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Smart Irrigation Management System for Precision Agriculture and Climate Resilience

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Abstract - In recent years, there have been significant climate alterations and substantial increases in pollution levels. The globe must prioritize the consideration of temperature fluctuations and increases in extreme weather phenomena. Unanticipated precipitation or it lack can significantly impact water levels, soil quality, crops, and food security. Conversely, adaptation may be as simple as enhancing efficiency through plug-and-play systems and implementing minimal modifications to irrigation management. This study aims to deliver a thorough examination of the global difficulties and potential impact of smart irrigation management systems on environmental preservation and sustainability attainment. These solutions are designed to build complementary frameworks that support modern administrations in boosting their adaptability, productivity, and overall efficiency. The document outlines the key environmental challenges, organized by likelihood and potential impact, and proposes an intelligent, user-friendly irrigation system for precision agriculture. This system is designed to maximize water efficiency in farming with minimal human involvement while incorporating soil characteristics and surrounding environmental factors.

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Introduction

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The immediate economic and humanitarian impacts of COVID-19 are profound, threatening to reverse years of progress in reducing inequalities and poverty. They also weaken international cooperation and social cohesion. Rising social unrest, political division, and geopolitical strain will shape how effectively the world can respond to major threats in the coming decade, including cyber-attacks, weapons of mass destruction, and, most critically, climate change [1–2]. The 2021 Global Risks Report summarizes the findings from the latest Global Risk Perception Survey (GRPS). It offers a detailed

assessment of widening economic and social disparities, key industries, their interdependencies, and how these dynamics affect the global capacity to confront urgent risks that demand solidarity and cross-border collaboration. The report, which provides recommendations for strengthening resilience, draws on insights gained from the pandemic and past risk evaluations. Contemporary global threats fall into five main categories: (i) economic risks, (ii) environmental risks, (iii) geopolitical risks, (iv) societal risks, and (v) technological risks [3–4].

This year's analysis anticipates deepening regional and global rifts, alongside a slowing economy. Ongoing geopolitical turbulence is pushing the world toward an increasingly unstable, unilateral landscape defined by intensified competition among major powers, making coordinated action between business leaders and governments crucial for addressing shared challenges. Joint efforts among international leaders, industries, and policymakers are vital to counter major threats related to climate stability, environmental integrity, public health, and technological infrastructure. Environmental risks, in particular, are projected to receive even greater attention over the next decade. Concerns about ecological degradation have grown steadily in recent years, and for the second year in a row, biodiversity loss and environmental threats are ranked among the top five global risks when assessed by both likelihood and potential impact. **Fig. 1** offers a concise summary of the shared and distinct challenges reflected in both the impact and likelihood rankings [5-6].

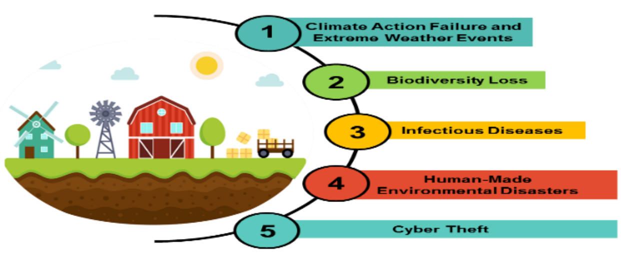

Fig.1: Top 5 Common Global Risks. Landscape.

Producers are increasingly required to consider temperature variability and the growing frequency of extreme weather events driven by a more unpredictable climate. Sudden rainfall-whether excessive or lacking- can severely disrupt water availability, degrade soil conditions, damage crops, and ultimately threaten food security [7]. However, adaptation can sometimes be straightforward, involving improved efficiency through plug-and-play technologies and small adjustments to irrigation practices. This section examines how enhancing climate resilience promotes long-term sustainability while also enhancing crop vitality and yields in the short term. **Fig.2** depicts the influence of climate change on the hydrological cycle of the region.

