Life Science Studies

Journal homepage: www.journal.inrrd.com/lss

Original article

Design and Evaluation of a Low-Cost, Solar-Powered Smart Irrigation System Using Arduino and GSM

Jawad Tahmeed Bin Taufik[1], Most. Moslema Haque[2], Kamrun Nahar[3], Raqibul Islam[3] and Mohammad Liton Hossain[4*]

[1]*Institute for Electronic Appliances and Circuits, Faculty of Computer Science and Electrical Engineering, University of Rostock, Albert-Einstein-Str. 2, 18059, Rostock, Germany*
[2]*Department of Crop Science and Technology, University of Rajshahi, Rajshahi 6205, Bangladesh*
[3]*School of Management, Kettering University, Flint, Michigan 48504, USA*
[4]*Department of Electronics and Communication Engineering, Institute of Science and Technology (IST), National University, Dhaka 1209, Bangladesh*

ARTICLE INFO

Article history
Received 03 February 2025
Revised 29 March 2025
Accepted 04 April 2025
Available online 13 April 2025

Keywords
GSM communication
Solar energy
Microcontroller
Capacitive moisture sensing
Drip irrigation

ABSTRACT

This paper presents the design and implementation of a Global System for Mobile Communications (GSM)-based smart irrigation system that is powered by solar energy. The system incorporates a microcontroller as the smart component and uses the drip irrigation method to reduce water usage. The objective of the proposed system is to reduce human intervention in crop maintenance and provide an affordable solution to rural farmers. Use of the combination of solar panel and Li-ion battery enables the system to run 24x7, while using a moisture sensor and electric relay helps to remotely control irrigation through water pumps. The system automatically and periodically checks for soil condition and suggests to farmers the appropriate action. Incorporating drip irrigation takes care of the environment compared to the conventional method. This study effectively demonstrates automation and smart control in agro-management. It also portrays the significance of integrating renewable energy and wireless communication in a low-cost setup, an approach to integrate farmers from developing countries into modern technology.

Introduction

Agriculture is the foundation of human civilization and the backbone of many developing countries' economies like Bangladesh (Coleman et al. 2004; Workie et al. 2020; Mishra & Pradhan 2023). Traditional agricultural practices have become inadequate (Jha et al. 2019), particularly when it comes to irrigation, due to many challenges such as climate change, water scarcity, and limited energy (Hanjra & Qureshi 2010; Misra 2014; Elmahdi 2024). Water is a crucial agricultural input, but it is not distributed uniformly on different parts of the planet (Chen et al. 2018). On the other side, inadequate management and improper use of water for irrigation have reduced production and harmed the environment. Traditional irrigation systems still dominate the agricultural of Bangladesh (Rasul & Thapa 2003; Belay & Bewket 2013), characterized inefficient water usage (Schulze et al. 2013). These conventional systems often depend on manual operation (Abioye et al. 2020), where farmers determine irrigation timing based on their personal preferences and emotions rather than data (Meempatta et al. 2019), resulting in either over-irrigation or under-

*Corresponding author
Email address: lit702@gmail.com (Mohammad Liton Hossain)

irrigation (Teshome et al. 2018; Kidane 2023). This leads to a waste of water and also affects soil health and crop yield. Additionally, much of the irrigation water gets lost through evaporation or seepage due to the absence of targeted irrigation techniques such as drip or sprinkler systems (Varman 2025). To overcome these problems, there is a pressing need for more energy-efficient, sustainable, and user-friendly irrigation methods (Sheline 2024). Researchers and technologists have been inspired to investigate smart solutions that combine electronics, automation, and communication technologies (Obaideen et al. 2022). In recent years, the advent of microcontrollers, wireless communication networks, sensors, and renewable energy sources has created new opportunities to transform traditional irrigation into a smart, efficient system (Bouali et al. 2021; Qian et al. 2024).

