Development of A Smart Rainwater Harvesting System with Automated Real-Time Water Quality Monitoring

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Abstract

Water scarcity in Sri Lanka is becoming an increasingly significant challenge due to irregular rainfall patterns and growing domestic water consumption. Increased household activities have raised water demand, while farmers, particularly in rural areas, often face difficulties in obtaining adequate quantities of clean water for agricultural purposes. Furthermore, atmospheric pollutants contribute to acid rain formation, which can negatively affect the quality of harvested rainwater. Conventional rainwater harvesting systems are generally designed for water collection and storage only, without evaluating water quality, which may result in the storage and use of contaminated water that is unsuitable for irrigation. Therefore, this study aimed to develop a smart automated rainwater harvesting system integrated with real-time water quality monitoring and sensor-based storage control to ensure the availability of safe and reliable irrigation water. The system was developed using an ESP32 microcontroller connected to pH, turbidity, and total dissolved solids (TDS) sensors. A two-tank configuration was employed, consisting of a primary assessment tank with a conical bottom for water quality evaluation and a secondary storage tank for retaining acceptable water. Sensor readings were transmitted and visualized through the Blynk IoT platform, while programmed automation logic-controlled solenoid valves to either transfer suitable water for storage or divert poor-quality water to drainage. Water was automatically rejected when the pH value was below 5.5 or above 7.5, or when turbidity exceeded the acceptable level. The results demonstrated that water stored in the secondary tank exhibited significantly improved quality compared with direct rooftop runoff and drainage discharge. Overall, the developed system provided effective automation, enhanced harvested water quality, and improved water management efficiency, offering a sustainable and practical solution for irrigation in both urban and rural environments.

Keywords: *Automatic water control; Clean water storage; IoT system; Smart rainwater harvesting; Two-tank design; Water quality monitoring*

INTRODUCTION

Human survival and development depend on water, and agriculture uses around 85% of the world's freshwater resources (El Mezouari *et al.*, 2022). Climate variability, urbanization, industrialization, and population growth have increased the strain on water supplies, resulting in pollution, unpredictable rainfall, and scarcity. Sustainable solutions are required since traditional water delivery systems are unable to keep up with the increasing demand (Obaideen *et al.*, 2022). Rainwater harvesting (RWH) is a longstanding, inexpensive technique for gathering and storing rainwater for use in homes, businesses, and agriculture (Roman *et al.*, 2017; Shetty *et al.*, 2020). It is an efficient and longlasting method of conserving water since it lessens the strain on centralized systems and groundwater while lowering stormwater runoff (Boers and Ben-Asher, 1982; Campisano *et al.*, 2017).

Particularly in regions impacted by NO_x and SO_2 emissions, acidic water ($pH < 5.5$) presents serious dangers to irrigation systems and agriculture. It shortens the lifespan of systems and increases maintenance costs by corroding metal tanks, pumps, pipes, and valves (Zhang *et al.*, 2023). In addition to acidifying the soil, frequent use of acidic water also mobilizes harmful manganese and aluminium, depletes vital nutrients, lowers microbial activity, and inhibits root function, all of which eventually diminish crop development and production (Singh and Agrawal, 2008). In low-buffer soils and systems that hold untreated rainwater, these issues are more serious. The majority of RWH systems do not have automatic pH regulation, which emphasizes the necessity for intelligent sensor-based monitoring to identify and redirect acidic water, safeguard soil health, and enhance irrigation systems' sustainability (Banna *et al.*, 2014; García *et al.*, 2020).

Rainwater that has been harvested frequently has high turbidity and elevated TDS levels due to the presence of dust, sediments, bird droppings, and organic material (Meera and Ahammed, 2006; WHO, 2022). High turbidity increases system maintenance and malfunctions, jams drip and sprinkler emitters, and encourages the growth of biofilms (Abdulla and Al-Shareef, 2009).

