Development of Portable Solar Water Purification System for Disaster Relief with IoT System

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ABSTRACT
Access to clean water remains a critical global challenge, particularly in disaster prone and rural areas where infrastructure is often damaged and electricity access is limited. This study aims to develop a portable solar powered water purification system integrated with Internet of Things technology to support emergency water supply. The system utilizes a five stage filtration process powered by a 12 V solar panel and monitored using an Arduino Uno microcontroller connected to pH, turbidity, and temperature sensors. Real time data transmission is enabled through an ESP8266 module and monitored via a mobile application platform. Performance evaluation was conducted by measuring temperature, turbidity, and pH across five filtration stages. The results indicate a significant reduction in turbidity from 724 NTU to 26 NTU and stable temperature variation within 0.4 °C, demonstrating effective particle removal and thermal consistency. However, instability was observed in the pH parameter, including an unrealistic initial reading and a final acidic value of 3.67, indicating the need for sensor recalibration and chemical stabilization. The findings suggest that integrating renewable energy, multi stage filtration, and real time monitoring provides a promising approach for portable water treatment systems, although further optimization is required to ensure drinking water safety standards in disaster relief applications.

Keywords : Disaster Relief; Internet of Things; Portable Water Purification; Solar Energy; Water Quality Monitoring.

ABSTRAK
Akses terhadap air bersih masih menjadi tantangan global yang signifikan, khususnya di daerah rawan bencana dan wilayah terpencil dengan keterbatasan infrastruktur dan pasokan listrik. Penelitian ini bertujuan untuk mengembangkan sistem pemurnian air portabel berbasis energi surya yang terintegrasi dengan teknologi Internet of Things untuk mendukung penyediaan air darurat. Sistem menggunakan proses filtrasi lima tahap yang ditenagai panel surya 12 V dan dimonitor melalui mikrokontroler Arduino Uno yang terhubung dengan sensor pH, kekeruhan, dan suhu. Transmisi data secara waktu nyata dilakukan menggunakan modul ESP8266 dan dipantau melalui aplikasi seluler. Evaluasi kinerja dilakukan dengan mengukur suhu, kekeruhan, dan pH pada setiap tahap filtrasi. Hasil penelitian menunjukkan penurunan kekeruhan yang signifikan dari 724 NTU menjadi 26 NTU serta kestabilan suhu dengan variasi hanya 0,4 °C, yang menunjukkan efektivitas penyaringan partikel dan konsistensi termal. Namun, ditemukan ketidakstabilan pada parameter pH, termasuk pembacaan awal yang tidak realistis dan nilai akhir yang terlalu asam sebesar 3,67, sehingga diperlukan kalibrasi ulang sensor dan stabilisasi kimia. Integrasi energi terbarukan, filtrasi bertahap, dan pemantauan waktu nyata menunjukkan potensi besar untuk aplikasi penanganan bencana, meskipun optimalisasi lanjutan diperlukan agar memenuhi standar air minum.

***Kata kunci** : Energi Surya; Internet of Things; Kualitas Air; Pemurnian Air Portabel; Penanggulangan Bencana.*

INTRODUCTION
Access to clean water remains a major global concern, particularly in rural and disaster prone regions where basic infrastructure is often limited or severely damaged during emergencies. Natural disasters such as floods frequently destroy water supply systems and contaminate available sources, creating serious public health threats including outbreaks of waterborne diseases such as cholera and diarrhea (Arasu et al., 2019; Ashhar & Haw, 2023). This condition becomes more critical in communities that lack rapid emergency

response services, where contaminated water is often the only accessible source for daily consumption. Environmental pollution caused by industrial discharge, agricultural runoff, and improper waste management further degrades water quality. In developing regions, limited financial and technological resources hinder the implementation of centralized purification systems, forcing populations to depend on untreated water. Such dependence increases exposure to harmful microorganisms, toxic chemicals, and heavy metals that may lead to long term health complications (L. et al., 2021; Varghese et al., 2020).