GSM has appeared as a viable option, as it has huge rural connectivity due to the widespread reach of mobile networks in Bangladesh (Siddiquee 2016; Li et al. 2020). At the same time, solar energy is also a sustainable and cost-effective power source in regions that suffer from unreliable electricity supply or a complete lack of grid access (dos Santos Isaías et al. 2019; Salehin et al. 2023). This study proposes the design, execution, and assessment of a low-cost, Arduino- and GSM-based, solar-powered smart irrigation system. The primary objective of the system is to empower farmers in rural and off-grid areas by offering a user-friendly, automated irrigation solution that can be remotely controlled through mobile phones (Sabo et al. 2023). This system includes a few core components working together. An Arduino Pro Mini acts as the brain, managing everything, while a SIM800L GSM module handles wireless communication (Akwu et al. 2020). A capacitive soil moisture sensor keeps track of real-time soil conditions (Liao et al. 2021) which is powered sustainably using a small solar setup, includes a mini solar panel, a charge controller circuit, and a lithium-ion battery (Wazed et al. 2018; Manfo & Şahin 2024). The water pump is powered by the main electrical supply and controlled through an electric relay module (Deveci et al. 2015). The system architecture assists farmers in operating the irrigation pump and receiving real-time soil moisture updates by sending simple SMS commands (Olujimi et al. 2022; Nsoh et al. 2024). Based on the command received, the system responds accordingly, turns the pump on or off automatically, and informs the user about the current soil moisture level (Yasin et al. 2019; Ahmed et al. 2021). Moreover, the system runs an automated loop that checks the soil condition every ten seconds and sends proactive SMS alerts to the farmer, and can suggest irrigation actions when needed. This dual mode of operation- manual control via SMS and automatic monitoring — makes the system highly practical and efficient (Akwu et al. 2020). The system remains affordable and practical for smallholder farmers by using low-cost and readily available components. GSM, in contrast, provides a more feasible communication option for low-resource settings due to the ubiquity of mobile networks (Van de Zande 2023).

The capacitive soil moisture sensor, which is used in this system, is low-cost yet efficient in reliably detecting moisture levels when correctly adjusted. The GSM module, renowned for reliability and widespread usage, communicates with the Arduino via UART using conventional AT instructions for wireless communication (Suman et al. 2017; Akwu et al. 2020). Due to its simplicity, reliability, and low cost, especially in areas where internet access is limited or unavailable, the SMS-based control system was chosen over internet-based platforms (Baumüller 2015). However, some difficulties, such as weak GSM signals and cloudy weather, affected solar charging. In the Future, this may include the following developments, such as integration of IoT systems for web-based monitoring, AI algorithms for predictive irrigation scheduling, and more powerful sensors for multi-parameter environmental monitoring. This study not only addresses the immediate needs of rural agriculture but also sets the framework for future scalable, intelligent irrigation systems.

Quite a few approaches and demonstrations of smart irrigation system development have been done in recent years, integrating various technologies such as GSM, Zigbee, Wi-Fi, and Internet of Things (IoT). Among them, systems utilizing GSM technology are particularly suited for rural deployment due to the wide availability of mobile networks.

A promising work (Prasad et al. 2017) was done on a GSM based smart agriculture system with auto solar tracking that is automated and incorporates an ARM microcontroller and GSM technology. It includes a solar tracking system to maximize energy capture, which is stored in a DC battery and used to power the irrigation pump based on sensing soil condition.

Another work on ARM7 (Pergad & Patil 2015) and GSM based water management in irrigation systems presents several automatic watering ways using soil moisture and temperature sensors placed at plant roots. They use microcontrollers, solar power, and GSM or internet technologies for real-time monitoring and control. One novel idea presented here was using acoustic sensing to detect soil moisture based on sound speed variation.
The study by (Bhole & Chaudhari 2016) uses a single-axis solar tracker with four LDRs to capture maximum sunlight, generating electricity stored in a DC battery to power an irrigation pump. LDR and soil moisture sensor-based data are converted to digital signals via an ADC and processed by an AVR microcontroller, indicating a cheaper solution. The system automatically starts the pump when soil moisture is low and notifies the farmer via GSM.

The paper presented by Yadav et al. (2014) shows various designs of automatic irrigation systems using microcontrollers (ARM7, 8051, ATmega328) and solar power. Key features include soil moisture, temperature, and humidity sensors placed in the root zones, with GSM and internet (Zigbee, Android, GPRS) technologies enabling remote monitoring and controlling via SMS or mobile apps. The systems use algorithms to control water supply based on sensor thresholds, ensuring efficient irrigation and water conservation. Some models use IR sensors, LCDs, and buzzers for real-time status updates.