The suggested solution employs a two-tank automatic purification technique that is managed by a turbidity sensor in order to address this. Every collected water goes into the main tank, where turbidity is constantly checked. The drain valve opens to remove contaminated water and sediments if turbidity over the threshold. Only clean water is sent to the secondary tank for storage and irrigation when the drain closes and the transfer valve opens once turbidity reaches the safe range. A cloth-covered gravel, sand, and charcoal filter further enhances water quality (Shaheed *et al.*, 2017; Muktiningsih and Putri, 2021).

This study's primary goal is to create an automated rainwater harvesting system with intelligent valve management and real-time water quality monitoring so that only water acceptable for irrigation is stored and utilized (Nwamekwe *et al.*, 2026; García *et al.*, 2020). Furthermore, real-time monitoring and remote control via mobile devices are made possible by the system's integration with the Blynk IoT platform, which improves system efficiency and user accessibility (Choong and Chia, 2026; Sirisha *et al.*, 2026).

MATERIALS AND METHODS

Sensor Calibration

pH Sensor

The pH electrode was interfaced with the ESP32 ADC (Analog to Digital Conversion) via a voltage divider. Calibration used standard buffers (pH 4, 7, 10), and average ADC readings (ADC_{avg}) were used to determine the linear calibration equation:

$$pH = g \times ADC_{avg} + b \tag{1}$$

Turbidity Sensor

Three water samples (clear, moderate turbidity, high turbidity) were measured, and average ADC readings were used to establish a linear relation:

$$Turbidity\ (NTU) = g \times ADC_{avg} + b \tag{2}$$

TDS Sensor

Standard NaCl solutions (113, 342, 707 ppm) were prepared, and average ADC readings were used to calculate the calibration line:

$$TDS = g \times ADC_{avg} + b \tag{3}$$

Circuit Preparation

All components were mounted on a dot board with the ESP32 as the central controller. A 12V supply with an LM2596 buck converter provided regulated voltage. Sensor connections: TDS (pin 34), turbidity (pin 32), pH (pin 35); relay controls: water pump (pin 25), solenoid valve (pin 26). Sensor data and control signals were integrated with the Blynk IoT Dashboard (Fig. 1) for real-time monitoring and remote management (Blynk Inc., 2023; Choong and Chia, 2026). The complete circuit was enclosed in a water-resistant plastic casing to ensure safety during operation

Programming

The ESP32 microcontroller was programmed using the Arduino IDE. The code was compiled, uploaded via USB, and tested to ensure proper operation of all sensors, relays, and dashboard functions (ESP32 DT, 2023).

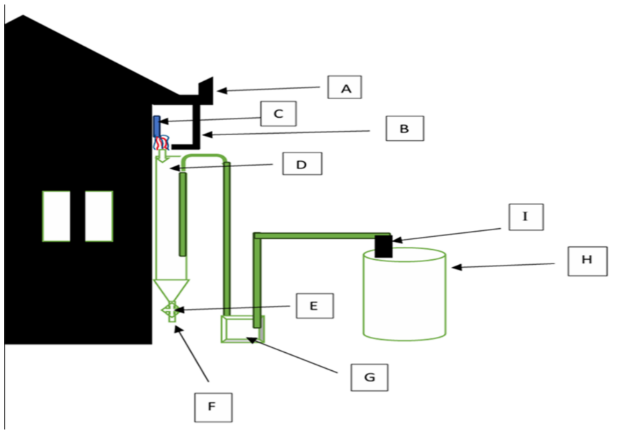
Automation Logic

The system (Fig. 2) continuously monitored pH and turbidity. Sensors were stabilized, readings averaged, and converted using calibration curves. If pH was 5.5–7.5 and water was clear, the pump (pin 25) ran for 10 minutes to transfer water to the secondary tank. If pH was outside this range or water was turbid, the solenoid valve (pin 26) opened for 10 minutes to drain poor-quality water. After each cycle, actuators turned off, sensors stabilized, and readings were repeated. Hysteresis prevented frequent switching, and the solenoid valve had priority to remove contaminated water. All data were sent to the Blynk IoT dashboard (Blynk Inc., 2023) for monitoring and manual control, ensuring only safe water reached the irrigation tank.