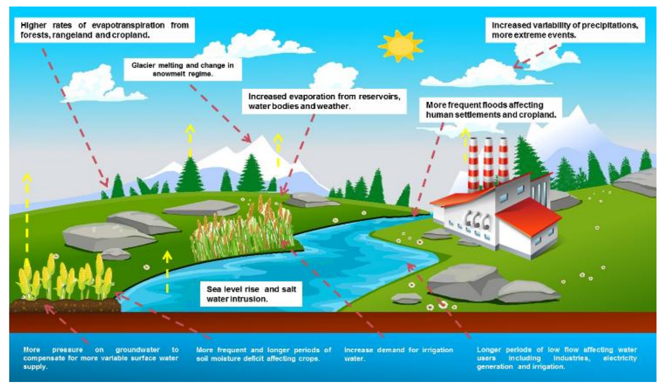

Fig.2: Impacts of Climate Change on the Water Cycle.

Advanced water treatment approaches can help manage heavy rainfall and excess surface water by lowering volumes and limiting saltwater intrusion, while also providing support during prolonged heatwaves and periods of water shortage, as shown in **Tab. 1**.

Tab.1:**1PROS & CONS OF USING SMART IRRIGATION**.

SN#	Pros	Cons
1	Reduction in Human Error	High Costs
2	Zero Risks	Lack of Creativity
3	24/7 Availability	Cause of Unemployment
4	Digital Assistance	Make Humans Lazy
5	New Innovations	No Ethics
6	Unbiased Decisions	Dependency on Machines

This study introduces an intelligent precision irrigation system built using IoT technology. It can be applied across multiple domains to reduce global agricultural water consumption, including household farming, space mission food production, and sustainable architectural design. The proposed system aims to:

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(i) Promote smart farming and sustainable agricultural practices.

(ii) Provide an innovative, eco-friendly solution to resource limitations.

(iii) Increasing crop yields to meet the rising global food demand.

(iv) Protect soil in areas that depend on chemical fertilizers.

(v) Reducing resource use by recycling water required for plant growth

(vi) Apply bioremediation to lower pollution levels.

This study makes four major contributions. First, it highlights the global risks identified in 2021 and clarifies the top five threats facing the world. Second, it outlines the primary irrigation challenges driven by climate change. Third, it discusses sustainable and climate-aligned approaches to address these issues. Fourth, it presents an accessible and efficient plant irrigation solution using embedded system technology.

The remainder of this paper is structured as follows: a review of the related literature is presented first, followed by the study's motivation and problem statement. Next, the proposed irrigation system is described, followed by an analysis and future directions.

Hummen et al. [8] proposed a method built on major technological progress, underscoring the need for smart, environmentally conscious solutions to preserve the planet for future generations [9-10]. Governments, investors, and researchers must develop sustainable intelligent technologies to address global challenges. Corporations have begun adopting strategies to further reduce their carbon emissions, and asset managers worldwide now prioritize climate considerations in investment decisions. Unlike governments, banks have introduced standards, viewing climate change as both a systemic risk and a capital concern for climate initiatives. Consequently, climate change represents both a major threat and a business opportunity [11].

The following subsections discuss the approaches to solving soil-related issues. Labor shortages and inadequate water supply remain the two dominant risks affecting agriculture. According to the World Wildlife Fund (WWF), by 2025, nearly two-thirds of the world's population may face water scarcity, endangering ecosystems and public health [12-13]. Automated irrigation systems help address these issues by delivering water at predetermined times and volumes, while continuously measuring soil moisture levels [14]. These systems can be used in both home gardens and commercial agricultural settings.

Significant progress has been made in Smart Agricultural Systems over the past few decades, demonstrating the global importance of agriculture. In India, for example, more than 70% of the population depends on this sector. Traditionally, irrigation relied on mechanical mills and other manual methods, often without precise knowledge of the crop-specific water requirements. These conventional practices have led to substantial water waste and, in many cases, crop loss due to insufficient irrigation [12]. Modern technological innovations have produced advanced irrigation systems that eliminate the need for direct farmer involvement in irrigation.