An android mobile-based work was done by Pavithra & Srinath (2014), which discusses a greenhouse-based irrigation system in India using Android and GSM technologies for remote control and monitoring. The system can maintain uniform temperature and humidity conditions across large farms, addressing variability due to changing atmospheric conditions. An Android app using GPRS connection allows users to send commands via SMS, while the system, based on ARM7, receives sensor data, processes it, and controls irrigation accordingly. It uses drip irrigation and monitors soil moisture and water levels, automatically turning off the motor once optimal conditions are reached. The system provides feedback to the user via SMS and uses LCDs for real-time data display.

Methodology

The methodology adopted in this study includes the design, development, implementation, and evaluation of a low-cost, GSM-based, solar-powered smart irrigation system by using an Arduino microcontroller. Based on soil moisture levels, the system architecture integrates both hardware and software components to ensure real-time remote monitoring and control of irrigation. At first, an Arduino Pro Mini was chosen as the central processing unit due to its affordability, low power consumption, and ease of programming (Akwu et al. 2020; Ali et al. 2024). A SIM800L GSM module was used for mobile communication, allowing users to send SMS commands ("on", "off", "status") to control the irrigation pump and receive soil condition updates. To determine moisture thresholds (dry, moist, wet), a capacitive soil moisture sensor was adjusted manually by using various soil samples, which were then programmed into the microcontroller as a reference table. The Arduino's analog-to-digital converter (ADC) acquires the sensor readings. To ensure off-grid, sustainable operation, a mini solar panel connected to a charge controller was used to recharge a 3.7V, 5000mAh lithium-ion battery. The system operates a relay-controlled water pump linked to the mains supply. The software component was created in Arduino IDE, utilizing AT commands to interface with the GSM module for reading and transmitting SMS. The system monitors incoming signals, soil conditions, and pump functioning at 10-second intervals. Field testing was performed in a rural environment to verify system operation, communication dependability, energy sustainability, and soil moisture monitoring precision. Data was gathered to evaluate the system's efficacy and pinpoint any operational constraints in real-world scenarios.

System architecture

The proposed system comprises both hardware and software components integrated to provide remote irrigation capabilities (Fig. 1). At the center is a Microcontroller that controls the smart aspects. An Arduino Pro Mini serves as a cheap and available solution here. For the GSM based mobile communication part, a GSM module, SIM800L, has been used, which can encode and decode SMS (Artawan et al. 2018). It is connected via a UART (Peña & Legaspi 2020) communication channel with the Arduino. Exploiting the ADC (Gray 2006) capability of the Arduino, a low-cost capacitive sensor (Eller & Denoth 1996) senses the moisture of the soil for monitoring purposes and to take appropriate actions. To power up the system, a mini solar panel, along with a charge converter circuit and a Li-ion battery, has been used. The Arduino board can turn on or off a water pump with the help of an electric Relay module. The Water pump takes power from the mains. Below is shown a complete system architecture diagram.

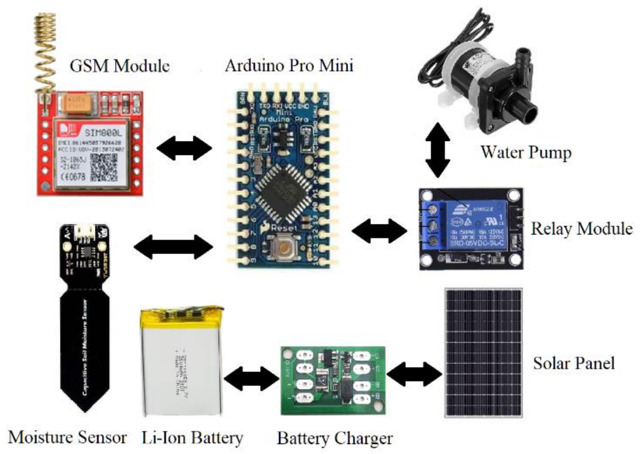

Fig. 1. Proposed system architecture for low-cost and solar-powered smart irrigation system

