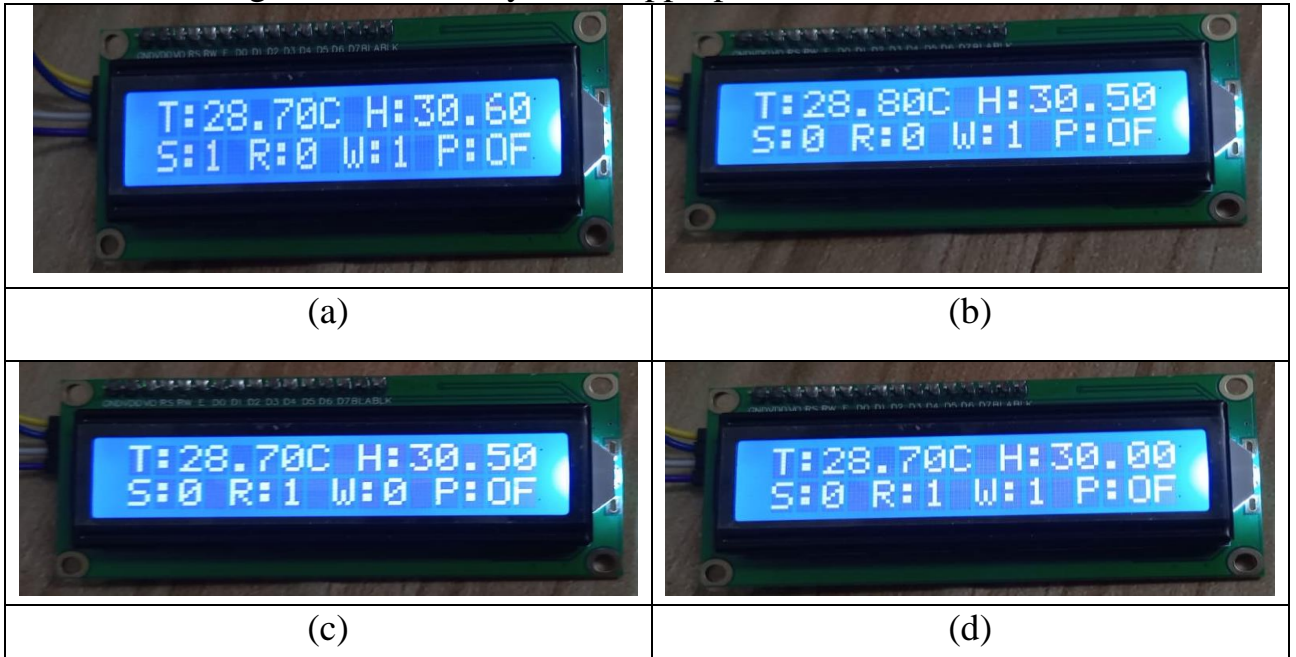
**2. Soil Moisture Sensor Lifted ( $S = 0$ ):**

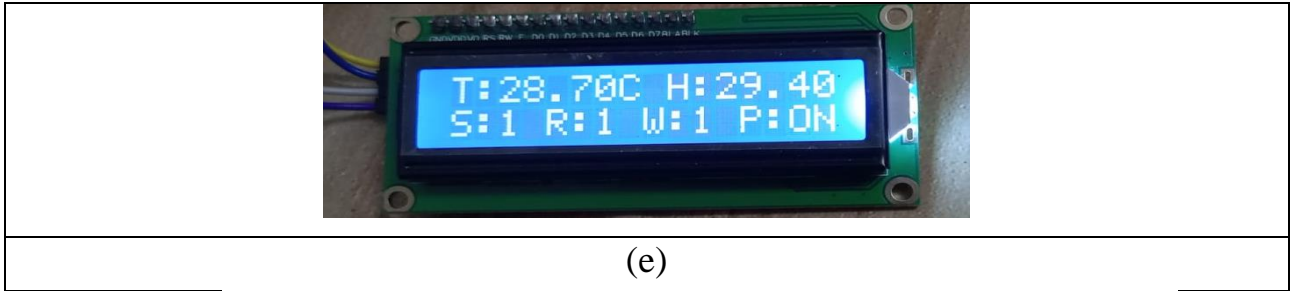
During the times from 2:15 to 2:25, the soil moisture sensor was lifted away from the soil, simulating moist conditions. Regardless of water level and rain sensor readings value, the pump stayed OFF. This reflects the system's proper response to perceived non-dry conditions.

**3. Water Droplets Applied to Rain Sensor ( $R = 0$ ):**

during both times, 2:30 and 2:35, water droplets were applied to the rain sensor to simulate rainfall. As a result, the system halted pump operation, even though the soil was dry and water level sufficient. This shows the system effectively suspends irrigation during rain detection to avoid water waste.