In summary, climate change reshapes the hydrological cycle and directly affects irrigation by altering rainfall patterns, increasing the frequency of floods and droughts, raising air temperatures that intensify evapotranspiration and water demand, and elevating sea levels that contribute to the salinization of freshwater resources.

Soil salinization is increasing at an accelerating rate worldwide, leading to more severe impacts and a heightened need for effective remediation strategies. Current assessments show that approximately 20% of cultivated land and 33% of irrigated agricultural areas worldwide face salinity-related risks. As noted earlier, proper water management can prevent salt migration to the surface. The same approach can be applied to alleviate persistent soil salinity problems.

Salt accumulation in soil can occur for several reasons, including the use of poor-quality irrigation water and fertilizer [15]. These salts hinder nutrient uptake in plants and restrict water infiltration, making their removal essential for sustainable agricultural production. To address this, producers are steadily shifting toward sustainable leaching practices that reduce chemical runoff and avoid water-intensive steaming approaches, both of which have significant negative impacts.

A. Soil Moisture Retention Over Longer Periods

Extended soil moisture can greatly affect harvest schedules, particularly during high-summer heat or unexpected prolonged droughts. Modern irrigation techniques modify water behavior to enhance its penetration into soil micropores [9]. Consequently, soils retain moisture for longer durations, allowing for fewer irrigation cycles. Efficiency gains can reduce water use by as much as 30%, improving the ability of growers to cope with fluctuating water availability [8]. Real-time

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monitoring further showed that crops irrigated with smart systems handle stress more effectively, grow more vigorously, and depend less on internal reserves.

B. Irrigation with Saline Water

In many regions, soil salinity is strongly associated with poor irrigation water quality. Elevated electrical conductivity in saline or brackish water has detrimental effects on numerous crops [1]. In the short term, such water harms plants, and in the medium and long terms, it raises soil salinity and electrical conductivity. This progression can render vast agricultural areas unproductive [2].

However, recent innovations have offered practical solutions. Modern irrigation technologies, such as AQUA4D®, make it possible to irrigate using saline water. Despite seeming counterintuitive, the process works: before reaching the crops, AQUA4D® modifies the mineral structure of the water, breaking down excess salts, preventing crystallization, and enabling their removal from the root zone of the crops. This serves two functions simultaneously: facilitating irrigation with saline or brackish water and aiding in the leaching of accumulated salts from the soil.

PROPOSED MODEL

This section presents the proposed system, which is divided into two phases.

(i) the simulation phase and

(ii) Hardware implementation phase.

In the simulation phase, basic circuits were used to verify the functionality of the system. In the hardware phase, additional features and capabilities were integrated into the final design. A range of sensors is incorporated to measure the environmental and crop-related parameters essential for optimal production. The water-pumping mechanism is automated so that the valve is activated based on soil moisture readings.

The proposed solution employs an IoT-based framework with an emphasis on scalability and sustainability. **From Figs. 3 to 6** provide a comprehensive overview of the vertical farm layout.