Operation

A fully recharged Li-ion battery is deployed with the setup. During the day, the solar panel absorbs sunlight, and energy is stored in the battery. At night, the Li-ion battery keeps the system running. At startup, the Arduino first initializes and prepares the GSM module for mobile communication. The GSM module needs to be already equipped with a functional SIM card. The Arduino checks the network condition and the SMS buffer for any latest SMS. If there is any, it takes necessary actions and empties the buffer. All of these are done using the industry standard AT (Attention) command (Alam 2015). For example: <AT+CREG?> Command is used to check network registration status. <AT+CMGF=1> is used to set SMS mode to text mode. With each command, the GSM module either responds with "OK" or other text strings, which can be found in the datasheet for writing proper algorithms. <AT+CMGL="ALL"> command lists all messages. <AT+CMGR=1> command reads message at index 1. <AT+CMGD=1> can delete message at index 1. Below is an example of sending an SMS: AT+CMGS="+8801xxxxxxxxx" > Hello from SIM800L!<Ctrl+Z>

A user/farmer can send "on"/"off" text as SMS from their mobile phone to either turn on/off the water pump, or send "status" to check soil condition. Upon sending "on"/"off", the system sends a return SMS writing "pump is on"/"pump is off" and when the status query is sent, the system texts back the soil moisture condition as, "soil is dry"/"soil is moist"/"soil is wet". Apart from that, the system automatically checks for soil condition every 10 seconds and sends the user an SMS reminding them to turn on or off the pump according to the situation. Upon electrical startup, the microcontroller takes over the whole system logically. At first, it initializes the GSM and other modules for communication/operation and then runs a continuous loop of approximate 10 seconds. Within each visit in the loop, receiving SMS requests, soil monitoring, and SMS responses are handled (Fig. 2).

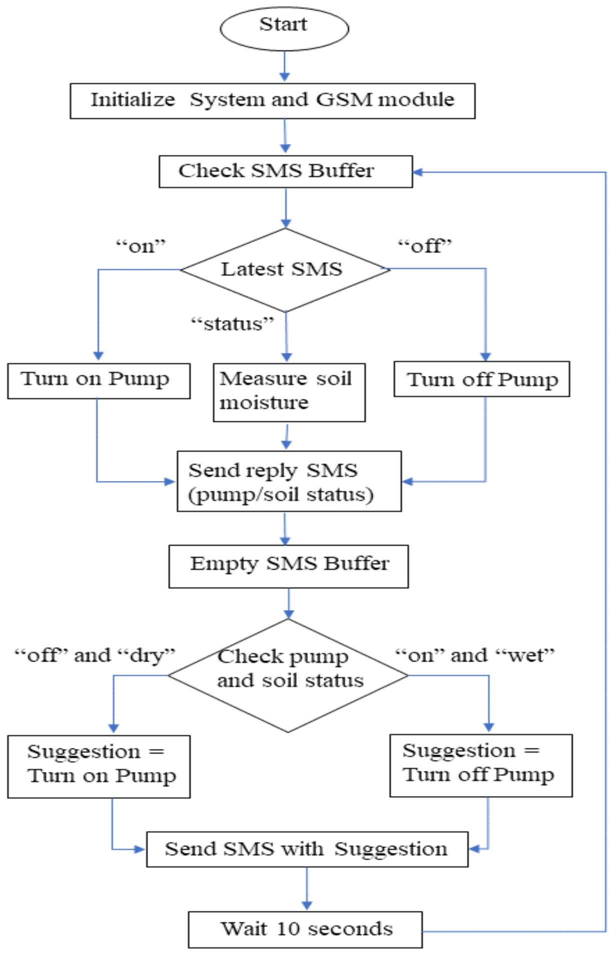

Fig. 2. Flow chart of the algorithm for low-cost and solar-powered smart irrigation system operation

Results and Evaluation

Cost estimation

The smart irrigation system that has talked about so far offers a viable, low-cost solution for farmers, particularly in rural or off-grid areas of Bangladesh. The costs of the components used to construct the smart irrigation system are summarized in Table 1. It is worth noting that the prices of these devices vary depending on the supplier chosen. The given prices are based on locally available renowned suppliers. The total cost is approximately 5000 BDT or 42 USD which indicate the system's simplicity and cost effectiveness.