The challenge is further intensified by the limited availability of freshwater, as only a small fraction of the Earth's water resources is directly accessible for human use. Climate change has exacerbated water scarcity by altering rainfall patterns and reducing groundwater reserves, particularly in already vulnerable areas. At the same time, population growth and urbanization continue to increase global demand for clean water, placing additional pressure on limited natural resources (Sangari et al., 2021; Yoon et al., 2022). These interconnected factors highlight the urgent need for innovative, sustainable, and deployable water purification technologies that can operate effectively under emergency and off grid conditions.

Several studies have proposed portable solar powered water purification systems as practical solutions for disaster and rural applications (Arasu et al., 2019; Ashhar & Haw, 2023). Early developments focused primarily on portability and solar energy efficiency, yet many lacked automation and remote monitoring features (Arasu, 2019). Subsequent technological advancements introduced nanotechnology based filtration methods, including nanofiber membranes and ultraviolet sterilization, which significantly improved the removal of microscopic contaminants and chemical pollutants (Varghese et al., 2020). Other designs incorporated amphibious mobile units that combine solar power and ultrafiltration systems to enhance adaptability in difficult terrains during emergency deployment (Ashhar & Haw, 2023).

A major advancement in recent years is the integration of Internet of Things technology. IoT enabled systems facilitate real time monitoring of water quality parameters such as pH, turbidity, and temperature, while also supporting automated system responses. This capability is particularly valuable in disaster scenarios where manpower and technical supervision are limited (L. et al., 2021). Nevertheless, existing systems often demonstrate partial integration, where smart monitoring features are not fully combined with advanced multi stage filtration processes. Alternative purification approaches, including TiO_2 based photocatalysis and biomass derived hydrogel evaporators, offer energy efficient and cost effective solutions, yet they may lack IoT compatibility or present scalability limitations for field implementation (Carpio et al., 2023; Guo et al., 2020).

Based on these findings, the literature consistently indicates that an effective disaster relief water purification system should integrate renewable solar energy, advanced filtration mechanisms, and IoT based real time monitoring to ensure efficiency, autonomy, and operational reliability (Guo et al., 2020; Kabir & Binzaid, 2022; L. et al., 2021; Varghese et al., 2020). Therefore, this study proposes the development of a portable solar powered water purification system equipped with IoT technology to provide continuous water quality monitoring and improve system responsiveness in emergency contexts. By combining sustainable energy utilization, intelligent monitoring, and enhanced filtration performance, the proposed system aims to contribute to broader efforts toward universal access to safe and clean water in alignment with global development objectives (Mohammed & Ali, 2023; Ramesh & Roy, 2019).

RESEARCH METHOD

The research employed a system development approach consisting of design planning, hardware assembly, software programming, and system testing. The overall research procedure is illustrated in Figure 1. The flowchart describes the sequential stages undertaken in the study, beginning from conceptual design, hardware configuration, software integration, and ending with performance testing and evaluation. The flowchart served as a structured guideline to ensure systematic execution before data collection and system optimization were conducted.