Primary Tank System

The primary tank was a vertical 4-inch (0.1016 m) PVC pipe, 2 m high, with a conical base to collect sediments (Fig. 2).

Fig. 1: Blynk IoT dashboard.



A – Roof top; B – Roof top collection pipe; C – Water quality monitoring unit; D – Primary tank; E – Solenoid valve; F – Drainage outlet pipe; G – Pump; H – Secondary storage tank; I – Filtration system.

Fig. 2: The diagram of the system.

The 2 m water column (~0.2 bar) facilitated flushing of settled particles through a solenoid valve at the base. The cylindrical portion held ~16.2 L, slightly more with the conical base. TDS, turbidity, and pH sensors at the top enabled real-time water quality monitoring. The system used sensor readings to either transfer water to the secondary tank or drain poor-quality water. Mounted vertically on a frame and connected to the roof collection pipe, the tank functioned as both temporary storage and a water quality evaluation unit (Shaheed *et al.*, 2017).

Secondary Storage Tank System

A 10 L bucket served as the secondary tank (Fig. 2) for easy testing, though the design can scale to larger reservoirs. Water from the primary tank passed through a charcoal–sand filter, which removed odors, organic compounds, and fine particles, slightly reducing TDS. This ensured the secondary tank stored safe, irrigation-ready water, while the primary tank functioned as a quality evaluation unit (Muktiningsih and Putri, 2021).

Determination of Amount of Rainfall

Five rainfall events were selected, and the rainfall depth for each event was measured over a two-minute period in both the morning and evening. The recorded values were then converted to represent the corresponding daily rainfall depth.

Water Sampling and Analysis

Water samples were collected from three sources: direct rooftop harvest, automated system drainage, and secondary tank storage. For each source, three samples were taken from upper, middle, and lower layers in 10 L buckets to account for vertical variation. Rainfall depth was measured twice daily, and the average was recorded.

Water quality was assessed for pH, TDS, TSS, and turbidity. pH was measured using a calibrated meter with buffer solutions; turbidity was measured with a cuvette-based meter; TSS and TDS were determined by filtering, drying, and weighing samples (Adebowale *et al.*, 2026; APHA, 2017; Deswal and Deswal, 2027; Singh and Deswal, 2025).

Data were analysed in R-Studio. Mean, standard deviation, and range were calculated, and one-way ANOVA with Tukey’s HSD tested for significant differences among sources. Results were summarized in tables and graphs for interpretation.

RESULTS AND DISCUSSION

This section presents the performance of the automated rainwater harvesting system, showing how its mechanical and electronic components improve water quality management. It highlights real-time data transfer to the Blynk IoT platform, automated storage of safe water in the secondary tank, and reduced human intervention for efficient irrigation management.

Amount of Rainfall

Rainfall events on September 27–29 and October 4–5 were used to evaluate the system. Daily rainfall ranged from 9–18 mm (Table 1). On September 27–28, pH, turbidity, and TDS were within safe limits, and water was successfully stored in the secondary tank. On October 4–5, initial runoff contained dust and debris, causing higher turbidity and low pH (<5.5). The system diverted this poor-quality water, preventing contamination of the storage tank. Sediments settled in the primary tank, confirming effective capture. These results show that the automated system reliably distinguished between clean and contaminated water, responding appropriately under varying rainfall conditions to ensure safe irrigation storage (Shaheed *et al.*, 2017; Zhang *et al.*, 2023).

Table 1: Amount of rainfall.

Date	Rainfall depth (mm) for two minutes		Average depth (mm) for the day
	Morning	Evening	
Sept 27	16mm	10mm	13mm
Sept 28	20mm	16mm	18mm
Sept 29	12mm	-	12mm
Oct 4	14mm	16mm	15mm
Oct 5	6mm	12mm	9mm

pH

Upper-layer samples showed pH of 6.80 to 6.81 in the secondary storage tank (S tank) and direct rainwater harvesting tank (DRH), within the safe irrigation range (5.5–7.5), while the drainage outlet (DO) tank was more acidic at 5.23. The lower DO pH is due to initial runoff and CO_2 interaction (Table 2). The automated system maintained near-neutral pH in storage while diverting low-quality water effectively.