Table 1. Affordability and simplicity of the systems

Component	Quantity	Price	
		USD	BDT
Arduino Pro Mini microcontroller	1	4.1	500
SIM800L GSM module	1	3.3	400
Capacitive soil moisture sensor (555 IC based)	1	2.3	280
Relay module (5V)	1	0.8	100
Solar panel (5V 10W)	1	16.5	2000
Battery charger Module (TP4056)	1	0.4	50
Li-ion battery (5Ah)	1	8.25	1000
PCB, cables, and accessories	as needed	6.6	800
Total price		**42.25**	**5130**

(Price source: store.roboticsbd.com, bdtronics.com, daraz.com.bd)

After the initial development was done and the prototype was wired up together, it was tested using a pre-recharged Li-ion battery (5000 mAh) and a SIM card that already had credit in it. The system could successfully turn the irrigation pump ON and OFF based on user SMSs, and it also texted when the soil condition was inquired. Using the capacitive moisture sensor, the smart suggestion function was also tested successfully. The sensor was calibrated manually using different samples of moist/dry soil, and the calibration values were saved as a lookup table in the code. In terms of power, the battery capacity of 5000 mAh results in 5 Ah × 3.7V = 18.5 Wh, which could be easily fulfilled by a 10W or 20W solar panel. This battery backup can ensure up to 8 hours of operation during nighttime. It could be increased further by using a bigger solar panel and battery. The panel provided sufficient charge during the day. The system was tested in rural Bangladesh, which is mostly covered by the GSM network; thus, the system achieved 100% reliable mobile communication. With this setup, some challenges could be encountered, though. A poor GSM signal strength affects reliability, and the battery might run out of power during prolonged cloudy weather. In a practical sense, this setup reduced manual intervention by automating the irrigation based on remote control and reduced water wastage by applying a drip irrigation system, which offers a promising tech combination.

Power budget estimation and system feasibility

Northern Bangladesh, particularly during the pre-monsoon month of March, receives substantial solar irradiance averaging 5.0–5.5 kWh/m²/day, with 5–6 peak sun hours under typically clear skies interrupted by occasional cloud cover (Akand et al. 2015; IDCOL 2016). Regional climate data from the Bangladesh Meteorological Department, specifically from Rajshahi and Rangpur weather stations, indicate ambient temperatures averaging 30–35°C during this period (Shamsuzzoha et al. 2014). These conditions are favorable for photovoltaic (PV) operation, though thermal derating and environmental factors must be considered.

Solar panel characteristics and realistic output

A 10W-rated PV panel at 5V (maximum 2A) theoretically generates up to 55 Wh/day under ideal conditions (10W × 5.5 hours). However, several real-world loss factors reduce this output-

Panel efficiency: 80–85% in optimal sunlight

Temperature derating: ~0.4–0.5% per °C above 25°C, leading to 2–5% efficiency loss at 30–35°C

Dust/pollution accumulation: 5–10% loss (Sharif et al. 2018)

Non-optimal alignment/positioning: 5–15% loss (Stoffel et al. 2010)

Charge controller efficiency: ~85–90%

System power demand

Based on data sheet specifications and system profiling, the power consumption of the embedded soil monitoring and irrigation advisory device is summarized below-

Idle current (Sleep mode): ~2 mA
Active sensing (10-second loop, soil moisture ADC readout): ~20 mA
Average daily consumption without networking: ~23 mA

Over a 24-hour period at 4.2V system voltage (typical for Li-ion systems), the baseline energy requirement is

$$E_{base} = 4.2V \times 23mA \times 24h = 2.32Wh$$

Network and actuator operations

The GSM module (SIM800L) draws ~200 mA during communication events, and each message transmission/reception takes ~2 seconds. If the system handles 4 SMS requests (Tx + Rx) and sends 4 recommendation messages per day, total networking consumption is

$$E_{net} = \left(\frac{8 \times 4.2\,V \times 200mA \times 2s}{86400s}\right) \times 24h \approx 3.73\,mWh$$

The relay controlling the water pump (50 mA) is estimated to operate for 4 hours daily

$$E_{relay} = 4.2\,V \times 0.05\,A \times 4h = 0.84\,Wh$$

Total daily energy demand

This daily energy demand is significantly lower than the expected usable energy output (32–40 Wh/day), confirming the sufficiency of the PV system to meet operational requirements even under suboptimal conditions. Summing all components

$$E_{total} = 2.32\,Wh + 0.00373\,Wh + 0.84\,Wh \approx 3.16\,Wh$$

It is further assumed that user interaction (e.g., SMS inquiry) occurs predominantly between 6:00 AM and 10:00 PM. During nighttime, the system remains in low-power mode with periodic checks and occasional automated message transmission.