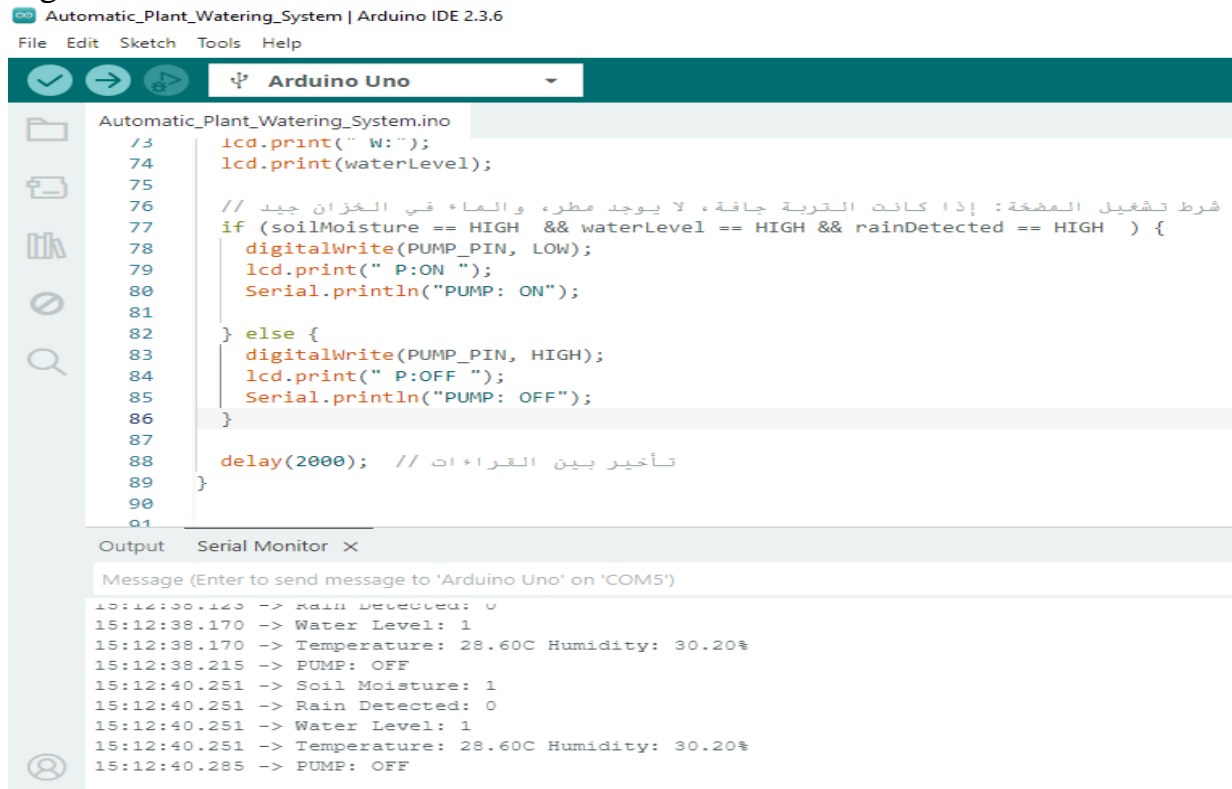
These results confirm that the system responds intelligently and accurately to environmental conditions and experimental changes. It conserves resources and ensures irrigation occurs only under appropriate conditions.





**Figure 11: - LCD results in case of (a). S=1, R=0, W=1, P=OFF, (b). S=0, R=0, W=1, P=OFF, (c). S=0, R=1, W=0, P=OFF, (d). S=0, R=1, W=1, P=OFF, (e). S=1, R=1, W=1, P=ON**

Serial Monitor also offered complete sensor logs and decision outputs for debugging and analysis. This feature is especially useful for future improvements, like integrating cloud-based logging or mobile notifications. Figure 12 show serial monitor results.



```

Automatic_Plant_Watering_System.ino
73   lcd.print(" W:");
74   lcd.print(waterLevel);
75
76   // شرط تشغيل المضخة: إذا كانت التربة جافة، لا يوجد مطر، والماء في الخزان جيد
77   if (soilMoisture == HIGH && waterLevel == HIGH && rainDetected == HIGH ) {
78     digitalWrite(PUMP_PIN, LOW);
79     lcd.print(" P:ON ");
80     Serial.println("PUMP: ON");
81
82   } else {
83     digitalWrite(PUMP_PIN, HIGH);
84     lcd.print(" P:OFF ");
85     Serial.println("PUMP: OFF");
86   }
87
88   delay(2000); // تأخير بين القراءات
89 }
90
91
Output Serial Monitor X
Message (Enter to send message to 'Arduino Uno' on 'COM5')
15:12:38.125 -> Rain Detected: 0
15:12:38.170 -> Water Level: 1
15:12:38.170 -> Temperature: 28.60C Humidity: 30.20%
15:12:38.215 -> PUMP: OFF
15:12:40.251 -> Soil Moisture: 1
15:12:40.251 -> Rain Detected: 0
15:12:40.251 -> Water Level: 1
15:12:40.251 -> Temperature: 28.60C Humidity: 30.20%
15:12:40.285 -> PUMP: OFF
  