Middle-layer pH values were 5.94 (DRH), 5.97 (S tank), and 5.31 (DO tank). The DRH and S tanks were slightly acidic but marginally suitable for short-term irrigation, while the DO tank was below the safe range (<5.5) and unsuitable without treatment. Acidic water may harm soil and crops, so

Table 2: Values of pH.

Collected Depth	Direct rainwater harvested tank		Secondary Storage tank		Drainage outlet tank	
	pH	**T (°C)**	**pH**	**T (°C)**	**pH**	**T**
Upper layer	6.81	27.6	6.80	27.1	5.23	28.1
Middle layer	5.94	27.8	5.97	28	5.31	28.1
Bottom layer	5.33	28	6.60	27.4	4.99	28.4

pH adjustment is recommended for long-term use (Singh and Agrawal, 2008).

Bottom-layer pH values were 5.33 (DRH), 6.60 (S tank), and 4.99 (DO tank). Only the S tank water was within the safe irrigation range (5.5–7.5). DRH and DO tanks were acidic, with the DO tank highly acidic due to sediment, organic decomposition, and possible acid rain. pH adjustment (liming, aeration, or blending) is recommended before irrigation use (Meera and Ahammed, 2006).

One-way ANOVA showed a marginally non-significant difference (F = 4.965, p = 0.053). Tukey HSD indicated the secondary tank had the highest pH (6.46) within the ideal irrigation range, DRH was 6.03, and DO was lowest at 5.17. Practically, the secondary tank provided the most suitable water for irrigation.

Turbidity

Turbidity was highest in the DO tank (31 FTU), moderate in the DRH tank (12 FTU), and lowest in the secondary tank (7 FTU), as tabulated in Table 3. High DO turbidity reflects debris and organic particles, while the secondary tank maintained low turbidity due to sediment-settling design and a gravel–sand–charcoal filter (Shaheed *et al.*, 2017; Muktiningsih and Putri, 2021).

Turbidity was highest in the DO tank (47 FTU), moderate in the DRH tank (10 FTU), and lowest in the secondary tank (6 FTU). The secondary tank's low turbidity reflects effective sediment settling, pump placement, and gravel–sand–charcoal filtration, ensuring cleaner water for irrigation.

Turbidity was highest in the DO tank (64 FTU), moderate in the DRH tank (40 FTU), and lowest in the secondary tank (1 FTU). The secondary tank maintained very low turbidity due to selective transfer of clean water, conical-bottom sediment settling, pump inlet placement, and gravel–sand–charcoal filtration, ensuring water suitable for irrigation.

One-way ANOVA showed a significant difference among sources (F = 7.414, p = 0.0239). Tukey HSD indicated the Secondary tank had the lowest turbidity (4.67 FTU), DRH was moderate (20.67 FTU), and DO was highest (47.33 FTU), confirming the Secondary tank water as most suitable for irrigation.

Table 3: Values of Turbidity.

Collected Depth	Turbidity		
	Direct rainfall harvested tank	**Secondary storage tank**	**Drainage outlet tank**
Upper layer	12 FTU	7 FTU	31 FTU
Middle layer	10 FTU	6 FTU	47 FTU
Bottom layer	40 FTU	1 FTU	64 FTU

TSS (Total Suspended Solids)

The Total Suspended Solids (TSS) concentration obtained from 50 mL of each water sample (Table 4) was converted to represent 1 L (Table 5). The conversion was done using the proportional relationship:

$$TSS_{1L} = TSS_{(50ml)} \times 20 \tag{4}$$

Once the TSS values for 1 L were calculated for the upper, middle, and bottom layers, the average TSS for each source was computed using the formula:

$$Average\ TSS_{1L} = [Upper\ layer\ TSS_{1L} + Middle\ layer\ TSSTSS_{1L} + Bottom\ layer\ TSS_{1L}\ ] \div 3 \tag{4}$$