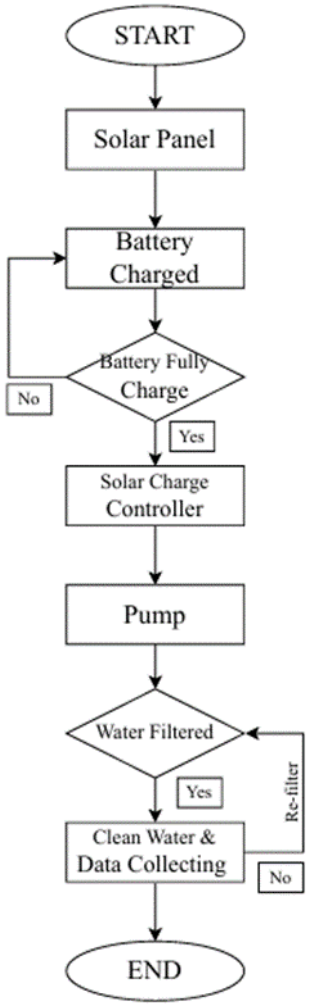


Figure 1. Research Flowchart

Following the research workflow, the system architecture was designed and is presented in Figure 2. The block diagram illustrates the configuration of the Internet of Things based water quality monitoring system using an Arduino Uno microcontroller as the central processing unit. Three sensors consisting of a pH sensor, turbidity sensor, and temperature sensor were directly connected to the Arduino Uno to measure water parameters in real time. The measured data were processed by the microcontroller and displayed locally on a 20 × 4 I2C LCD module. In addition, an ESP8266 WiFi module was integrated to transmit the data to a mobile monitoring platform through an internet connection, allowing both local and remote monitoring of system performance.

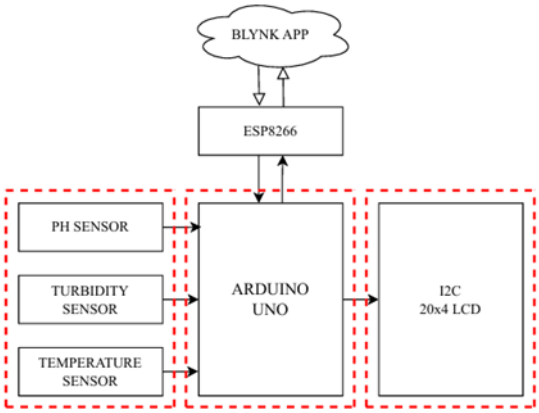


Figure 2. System Block Diagram

The hardware components used in this study are summarized in Table 1. The system utilized a 12 V solar panel as the primary energy source, supported by a solar charge controller and a 12 V battery to ensure stable power supply. A 12 V pump was installed to circulate water through the filtration system. The Arduino Uno functioned as the main controller, while the LCD 20 × 4 I2C module displayed measurement results. The pH sensor, turbidity sensor, and temperature sensor were employed to monitor water quality parameters. The ESP8266 module enabled wireless communication between the system and the mobile application interface.

Table 1. Tools and Hardware Used

No	Component	Quantity
1	Solar panel 12 V	1
2	Solar charge controller	1
3	Battery 12 V	1
4	Switch	2
5	Arduino Uno	1
6	Pump 12 V	1
7	LCD 20 × 4 I2C	1
8	pH sensor	1
9	Turbidity sensor	1
10	Temperature sensor	1
11	ESP8266	1

The electrical configuration of the system is illustrated in Figure 3. The wiring diagram demonstrates the interconnection between the solar power subsystem, microcontroller, sensors, pump, and communication module. The solar panel was connected to the solar charge controller and battery to ensure continuous energy storage and distribution. All sensors were connected to the appropriate analog and digital input pins of the Arduino Uno, while the ESP8266 module was connected via serial communication to enable wireless data transmission.

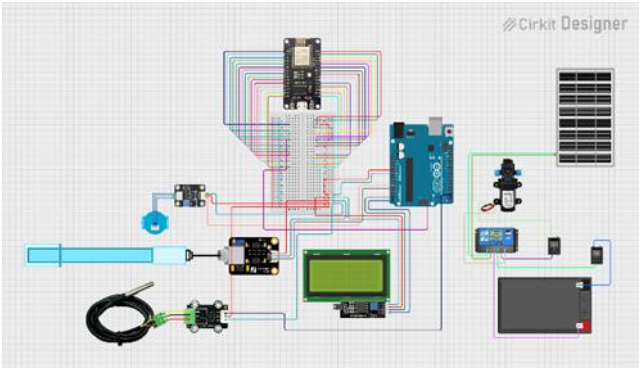


Figure 3. Wiring Diagram

The software implementation involved two main platforms, namely the Arduino Integrated Development Environment and the Blynk mobile application. The Arduino Integrated Development Environment shown in Figure 4 was used to develop and upload the program code to the microcontroller using the C++ programming language. The program was designed to continuously read sensor data, process measurements, display results on the LCD module, and transmit data via the ESP8266 module. Supporting libraries were incorporated to ensure stable WiFi communication and synchronized data handling.