```

**Figure 12: - Serial monitor results**

## VII. Limitations and Future Work:

### 1) Dependence on real-time readings only, without prediction:

The system makes irrigation decisions based solely on current sensor values, limiting its long-term efficiency.

➤ *Future Work:* Implement AI-based prediction algorithms that use historical data to generate smart irrigation schedules.

**2) Absence of a user-friendly interface for remote monitoring or control:**

Users currently have no simple visual way to monitor or control the system.

➤ *Future Work:* Develop a mobile application or dashboard to display sensor data and allow remote control with alerts and notifications by deploying remote communication modules (Wi-Fi, Bluetooth, or GSM).

**3) Dependence on traditional electrical power:**

In isolated or rural places, a stable power supply might be challenging.

➤ *Future work:* Use solar panels to power the system and make it sustainable in off-grid situations.

**4) Wired connections and implementation in a small-scale area.**

limit communication range and scalability in big agricultural areas.

➤ *Future work:* Integrate long-range communication technologies.

### VIII. Conclusion

In the face of mounting issues such as water shortages and climate change, contemporary agriculture must implement efficient, smart and long-term solutions. The designed smart environmental monitoring and irrigation system-based Arduino provides a realistic solution to these issues by automating the watering process using real-time sensor data. This automation greatly decreases the need for ongoing human involvement, cutting labor costs and operational overhead.

The system guarantees that water is used efficiently by continually monitoring soil moisture, rainfall, water level, temperature, and humidity. It starts the irrigation pump only when necessary, so conserving water and preventing over-irrigation. Such accuracy not only improves water sustainability but also helps to maintain stable soil conditions, which are essential for optimum crop development.

As a result, the system immediately contributes to crop quality and yield by ensuring ideal growing circumstances. Healthier plants produce higher yields, which benefit both smallholder farmers and commercial agricultural businesses. Furthermore, the system's modular and scalable design allows for future expansions like as interaction with IoT platforms, data analytics, and implementation in large-scale agricultural area.

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### دراسة كاملة في نظام مراقبة البيئة والري الذكي باستخدام الاردوينو

سجى حكمت داود

مدرس مساعد، ماجستير في علوم هندسة البرمجيات  
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#### مستخلص البحث:

استجابةً لنقص المياه المتزايد والحاجة المتزايدة لأساليب الزراعة المستدامة، تصف هذه الدراسة إنشاء نظام ذكي لمراقبة البيئة والري الآلي يعتمد على تقنية الاردوينو، يستخدم النظام عددًا من المستشعرات، بما في ذلك مستشعر رطوبة التربة، ومستشعر درجة الحرارة والرطوبة DHT11، ومستشعر المطر، ومستشعر مستوى الماء، لمراقبة الظروف البيئية آنيًا. يتم عرض بيانات المستشعر على شاشة LCD، وعلى الشاشة التسلسلية لتصحيح الأخطاء والمراقبة. تعمل مضخة المياه التي يتم التحكم بها بواسطة مُرحّل بناءً على ظروف معينة، مثل جفاف التربة، وعدم ملاحظة هطول أمطار، ووجود مستوى كافٍ من الماء في الخزان. يتم استخدام Arduino IDE للبرمجة و Tinkercad للمحاكاة والاختبار قبل التنفيذ المادي والتي تعزز عملية التطوير وتقليل الأخطاء. يُحسّن هذا النظام المقترح إدارة المياه، ويُقلل من التدخل اليدوي، ويُعزز الزراعة المستدامة. النهج المقترح منخفض التكلفة ومرن وقابل للتطوير، مما يجعله مناسبًا للتطبيقات الزراعية الصغيرة الحجم، وكذلك التطبيقات التعليمية والعملية. تُظهر النتائج أن الري الذكي لا يحفظ الموارد فحسب، بل يُحسّن أيضًا كفاءة الانتاج الزراعي.

**الكلمات المفتاحية:** - نظام الري الذكي، مراقبة البيئة، أردوينو، مستشعر رطوبة التربة، مستشعر DHT11، مراقبة مستوى المياه، مستشعر المطر.