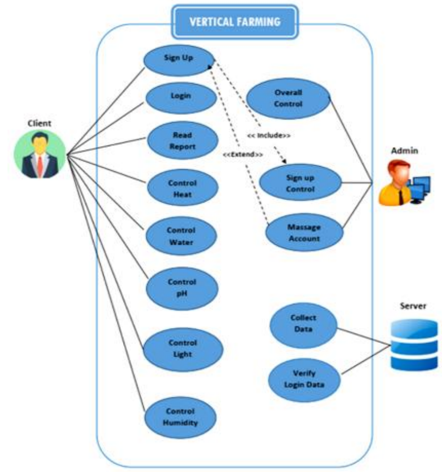

Fig.3: System Use Case Diagram

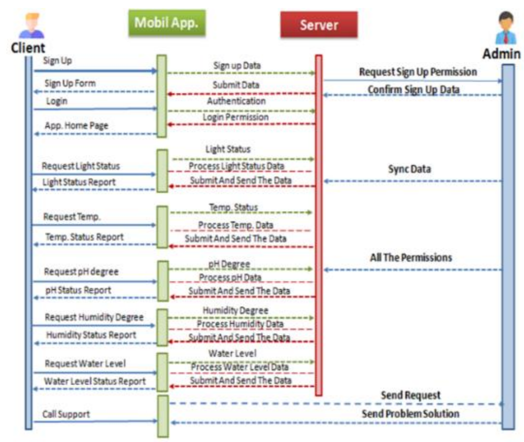

Fig.4: System Sequence Diagram.

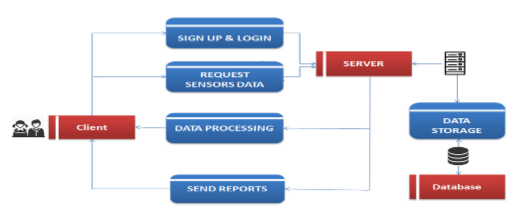

Fig.5: System Data-Flow Diagram.

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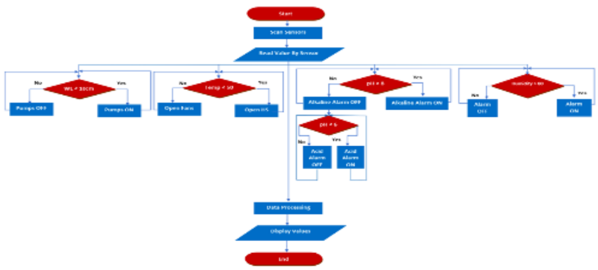

Fig.6: System Flowchart.

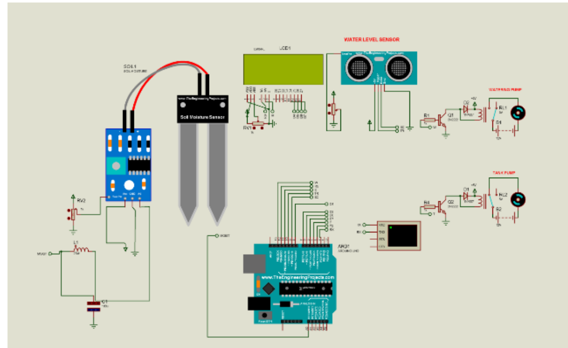

Fig.8: Circuit Diagram of the Proposed System.

A Raspberry Pi was employed to manage the overall operation of the system. It controls hydrological cycles, pH levels, nutrient dosing, lighting schedules, and ventilation processes. Continuous monitoring and adjustment of all system parameters are essential. The Raspberry Pi tracked all operational data and made it accessible through various web-based services. **Fig. 7** provides an overview of the proposed model.

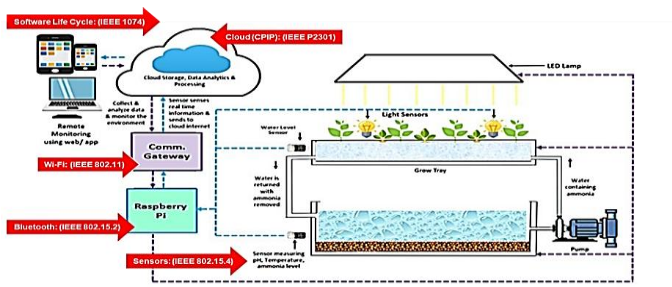

Fig.7: Proposed Model Scenario.

A. Simulation Phase

This section presents a Proteus simulation of the system to demonstrate its practical functionality. Performance evaluations were carried out using Proteus 8.0 Professional on a Windows 7 (64-bit) operating system with 8 GB of RAM and an Intel Core i5-3317U processor operating at 1.70 GHz. **Fig. 8** shows the basic circuit diagram of the proposed system.