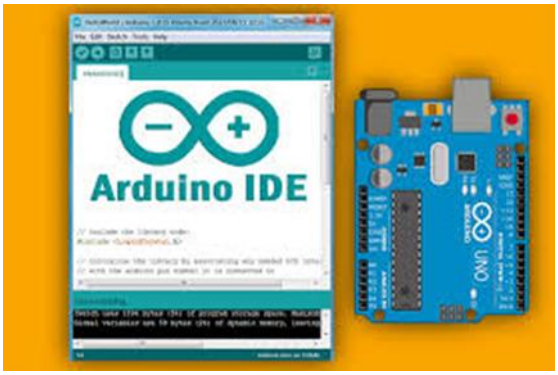


Figure 4. Arduino Integrated Development Environment

For remote monitoring, the Blynk mobile application shown in Figure 5 was configured as a digital dashboard interface. The application allowed users to visualize pH, turbidity, and temperature values in real time. The ESP8266 module transmitted data to the Blynk cloud server, enabling remote access via smartphone. A dedicated database account was created to store measurement records for monitoring and evaluation purposes.

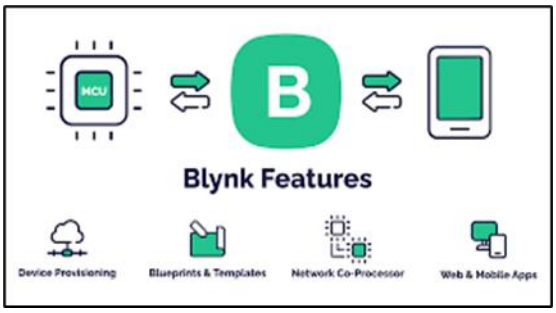


Figure 5. Blynk Mobile Application Interface

RESULT AND DISCUSSION

Water Quality Measurement Results

The performance of the five stage water filtration system was evaluated based on three key parameters consisting of temperature in degrees Celsius, turbidity in Nephelometric Turbidity Units, and pH level. Measurements were conducted consecutively at each filtration stage to determine the effectiveness of the system in improving water quality. The detailed results are presented in Table 2.

Table 2. Water Quality Test Results

Trial	Temp (°C)	Water Turbidity (NTU)	pH Level
1	30.7	724	20.59
2	30.8	537	8.34
3	30.8	121	7.88
4	31.1	51	6.36
5	31.1	26	3.67

As shown in Table 2, the results demonstrate positive improvement trends in turbidity reduction and thermal stability, although instability was observed in the pH parameter.

Temperature Analysis

The temperature values increased slightly from 30.7 °C in the first stage to 31.1 °C in the fifth stage. The total increase of 0.4 °C remains within acceptable tolerance limits and does not significantly affect water quality. In closed electronic filtration systems, minor temperature variations are commonly caused by heat generated from electronic components such as pumps, sensors, and microcontrollers. The relatively constant temperature indicates that the system maintains thermal stability and does not generate excessive heat that

could alter the physical properties of water or interfere with sensor performance. This stability suggests that the system is suitable for applications that require controlled temperature conditions, including hydroponics, aquaculture, and household water supply.

Turbidity Analysis

Turbidity values show a substantial and consistent decrease across filtration stages. The initial turbidity level of 724 NTU was reduced to 26 NTU at the final stage. This significant reduction indicates that each filtration stage contributes effectively to the removal of suspended particles. The most notable decrease occurred between the second and third stages, where turbidity dropped from 537 NTU to 121 NTU. This finding suggests that the primary filtration media used in the intermediate stage plays a crucial role in capturing fine and microscopic particles. Filtration materials such as activated carbon, fine sand, or micro ceramic filters are known for their capability to remove suspended solids and organic matter efficiently.