Conclusion

This work proposes a practical, cost-effective solution for tackling irrigation difficulties both in rural and resource-constrained agricultural regions, which involves the development of a GSM-based, solar-powered smart irrigation system with Arduino. By integrating low-cost components with widely available mobile networks and sustainable solar energy, the technology allows farmers to efficiently regulate irrigation and monitor soil moisture conditions via simple SMS instructions. The incorporation of a capacitive soil moisture sensor facilitates data-informed irrigation choices, remarkably diminishing water waste and manual effort. Field testing revealed that the system operates consistently, featuring efficient remote communication and sustainable power provision from a small solar configuration. Despite several drawbacks, including reliance on GSM signal strength and solar charging efficacy in overcast conditions, the system presents a viable approach for improving agricultural output in off-grid regions. The system's modular and scalable architecture facilitates future integration with IoT platforms, AI-driven decision-making, and web-based interfaces. This effort advances smart agricultural technology, promoting sustainable farming methods and enhanced resource management in poor countries.

Conflict of Interests: The authors declare that there are no conflicts of interest related to the publication of this manuscript. The research was conducted independently, and no financial or personal relationships influenced the results or interpretation of the findings.

Author's contribution: JTBT was responsible for the conceptualization and writing of the manuscript. MMH reviewed and corrected the manuscript. KN and RI contributed to information collection, data processing and revised manuscript. MLH provided overall supervision of the work. All authors read and approved the final manuscript.

References

Ahmed AA, Al Omari S, Awal R, Fares A & Chouikha M (2021). A distributed system for supporting smart irrigation using Internet of Things technology. Engineering Reports, 3(7),e12352.

Abioye EA, Abidin MSZ, Mahmud MSA, Buyamin S, Ishak MHI, Abd Rahman MKI ... & Ramli MSA (2020). A review on monitoring and advanced control strategies for precision irrigation. Computers and Electronics in Agriculture, 173, 105441.

Akand MAR, Basher MK, Asrafusjaman M, Chowdhuri N, Abedin A & Hoq M (2015).

Study and fabrication of crystalline silicon solar cell in Bangladesh: Using thermal diffusion technique. International Journal of Innovation and Scientific Research, 18(2), 417-426.

Akwu S, Bature UI, Jahun KI, Baba MA & Nasir AY (2020). Automatic plant irrigation control system using Arduino and GSM module. International Journal of Engineering and Manufacturing, 10(3), 12-26.

Alam M (2015). AT commands. International Journal of Scientific and Research Publications, 5(5), 538-542.

Ali SS, Ali S, Khan J, Khan Z, Saleem M, Munawwar S & Khawer H (2024). Design and implementation of a sustainable microcontroller-based solar power automatic water irrigation control and monitoring system. Pakistan Journal of Engineering Technology and Science, 12(01), 78-90.

Artawan MD, Gunawan AAN & Sumadiyasa M (2018). Use of short message service (SMS) based ATmega328 microcontroller and SIM800L modules as on/off control electronic equipments. Advances in Applied Physics, 6(1), 19-24.

Baumüller H (2015). Agricultural innovation and service delivery through mobile phones. Doctoral dissertation, Universitäts-und Landesbibliothek, Bonn.

Belay M & Bewket W (2013). Traditional irrigation and water management practices in highland Ethiopia: Case study in Dangila woreda. Irrigation and Drainage, 62(4), 435-448.

Bhole K & Chaudhari D (2016). Solar powered sensor-based irrigation system. International Research Journal of Engineering and Technology, 3(2), 15–19.

Bouali ET, Abid MR, Boufounas EM, Hamed TA & Benhaddou D (2021). Renewable energy integration into cloud & IoT-based smart agriculture. IEEE access, 10, 1175-1191.

Chen B, Han MY, Peng K, Zhou SL, Shao L, Wu XF ... & Chen GQ (2018). Global land-water nexus: Agricultural land and freshwater use embodied in worldwide supply chains. Science of the Total Environment, 613, 931-943.