This model functions by employing a Soil Moisture Sensor to measure moisture levels in the soil and control the water valves accordingly. When the moisture value drops below a predefined threshold, the system activates the valve via a relay or solenoid until the soil reaches the desired hydration level.

When the resistance at the sensor test pin was at its maximum, the circuit displayed 0 volts on the voltmeter. This indicates that the sensor is either in completely dry soil or not inserted at all, resulting in a moisture reading of zero. Conversely, when the resistance was minimal, the voltmeter showed its highest reading, indicating that the sensor was placed in saturated soil and that moisture levels were high. Within this simulation, the sensor output initially appears in the terminal; later, according to the programmed code, the data from each sensor is displayed in an organized and easily interpretable format. The pump is activated automatically whenever the soil moisture reading falls below the specified limit, signaling that the soil has dried and triggering water flow to the crops.

The system integrates several components.

(i) Water Level Sensor: Monitors the water reservoir level.

(ii) Moisture Sensor: Measures the soil moisture content.

(iii) Arduino UNO: Enables communication and control across all modules.

(iv) GSM Module – alerts the user regarding system operations and plant conditions.

Before installing the water-level sensor in the reservoir, it was interfaced with a microcontroller. Both the user and the associated application determine the appropriate depth and position of the sensor inside the tank. The Arduino continuously receives measurements from the water-level sensor and notifies us via an alarm or buzzer when the reservoir water level falls below a defined threshold.

Soil moisture sensors operate on similar principles. Once the probe is inserted into the soil near the plant, it begins

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transmitting moisture data to the microcontroller. The placement of the sensor is easily adjustable, allowing users to position it based on the specific needs of each plant species. In densely planted fields, a single sensor can monitor multiple plants by measuring the moisture at overlapping locations on the soil surface.

B. Hardware Implementation

This system provides fully automated plant irrigation without the need for human intervention. It is built using Arduino technology and can be easily assembled by individuals with little or no technical background. Its simplicity and practicality make it widely used in gardens and agricultural fields.

The proposed design employs a soil moisture sensor to measure the moisture content of the soil and send the readings to the Arduino. The sensor must be placed in the soil, near the plant. When the soil becomes dry, the sensor signals the Arduino to initiate the irrigation process. The Arduino then activates a relay module that briefly turns on the water pump.

All readings were processed using Arduino. If the soil moisture level falls below the threshold defined in the program, the pump is switched on to water the plants. Because directing all pumped water to a single spot could damage the crops, a servo motor was introduced to rotate the irrigation pipe in a controlled manner. This ensures an even distribution of water and represents an added enhancement to the system. The Arduino also continuously monitors the water-level sensor in the reservoir and alerts the user through an alarm or buzzer whenever the water level drops below a set limit.

The system was developed in the following phases.

(i) External body phase

(ii) Perception and control phase

(iii) Output visualization and regulation phase

For the external structure shown in Fig. 9, the materials used were as follows:

(i) wooden components,

(ii) insulating paint,

(iii) cork-based plant seedling trays, and

(iv) An RGB LED strip..

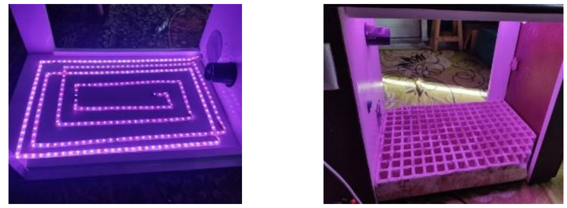

Fig.9: Lighting and Soil Preparing.