Although the final turbidity value of 26 NTU remains above the World Health Organization standard for potable water, which is less than 5 NTU, the downward trend demonstrates strong purification potential. With optimization of filtration media or the addition of an extra polishing stage, the system may achieve compliance with drinking water standards.

pH Analysis

The pH parameter presents the most critical issue in this evaluation. The first measurement recorded a value of 20.59, which is scientifically invalid because the pH scale ranges from 0 to 14. This anomaly likely resulted from sensor miscalibration, electrical interference, or improper initialization of the measurement system. Subsequent readings became more realistic, beginning at 8.34 in the second stage and progressively decreasing to 3.67 at the final stage.

The continuous decline in pH indicates that the filtration process induced acidification. This condition may be attributed to chemical interactions between water and filtration media. Materials such as ion exchange resins or activated carbon may absorb alkaline ions including Ca^{2+} and Mg^{2+}, thereby reducing the pH level. Water with a pH value below 4 is categorized as highly acidic and is unsuitable for drinking or agricultural purposes. Furthermore, acidic water may cause corrosion of pipelines and system components. Therefore, the system requires the integration of a final pH stabilization stage using buffering materials such as limestone or dolomite to restore the pH to a safe range between 6.5 and 8.5.

Overall Performance Evaluation

The performance trends of the three parameters are illustrated in Figure 6. The turbidity curve shows a sharp and consistent downward trajectory from the first to the fifth stage, confirming the effectiveness of particle removal. The temperature curve remains relatively stable throughout the filtration process, indicating thermal consistency. In contrast, the pH curve demonstrates a continuous downward pattern, emphasizing the need for chemical stabilization within the system.

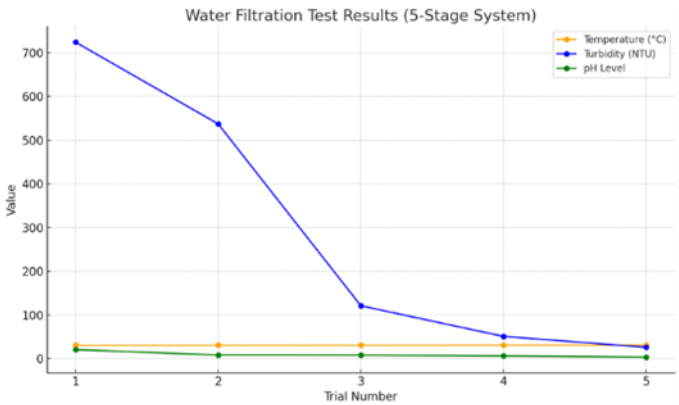


Figure 6. Graphs Visualizing Three Parameters

Figure 6 provides a comprehensive visualization that facilitates the interpretation of system behavior. The graphical representation clearly highlights the strengths of the filtration system in turbidity reduction and temperature stability while simultaneously revealing the weakness related to pH imbalance. These findings serve as a foundation for further refinement of filtration media composition, sensor calibration procedures, and the addition of a pH neutralization stage to enhance overall system reliability and safety for practical implementation.

CONCLUSION

The results of this study indicate that the proposed five stage water filtration system is capable of significantly reducing turbidity and maintaining stable temperature conditions throughout the filtration process. The substantial decrease in turbidity demonstrates the effectiveness of the filtration media in removing suspended particles, while the minimal temperature variation confirms the thermal stability of the system during operation. However, the system still requires three to five filtration cycles to produce visibly clear water, which reflects limited efficiency in terms of time and energy utilization. In addition, the instability observed in the pH parameter, including an unrealistic initial reading and a final acidic value of 3.67, reveals a critical limitation in chemical balance control. Without proper stabilization, the filtered water cannot yet be categorized as safe for drinking or certain technical applications.

Based on these findings, several improvements are recommended to enhance system reliability and scalability. Recalibration of the pH sensor is necessary to ensure measurement accuracy and eliminate potential electrical interference. Optimization of the filtration media in the early stages is also required to improve overall purification efficiency and reduce the number of filtration cycles. Furthermore, the integration of a remineralization or pH buffering stage at the final phase of filtration is essential to restore water to a safe pH range suitable for consumption. With these enhancements, the system has the potential to become a more effective and practical solution for portable clean water production, particularly in disaster relief and remote area applications.

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