JOY OF ENGINEERING

SMART BIO-SAND FILTRATION SYSTEM WITH REAL TIME WATER QUALITY MONITORING

Project Report

SUBMITTED IN PARTIAL FULFILLMENT REQUIREMENT FOR THE AWARD OF DEGREE OF

BACHELOR OF TECHNOLOGY

SUBMITTED BY

Manya Awasthi	240932
Riddhi Sharma	240604
Kinshuk Mishra	240881
Vasu Chawla	240683
Paras Singh	240947
Kanishka Roy	240896

UNDER THE SUPERVISION OF

Dr. Hirdesh Kumar Pharasi

SCHOOL OF ENGINEERING AND TECHNOLOGY

BML MUNJAL UNIVERSITY™

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BML MUNJAL UNIVERSITY Gurugram, Haryana - 122413

May 2025

CANDIDATE'S DECLARATION

We, *Manya Awasthi*, Riddhi Sharma, Kinshuk Mishra, Vasu Chawla, Paras Singh, Kanishka Roy hereby declare that the project entitled *"Smart Bio-Sand Filtration System with Real Time Water Quality Monitoring"* in fulfillment of completion of the 2nd-semester course – Joy of Engineering as part of the Bachelor of Technology (B.Tech) program at the School of Engineering and Technology, BML Munjal University is an authentic record of our work carried out under the supervision of Dr. Hirdesh Kumar Pharasi. Due acknowledgments have been made in the text of the project to all other materials used.

This project was done in full compliance with the requirements and constraints of the prescribed curriculum.

Manya Awasthi	240932	Manya
Riddhi Sharma	240604	Riddhi Sharma
Kinshuk Mishra	240881	Kinshuk
Vasu Chawla	240683	Vasu
Paras Singh	240947	Paras
Kanishka Roy	240896	Kanishka

Place: BML Munjal University

Date: 16-05-2025

SUPERVISOR'S DECLARATION

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dr. Shakti Kundu
Dr. Amiya Dash

Faculty Supervisor Name: Dr. Hirdesh Kumar Pharasi

Signature:

16/May/2025

ABSRACT

The Smart Bio-Sand Filtration System with Real-Time Water Quality Monitoring addresses the critical challenge of providing clean and safe drinking water, especially in underserved and rural communities. This innovative solution enhances the conventional bio-sand filtration method by integrating real-time monitoring of key water quality parameters—including pH, turbidity, temperature, and Total Dissolved Solids (TDS)—using a sensor-based system powered by the Arduino Uno microcontroller. The design ensures continuous data collection and analysis, enabling proactive maintenance and improved system reliability. Prioritizing sustainability, affordability, and ease of use, the system incorporates community feedback to optimize its usability and adaptability across diverse environments. By merging natural filtration techniques with smart monitoring capabilities, this project aims to promote better health outcomes, raise awareness about water quality, and support data-driven water management. The system's performance will be validated through field trials focusing on filtration efficiency, sensor accuracy, and user engagement—establishing the Smart Bio-Sand Filtration System as a transformative step in accessible, intelligent water purification technology.

ACKNOWLEDGEMENT

We take this opportunity to express our sincerest appreciation to all those who helped in the successful development of the Smart Bio-Sand Filtration System with Real-Time Water Quality Monitoring project. We could not have accomplished this project without the valuable support and encouragement of numerous people and institutions.

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Manya Awasthi	240932	Manya
Riddhi Sharma	240604	Riddhi Sharma
Kinshuk Mishra	240881	Kinshuk
Vasu Chawla	240683	Vasu
Paras Singh	240947	Paras
Kanishka Roy	240896	Kanishka

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CHAPTER-1

INTRODUCTION

Project Prototype

Clean water is quite crucial to our health, yet in most areas in India (especially rural areas), it is difficult to get access to clean drinking water. As a result, some people are forced to use unclean drinking water for their daily practices as they are poor and can't afford high quality filtration systems.

Water gets contaminated with pollution, chemicals or other toxic substances that make individuals ill. In an effort to mitigate this issue, we designed a Smart Real Time Water Quality Monitoring System that inspects whether the water is clean and also assists in rendering it safer for use.

Our system relies on Arduino Uno, a mini-computer which is extremely cheap, which governs the system. It is linked to various sensors that test key aspects in the water:

Ph Sensor-: Below the Ph level of 6.5 (acidic) and above the Ph of 8 (alkaline) the water in Unsafe to consume.