The system's sensing and control components included an Arduino Uno, soil moisture sensor, temperature sensor, 12-volt water pump, jumper wires, Bluetooth module, real-time clock (RTC) module, TIP121 transistor, heat source, 12-volt fan, 5-volt voltage regulator, on/off switch, and an alarm. Figs. 10 and 11 illustrate the hardware circuits, whereas Fig.12 depicts the output display and control phase, respectively, utilizing (i) a 2×16 LCD and (ii) push buttons. Fig. 13 illustrates the completed external structure

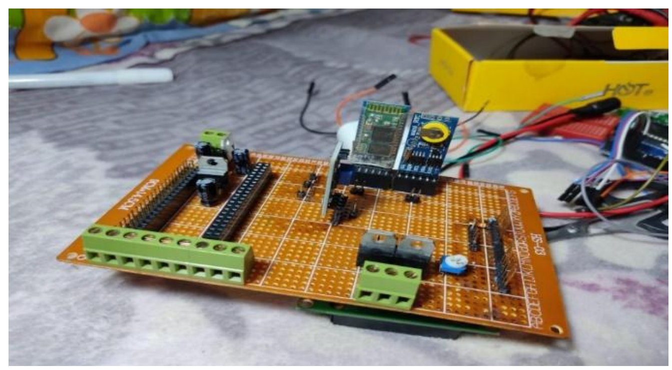

Fig.10: Hardware Circuits

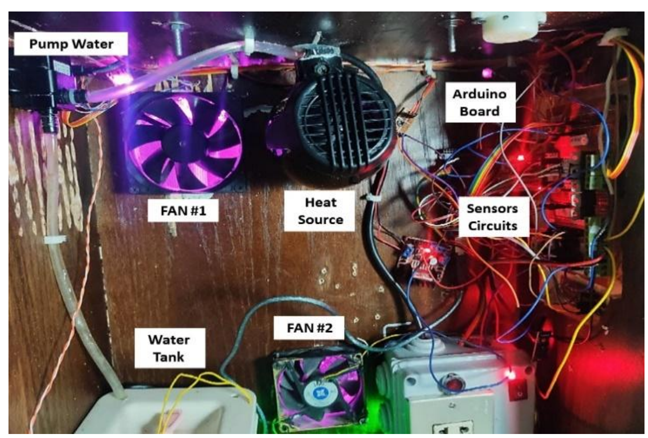

Fig.11: Hardware Detailed Overview.

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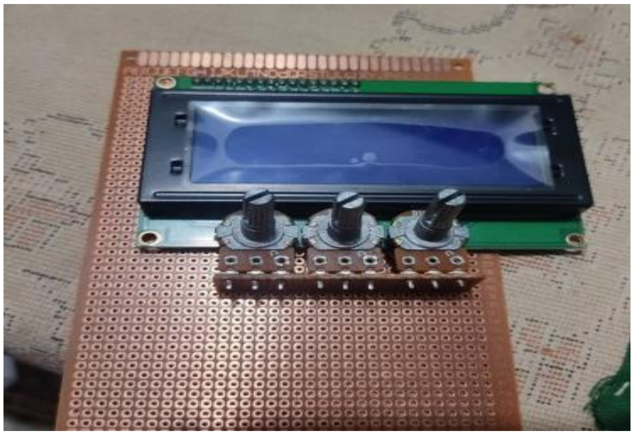

Fig.12: LCD Circuit Initialization.

Fig.13: Final System.

In **Tab 2**, clay soil is considered excessively moist when its volumetric water content (VWC) exceeds 60%. At a VWC of 50%, clay soil reaches field capacity, meaning it holds the maximum amount of water available for plant use, as shown in **Fig. 14** [4]. To further improve irrigation efficiency, farmers can determine the appropriate watering intervals for their crops based on flow rates and required water quantities using Eq. 1:

Moreover, to enhance irrigation efficiency, farmers are

$$t = v/Q \text{ (1) where: (t)} \qquad (1)$$

where t represents the time interval between irrigations, v the water volume (cm³), and Q the flow rate (cm³/s). This equation enables the precise scheduling of irrigation events according to the plant's water needs and the system's delivery rate.

Tab. 2: Value range for each sensor.