Finally, the total suspended solids content for the 10 L storage tank was obtained by multiplying the average 1 L value by 10:

$$TSS_{(10L)} = Average\ TSS \times 10 \tag{5}$$

TSS was highest in the DRH and DO tanks, indicating sediment accumulation, and lowest in the Secondary (S) tank (Table 6). The S tank's low TSS resulted from sediment settling, pump inlet placement above the conical base, gravel–sand filtration, and automated turbidity-based drainage of poor-quality water. This combination effectively minimized suspended solids, ensuring clean water for irrigation (Muktiningsih and Putri, 2021).

Table 4: TSS values for 50 mL.

Collected Depth	TSS values for 50mL		
	DRH tank	**S tank**	**DO tank**
Upper layer	0.2069 g	0.0113 g	1.2925 g
Middle layer	0.1517 g	0.0238 g	1.2386 g
Bottom layer	2.0720 g	0.0040 g	2.4220 g

Table 5: TSS values for 1L.

Collected Depth	TSS values for 1L		
	DRH tank	**S tank**	**DO tank**
Upper layer	4.138 g /L	0.226 g/L	25.85 g/L
Middle layer	3.034 g/L	0.476 g/L	24.772 g/L
Bottom layer	41.44g g/L	0.008 g/L	48.440 g/L

Table 6: Total TSS of tanks.

Total Suspended Solids of tanks	Source of water samples		
	DRH tank	**S tank**	**DO tank**
Total TSS	162.04 g	2.367g	330.2067g

One-way ANOVA showed no significant difference among sources (F = 3.684, p = 0.0904). Tukey HSD indicated the Secondary tank had the lowest TSS (0.237 g/L), while DRH and DO tanks had higher values (16.20 and 33.02 g/L). Overall, the Secondary tank water was the cleanest and most suitable for irrigation.

TDS (Total Dissolve Solids)

The Total Dissolve Solids (TDS) concentration obtained from 50 mL of each water sample was converted to represent 1 L. The conversion was done using the proportional relationship:

$$TDS(1L) = TDS(50ml) \times 20 \tag{6}$$

Once the TDS values for 1 L were calculated for the upper, middle, and bottom layers, the average TSS for each source was computed using the formula:

$$Average\ TDS_{(1L)} = [Upper\ layer\ \ TDS_{(1L)} + Middle\ layer\ \ TDS_{(1L)} + Bottom\ layer\ \ TDS_{(1L)} \div 3 \tag{7}$$

Finally, the total suspended solids content for the 10 L storage tank was obtained by multiplying the average 1 L value by 10:

$$TDS_{(10L)} = Average\ TDS \times 10 \tag{8}$$

TDS was lowest in the Secondary (S) tank (0.026–0.124 g), higher in DRH (0.122–0.474 g) and DO (0.222–0.27 g) tanks. The S tank's low TDS results from gravel–sand–charcoal filtration, which removes dissolved impurities and improves water quality for irrigation (Shaheed *et al.*, 2017).

One-way ANOVA showed no significant difference among sources (F = 3.711, p = 0.0893). Tukey HSD indicated the Secondary tank had the lowest TDS (0.065 g/L), while DRH and DO were higher (0.293 g/L and 0.241 g/L). Practically, the Secondary water was the cleanest and most suitable for irrigation.

Table 7: TDS values for 50 mL.

Collected Depth	TDS values for 50mL		
	DRH tank	**S tank**	**DO tank**
Upper layer	0.0061g	0.0013 g	0.0135 g
Middle layer	0.0237g	0.0023 g	0.0111g
Bottom layer	0.0141g	0.0062 g	0.0115 g

Table 5: TDS values for 1L.

Collected Depth	TDS values for 1L		
	DRH tank	**S tank**	**DO tank**
Upper layer	0.122 g/L	0.026 g/L	0.27 g/L
Middle layer	0.474 g/L	0.046 g/L	0.222 g/L
Bottom layer	0.282 g/L	0.124 g/L	0.230 g/L

Table 6: Total TDS of tanks.