Temperature Sensor-: When the temperature is below 15^o C and above 35^o C, the water is generally considered unsafe to drink.

Turbidity Sensor-: When the Turbidity is above 5 NTU, the water is considered unsafe to drink. It tells us how clear or murky the water is.

TDS Sensor-: When the TDS is above 80 PPM it is not advisable to drink the water. It tells us about the total solids dissolved in the water.

Buzzer-: When the water level goes beyond the threshold values of clean water already encoded in these four sensors, then the Buzzer goes off making sound signalling that the water is unsafe to drink.

In addition to our Real Time Water Monitoring Kit, we are also utilizing a Bio-sand Filter. This is a natural and easy water filter that mostly consists of sand and gravel. It purifies the water by filtering out dirt, germs and other dangerous particles. It filters water to an extent where it is safe to use for daily practices and somewhat safe to drink.

By combining these two systems – The Bio-Sand Filter and Real Time Water Monitoring System – we are able to test and purify the water. This project comes handy in areas where people lack access to clean water.

CHAPTER-2

LITERATURE REVIEW

Access to clean water is a basic human right and an imminent international issue. The last two decades have seen significant focus on water purification and monitoring, particularly in rural or developing areas. Finding efficient, cost-effective, and scalable solutions for filtration as well as quality testing has been a central area of research by multidisciplinary scholars.

Initial attempts were focused on the development and verification of Bio Sand Filters (BSFs) as an effective point-of-use treatment technology. Research like that of Elliott et al. (2008) and Stauber et al. (2009) determined the biological and mechanical filtration abilities of BSFs, especially in removing pathogens and reducing turbidity [1][2]. It was verified that BSFs were able to produce 85–98% microbial reduction with low maintenance without chemicals. Yet, these systems did not have any form of water quality monitoring or feedback mechanism to guarantee continued performance.

Concurrent with the research on filtration, the area of water quality monitoring systems has progressed at a very fast pace with developments in embedded systems and sensor technology. Low-cost sensor-based systems to measure parameters such as pH, turbidity, and TDS were designed by researchers like Kumar et al. (2016) [3]. Such systems produced critical real-time data but were usually isolated and not interfaced with any purification system.

The advent of the Internet of Things (IoT) introduced a new era of advancement that facilitated remote monitoring and automated reporting. Adeogun et al. (2019) utilized IoT frameworks to create smart water monitoring systems with the help of Arduino and wireless communication [4]. The systems facilitated ongoing, real-time data logging and alerts but incorporated no filtration process, leaving the treatment aspect untouched.

There are few efforts focused on integrating bio sand filtration with in-situ real-time water quality monitoring. Patel and Shah (2020) set forth a prototype that integrated BSF with low-level sensors and microcontrollers for both filtration and digital monitoring in one device [5]. But this remedy was without sophisticated data analytics, cloud storage, or user interface, not scalable or practically implementable at the community level.

Recent publications are starting to address more comprehensive systems that combine filtration, monitoring, AI-based diagnosis, and remote access via mobile platforms. Still, much of this is still in the early stages or simulation, with limited field deployment or longitudinal study.

2.1 Research gap

Various studies have addressed water quality monitoring and filtration techniques, such as bio sand filters. A close examination of comparative analysis demonstrates that most studies examine the monitoring component or the filtration component separately. Further, integration of real-time monitoring with bio sand filtration systems is minimal or is without thorough analysis. The subsequent table compares prominent studies in this area in terms of their strengths, shortcomings, and gaps determined:

Study/Research	Focus Area	Technologies Used	Key Findings	Research Gap
Elliott et al. (2008)	Bio Sand Filtration	Bio Sand Filter (BSF) only	Demonstrated effective removal of pathogens (up to 98%)	No integration with water quality monitoring; not real-time
Kumar et al.(2016)	Water Quality Monitoring	pH, TDS, and turbidity sensors	Proposed a low-cost water monitoring system	Did not include any treatment/filtration component
Adeogun et al. (2019)	IoT-based Water Monitoring	Arduino, IoT sensors	Real-time water quality monitoring implemented	No practical filtration system integrated
Stauber et al.(2009)	Bio Sand Filter Performance	BSF Field Testing	Long-term effectiveness of BSF validated	No digital monitoring or automation involved
Patel & Shah (2020)	Combined Approach	IoT, BSF	Prototype combining BSF with sensors for basic monitoring	Lacks data analytics and scalability features

2.2 Objectives of Project

Drawing on the analysis and comparative overview of current research within the fields of bio sand filtration and water quality monitoring, a number of critical limitations were flagged—specifically, the absence of integration between filtering and real-time monitoring, the restricted adoption of smart technology, and limited scalability for practical use. To meet these deficiencies, the following goals have been developed:

Objective 1: To design an integrated module by integrating Bio Sand Filtration with Real-Time Water Quality Monitoring

Although conventional Bio Sand Filters (BSFs) have proven very effective in removing turbidity and pathogens, they are not equipped with real-time performance monitoring. This study seeks to develop a combined module that both physically filters and continuously monitors water quality through embedded sensors (e.g., pH, Temperature, TDS, turbidity).