Coleman WD, Grant W & Josling TE (2004). Agriculture in the new global economy. Edward Elgar Publishing.

Deveci O, Onkol M, Unver HO & Ozturk Z (2015). Design and development of a low-cost solar powered drip irrigation system using Systems Modeling Language. Journal of Cleaner Production, 102, 529-544.

dos Santos Isaías DH, Cuamba BC & Leão AJ (2019). A review on renewable energy systems for irrigation in arid and semi-arid regions. Journal of Power and Energy Engineering, 7(10), 21-58.

Eller H & Denoth A (1996). A capacitive soil moisture sensor. Journal of Hydrology, 185(1-4), 137-146.

Elmahdi A (2024). Addressing water scarcity in agricultural irrigation: By exploring alternative water resources for sustainable irrigated agriculture. Irrigation and Drainage, 73(5), 1675-1683.

Gray N (2006). ABCs of ADCs (Analog-to-Digital Converter Basics). National Semiconductor.

Hanjra MA & Qureshi ME (2010). Global water crisis and future food security in an era of climate change. Food policy, 35(5), 365-377.

IDCOL (2016). Environmental impact assessment of 240kWp Standalone AC-DC coupled solar photovoltaic based Mini Grid Power Plant at Char Baghutia, Manikganj by Super Star Renewable Energy Limited. Infrastructure Development Company Limited (IDCOL). http://www.idcol.org/download/EIA_Report_SuperStar_SolarMini-grid_Manikganj.pdf

Jha K, Doshi A, Patel P & Shah M (2019). A comprehensive review on automation in agriculture using artificial intelligence. Artificial Intelligence in Agriculture, 2, 1-12.

Kidane D (2023). Deficit irrigation: A review from Ethiopia. Handbook of irrigation hydrology and management: Irrigation case studies, 69.

Li W, Awais M, Ru W, Shi W, Ajmal M, Uddin S & Liu C (2020). Review of sensor network-based irrigation systems using IoT and remote sensing. Advances in Meteorology, 1, 8396164.

Liao R, Zhang S, Zhang X, Wang M, Wu H & Zhangzhong L (2021). Development of smart irrigation systems based on real-time soil moisture data in a greenhouse: Proof of concept. Agricultural Water Management, 245, 106632.

Manfo TA & Şahin ME (2024). Development of an automatic photovoltaic cell-battery powered water irrigation system incorporated with Arduino software for agricultural activities. Gazi Journal of Engineering Sciences, 10(2), 314-328.

Meempatta L, Webb AJ, Horne AC, Keogh LA, Loch A & Stewardson MJ (2019). Reviewing the decision-making behavior of irrigators. Wiley Interdisciplinary Reviews: Water, 6(5), e1366.

Mishra VP & Pradhan AM (2023). Global agriculture economics: Trends and challenges. Innovative Strategies, 33.

Misra AK (2014). Climate change and challenges of water and food security. International Journal of Sustainable Built Environment, 3(1), 153-165.

Nsoh B, Katimbo A, Guo H, Heeren DM, Nakabuye HN, Qiao X ... & Kiraga S (2024). Internet of Things-based automated solutions utilizing machine learning for smart and real-time irrigation management: a review. Sensors, 24(23), 7480.

Obaideen K, Yousef BA, AlMallahi MN, Tan YC, Mahmoud M, Jaber H & Ramadan M (2022). An overview of smart irrigation systems using IoT. Energy Nexus, 7, 100124.

Olujimi A, Aaron I, Adebayo O, Afolarin A & Jonathan E (2022). Smart solar powered irrigation system. Journal Européen des Systèmes Automatisés, 55(4), 535.

Pavithra DS, & Srinath MS (2014). GSM based automatic irrigation control system for efficient use of resources and crop planning by using an Android mobile. IOSR Journal of Mechanical and Civil Engineering, 11(4), 49-54.

Peña E & Legaspi MG (2020). UART: A hardware communication protocol understanding universal asynchronous receiver/transmitter. Analog Dialog.

Pergad ND & Patil YP (2015). GSM based water management in irrigation system using ARM7. International Journal of Science and Research, 4(12), 1528–1530.

Prasad KSS, Kumar N, Sinha NK & Saha PK (2017). Water-saving irrigation system based on automatic control by using GSM technology. Middle-East Journal of Scientific Research, 2(8), 158–170.