Total Dissolved Solids of tanks	Source of water samples		
	DRH tank	**S tank**	**DO tank**
Total TDS	2.9267 g	1.82 g	2.4067 g

CONCLUSIONS

The automated rainwater harvesting system effectively diverted low-quality water while storing irrigation-suitable water in the secondary tank. Continuous monitoring of pH, TDS, TSS, and turbidity ensured only safe water was retained. The system reliably operated solenoid valves based on real-time sensor data and transmitted all information to the Blynk IoT dashboard for remote monitoring (Choong and Chia, 2026; Sirisha, 2026). The two-tank design, conical primary tank bottom, and filtration unit improved sediment removal and water separation (Shaheed *et al.*, 2017; Muktiningsih and Putri, 2021). The system performed well under varying rainfall intensities, consistently providing high-quality water. Overall, the study demonstrates that combining mechanical design with automated control enhances rainwater management, offering a sustainable and reliable solution for agricultural irrigation (Shetty *et al.*, 2022; Campisano *et al.*, 2017).

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The present research did not receive any financial support to conduct the research.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

REFERENCES

1) Abdulla, F.A. and Al-Shareef, A.W. (2009) 'Roof rainwater harvesting systems for household water supply in Jordan', *Desalination*, 243(1-3), pp. 195-207. https://doi.org/10.1016/j.desal.2008.05.013
2) Adebowale, I.J., Moses, P. and Abalist, R.O. (2026) ‘Organic contamination in water and sediment of Opokuma Community, Kolokuma/Opokuma Local Government Area, Bayelsa State, Niger Delta, Nigeria’, *International Journal of Technology, Health and Sustainability*, 2(1), pp. 333-339. https://ijths.com/wp-content/uploads/IJTHS-020192.pdf
3) APHA (2017) *Standard Methods for the Examination of Water and Wastewater*. 23rd edn. Washington, DC: American Public Health Association.
4) Ariyabandu, R. de S. (1999) 'Development of rainwater harvesting for domestic water use in rural Sri Lanka', *Asia-Pacific Journal of Rural Development*, 9(1), pp. 1-14. https://doi.org/10.1177/1018529119990101
5) Balasuriya, B.M.C.M. and Arachchige, U.S.P.R. (2021) 'Rainwater harvesting for drinking purposes in Sri Lanka', *Journal of Research in Technology and Engineering*, 2(3), pp. 37-46. https://www.jrte.org
6) Banna, M.H., Najjaran, H., Sadiq, R., *et al.* (2014) 'Miniaturized water quality monitoring pH and conductivity sensors', *Sensors and Actuators B: Chemical*, 193, pp. 434-444. https://doi.org/10.1016/j.snb.2013.12.002
7) Blynk Inc. (2023) *Blynk IoT Platform Documentation*. Available at: https://docs.blynk.io/ (Accessed: 15 June 2025).
8) Boers, Th.M. and Ben-Asher, J. (1982) 'A review of rainwater harvesting', *Agricultural Water Management*, 5(2), pp. 145-158. https://doi.org/10.1016/0378-3774(82)90004-X
9) Campisano, A., Butler, D., Ward, S., *et al.* (2017) 'Urban rainwater harvesting systems: Research, implementation and future perspectives', *Water Research*, 115, pp. 195-209. https://doi.org/10.1016/j.watres.2017.02.056
10) Choong, J.J. and Chia, K.S. (2026) 'IoT-based industrial wastewater monitoring system using ESP32 and Blynk', *Journal of Engineering Technology and Applied Physics*, 8(1), pp. 106-114. https://doi.org/10.33093/jetap.2026.8.1.15
11) Deswal, S. and Deswal, A. (2017) *A Basic Course in Environmental Studies*. 3rd ed. New Delhi: Dhanpat Rai & Co. (P) Ltd.