Sensor	**Value Range**
Soil Moisture	-10°C to +85°C
DHT11 | Temp	-55°C to +150°C
Humidity	40%
pH Sensor	6.5 to 7.5

To simplify the management of plant environmental conditions, a hybrid control system was developed, consisting of a central Control Board and a Mobile Application. A dedicated smartphone application allows users to operate and monitor the system remotely, enabling flexible and efficient hybrid control of the proposed solution. The soil moisture terms are summarized below..

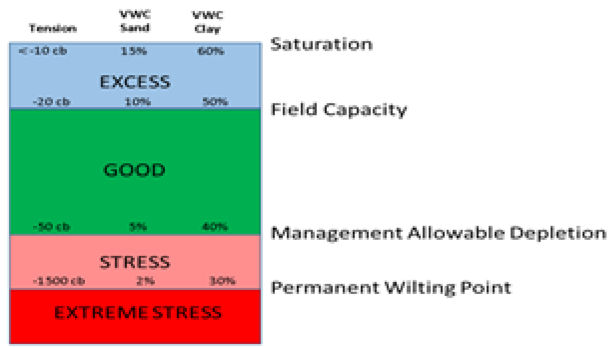

Fig.14: maximum amount of water available for plant use

Results and Analysis

The findings indicate that LED strip lighting supports the healthy development of indoor plants and allows for effective adjustment of the light color to meet plant requirements shown in **Fig.15.** However, LED strips alone generally do not provide sufficient brightness for most seedlings to thrive independently; thus, they are best used in combination with larger, more powerful grow lights. LED lighting offers several advantages for horticulture, including the production of minimal heat, thereby reducing the risk of drying or burning plants. For optimal growth, plants should receive light at approximately 6500 K, which closely matches natural daylight, whereas 3000 K lighting is essential for the budding, flowering, and fruiting stages. High-quality 5050 LED strips are recommended because they provide a higher lumen output suitable for successful seedling germination, despite their higher cost. **Fig. 16** shows the plant at various growth stages over several days.

Fig.17 presents a graph of the temperature fluctuations throughout the day, measured in °C. The temperature begins at approximately 15°C at midnight, rises steadily to nearly 30°C at midday, and then declines to approximately 20°C by the end of the day. Understanding this variation is valuable for fine-tuning heating and cooling strategies under optimal plant conditions. Likewise, the curve in **Fig. 18** illustrates changes in soil

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moisture percentage over a 24-hour cycle: moisture is at 100% at midnight, drops gradually to approximately 40% by 11:30 AM, and then increases again to approximately 70% by midnight. These trends confirm that the proposed system provides an environment conducive to healthy plant growth, which is consistent with the benchmarks shown in Fig. 15. Ultimately, recognizing these daily patterns helps optimize irrigation timing and overall environmental management of plants.

Fig.15: Hybrid System Management.

Fig.16: Plant at different Phases.

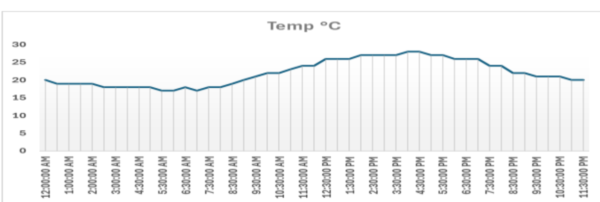

Fig.17: Temp. analysis over 24 Hrs.

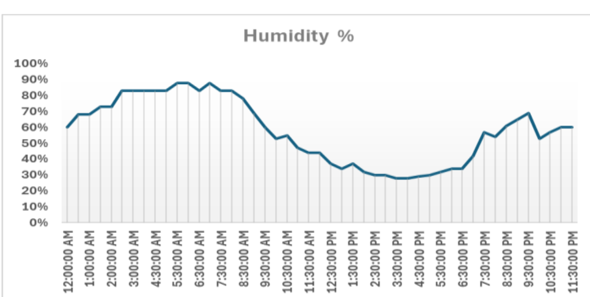

Fig.18: Soil humidity (%) analysis over 24 Hrs.