Qian M, Qian C, Xu G, Tian P & Yu W (2024). Smart irrigation systems from cyber–physical perspective: State of art and future directions. Future Internet, 16(7), 234.

Rasul G & Thapa GB (2003). Sustainability analysis of ecological and conventional agricultural systems in Bangladesh. World Development, 31(10), 1721-1741.

Sabo A, Chigozie O, Aliyu SY, Abubakar US, Muhammad M, Shamsudeen Y & Ibrahim S (2023). Development of a solar-powered system for soil monitoring with an automated irrigation feature. World Journal of Advanced Engineering Technology and Sciences, 10(2), 018-029.

Salehin MU, Joy JI, Hasan SW, Babui MJ & Khan F (2023). Utilization of solar energy in irrigation systems in Bangladesh. Energy and Power Engineering, 15(12), 468-481.

Schulze K, Spreer W, Keil A, Ongprasert S & Müller J (2013). Mango (*Mangifera indica* L. cv. Nam Dokmai) production in Northern Thailand-Costs and returns under extreme weather conditions and different irrigation treatments. Agricultural Water Management, 126, 46-55.

Shamsuzzoha M, Parvez A & Chowdhury AFMK (2014). Analysis of variability in rainfall patterns in greater Rajshahi division using GIS. Journal of Environmental Science and Natural Resources, *7*(2), 141-149.

Sharif SI, Anik MAR, Al-Amin M & Siddique MAB (2018). The prospect of renewable energy resources in Bangladesh: A study to achieve the national power demand. Energy and Power, *8*(1), 1-6.

Sheline C (2024). Design of an affordable, precise irrigation controller that lowers the barrier to water-and energy-sustainable agriculture. Massachusetts Institute of Technology.

Siddiquee ZA (2016). Feasibility study of fourth generation (4G/LTE) mobile network in Bangladesh. Master thesis, Bangladesh University of Engineering and Technology.

Stoffel T, Renné D, Myers D, Wilcox S, Sengupta M, George R & Turchi C (2010). Concentrating solar power. Best practices handbook for the collection and use of solar resource data.

National Renewable Energy Laboratory, USA. Technical Report NREL/TP-550-47465. https://www.nrel.gov/docs/fy10osti/47465.pdf

Suman S, Kumar S, Sarkar R & Ghosh G (2017). Solar-powered automatic irrigation system on sensing moisture content using Arduino and GSM. International Journal of Advanced Research in Electronics and Communication Engineering, 6(6), 549-555.

Teshome Y, Biazin B, Wolka K & Burka A (2018). Evaluating performance of traditional surface irrigation techniques in Cheleleka watershed in Central Rift Valley, Ethiopia. Applied Water Science, 8, 1-14.

Van de Zande GD (2023). Bringing the water-efficiency benefits of precision irrigation to resource-constrained farms through an automatic scheduling-manual operation irrigation tool. Doctoral dissertation, Massachusetts Institute of Technology.

Varman S (2025). Advanced Irrigation and Drainage Techniques. Educohack Press.

Wazed SM, Hughes BR, O'Connor D & Calautit JK (2018). A review of sustainable solar irrigation systems for Sub-Saharan Africa. Renewable and Sustainable Energy Reviews, 81, 1206-1225.

Workie E, Mackolil J, Nyika J & Ramadas S (2020). Deciphering the impact of COVID-19 pandemic on food security, agriculture, and livelihoods: A review of the evidence from developing countries. Current Research in Environmental Sustainability, 2, 100014.

Yadav R, Sharma M, Azharuddin M, Monis M & Sisodia K (2014). Smart irrigation system using GSM and solar panel. International Journal of Scientific Research and Management Studies, 3(17), 203-209.

Yasin HM, Zeebaree SR & Zebari IM (2019, April). Arduino based automatic irrigation system: Monitoring and SMS controlling. 4th Scientific International Conference Najaf (SICN)-2019, Al-Najef, Iraq. pp. 109-114.

How to cite this article: Taufik JTB, Haque MM, Nahar K, Islam R & Hossain ML (2025). Design and Evaluation of a Low-Cost, Solar-Powered Smart Irrigation System Using Arduino and GSM. Life Science Studies, 02(01), 25-33.