12) El Mezouari, A., El Fazziki, A. and Sadgal, M. (2022) 'Hadoop–Spark framework for machine learning-based smart irrigation planning', *SN Computer Science*, 3(1), 10. https://doi.org/10.1007/s42979-021-00915-y
13) ESP32 DT (2023) *ESP32 Arduino Core Documentation*. ESP32 Development Team Available at: https://docs.espressif.com/projects/arduino-esp32/ (Accessed: 15 June 2025).
14) García, L., Parra, L., Jimenez, J.M., *et al.* (2020) 'IoT-based smart irrigation systems: An overview on the recent trends on sensors and IoT systems for irrigation in precision agriculture', *Sensors*, 20(4), 1042. Available at: https://doi.org/10.3390/s20041042
15) Meera, V. and Ahammed, M.M. (2006) 'Water quality of rooftop rainwater harvesting systems: A review', *Journal of Water Supply: Research and Technology-Aqua*, 55(4), pp. 257-268. https://doi.org/10.2166/aqua.2006.0010
16) Muktiningsih, S.D. and Putri, D.M.A.R.M.S. (2021) 'Study of the potential use of rainwater as clean water with simple media gravity filters: A review', *Earth Environ. Sci.*, 733, 012147. https://iopscience.iop.org/article/10.1088/1755-1315/733/1/012147
17) Nwamekwe, C.O., Uchenna, P.C. and Onyedik, S.C. (2026) ‘Leveraging emerging technologies to enhance business processes in blue economy sectors: A case study of Anambra State’s industrial landscape’, *International Journal of Technology, Health and Sustainability*, 2(2), pp. 559-572. https://ijths.com/wp-content/uploads/IJTHS-0202024.pdf
18) Obaideen, K., Yousef, B.A.A., AlMallahi, M.N., *et al.* (2022) 'An overview of smart irrigation systems using IoT', *Energy Nexus*, 7, Article 100124. https://doi.org/10.1016/j.nexus.2022.100124
19) Roman, D.C., Braga, A.M., Shetty, N.H., *et al.* (2017) 'Design and modeling of an adaptively controlled rainwater harvesting system', *Water*, 9(12), 974. https://doi.org/10.3390/w9120974
20) Shaheed, R., Mohtar, W.H.M.W., and El-Shafie, A. (2017) 'Ensuring water security by utilizing roof-harvested rainwater and lake water treated with a low-cost integrated adsorption-filtration system, *Water Science and Engineering*, 10(2), pp. 115-124. https://doi.org/10.1016/j.wse.2017.05.002
21) Shetty, N.H., Wang, M., Elliott, R., *et al.* (2022) 'Examining how a smart rainwater harvesting system connected to a green roof can improve urban stormwater management', *Water*, 14(14), https://doi.org/10.3390/w14142216
22) Singh, A. and Agrawal, M. (2008) 'Acid rain and its ecological consequences', *Journal of Environmental Biology*, 29(1), pp. 15-24. https://www.jeb.co.in
23) Singh, A. and Deswal, S. (2025) ‘Groundwater quality assessment and thematic spatial mapping of Hisar district in Haryana (India)’, *International Journal of Technology, Health and Sustainability*, 1(1), pp. 37-45. https://ijths.com/wp-content/uploads/2025/12/IJTHS-010120.pdf
24) Sirisha, V., Sai, R., Yasodha, G., *et al.* (2026) 'IoT-based real-time water quality monitoring and predictive alert system using ESP32', *American Journal of AI Cyber Computing Management*, 6(1), pp. 340-346.
25) WHO (2022) *Guidelines for drinking-water quality: Incorporating the first and second addenda*. 4th edn. Geneva: World Health Organization. Available at: https://www.who.int/publications/i/item/9789240045064 (Accessed: 15 June 2025).
26) Zhang, Y., Li, J., Tan, J., *et al.* (2023) An overview of the direct and indirect effects of acid rain on plants: Relationships among acid rain, soil, microorganisms, and plants', *Science of The Total Environment*, 873, 162388. https://doi.org/10.1016/j.scitotenv.2023.162388