CONCLUSIONS

This study introduces the development of a prototype smart irrigation system engineered to optimize water consumption while requiring minimal human involvement. The proposed recommendation approach integrates soil and environmental parameters and leverages recorded meteorological data to shorten the irrigation periods. A classification model was applied to analyze the combined dataset and determine when irrigation was necessary. Additionally, this approach can be used to identify the appropriate pesticides to ensure optimal crop development..

REFERENCES

[1] J., J. P. Caves & W. S. Carus, The future of weapons of mass destruction: their nature and role in 2030, (2014)." NATIONAL DEFENSE UNIV FORT MCNAIR DC CENTER FOR THE STUDY OF WEAPONS OF MASS DESTRUCTION".

[2] A. Magen, and D. R. Barak, "Anticipating global and diffuse risks to prevent conflict and governance breakdown: lessons from the EU's southern neighbourhood". Democratization, 28(7), 1239-1260, (2021)..

[3] F. E. Granados. "The Global Risks Report 2021 [Internet]. c2021 [cited January 2021]. Available from: http://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2021.pdf.

[4] World Economic Forum [Internet]. c2021 [cited January 2021]. Available from: https://www.weforum.org/.

[5] A. Farhadi, From the Great Power Competition to Great Power Cooperation: Strategic Lessons from a Pandemic. In The Great Power Competition Volume 2 (pp. 1-17). Springer, Cham, (2022). .

[6] X. Ding, A. Appolloni, and M. Shahzad, "Environmental administrative penalty, corporate environmental disclosures and the cost of debt". Journal of Cleaner Production, 332, 129919, (2022). .

[7] M. M. Kansanga, I. Konkor, D. Kpienbaareh, K. Mohammed, E. Batung, H. N. Frimpong, and I. Luginaah, Time matters: A survival analysis of timing to seasonal food insecurity in semi-arid Ghana. Regional Environmental Change, 22(2), 1-16., (2022).

DOI: https://doi.org/XXXX.XXXX

[8] A. Ianeselli, M. Atienza, P. W. Kudella, U. Gerland, C. B. Mast, and D. Braun, Water cycles in a Hadean CO2 atmosphere drive the evolution of long DNA. Nature Physics, 18(5), 579-585, , (2022). .

[9] H. S. Al-Duais, M. A. Ismail, Z. A. M. Awad, & K. Al-Obaidi, Methods of harvesting water from air for sustainable buildings in hot and tropical climates. Malaysian Construction Research Journal, 12(1), 150-168, (2022).

[10] R. Lakshminarasimhan, Solar-driven water treatment: the path forward for the energy–water nexus. In Solar-Driven Water Treatment (pp. 337-362). Academic Press, (2022). .

[11] PWC. (2021). Creating a sustainable development strategy. Retrieved from https://www.pwc.ru/ru/publications/collection/pwc-sdg-challenge-2019-rus.pdf. Accessed 15 June 2021.

[12] Springer. Great Powers and Geopolitics International airs in a Rebalancing World [Internet]. c2021 [cited January 2021]. Available from: https://ir101.co.uk/wp-content/uploads/2017/11/klieman-great-powers-and-geopolitics.pdf.

[13] Nature Communications. The Role of Artificial Intelligence in Achieving The Sustainable Development Goals [Internet]. c2020 [cited January 2020]. Available from: https://www.nature.com/articles/s41467-019-14108-y.

[14] , A. J., Both, L. Benjamin, J. Franklin, G., Holroyd, L. D. Incoll, M. G. Lefsrud, and G. Pitkin, “Guidelines for measuring and reporting environmental parameters for experiments in greenhouses”. Plant Methods, 11(1), 1-18, (2015). .

[15] M. Farooq, , S. K., Singh and S. Kanga, “Mainstreaming adaptation strategies in relevant flagship schemes to overcome vulnerabilities of climate change to agriculture sector”. Res. J. Agri. Sci.: Int. J., 12, 637-646, (2021).

DOI: https://doi.org/XXXX.XXXX