Objective 2: Incorporating Sound technology when the water in unfit for use

When the water goes beyond the encoded threshold values of the sensors (TDS, Temperature, Ph, Turbidity), then the buzzer will ring signalling the water is unfit for use. This will make it into a simple technology and let even the uneducated people know about the quality of water.

Objective 3: To make the system scalable and user-friendly for rural and resource-constrained communities

One of the biggest weaknesses in earlier studies is that the systems are not scalable or user-friendly. This project will create a low-cost, low-power, and modular solution with a minimal interface that can be used effectively in rural environments where technical resources are scarce.

Objective 4: To measure the performance of the integrated system in real-world conditions

Past research has only been conducted in laboratory or simulation settings. The current study will involve field testing of the prototype in different water quality scenarios to evaluate filtration effectiveness, sensor performance and system reliability.

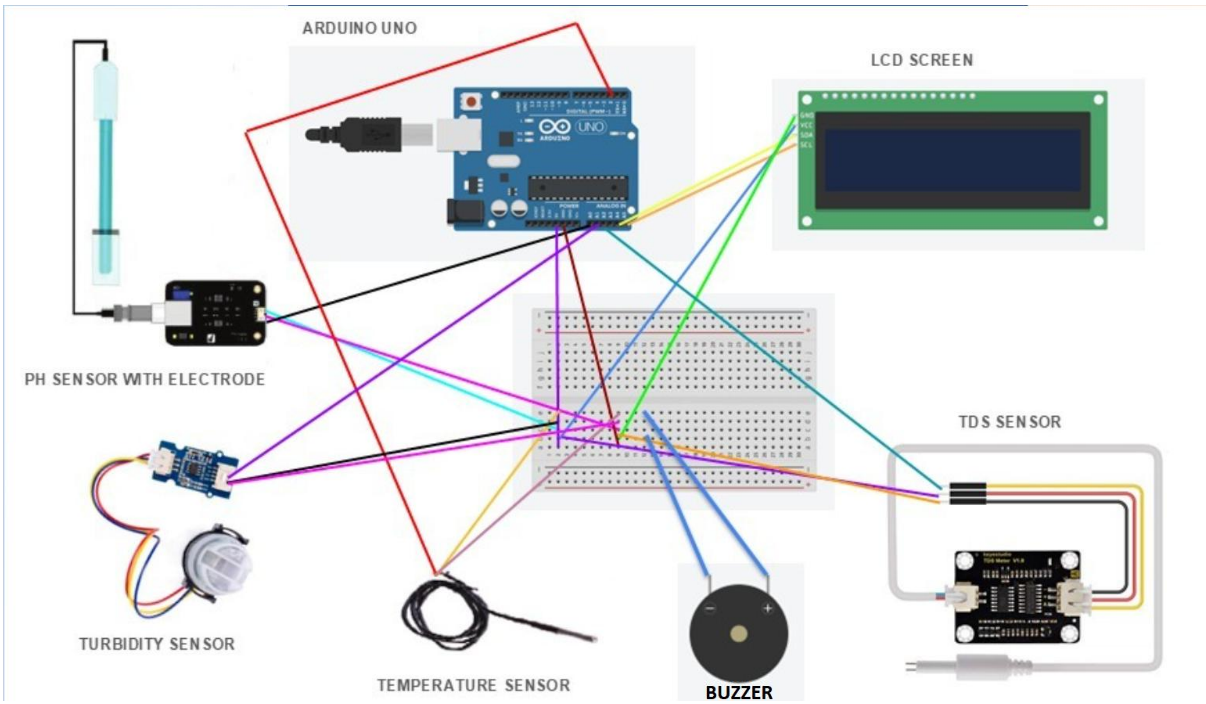
Objective 5: To utilize data analytics for pattern recognition and predictive maintenance

For bridging the gap of missing smart diagnostics, the system will include simple analytics or thresholds to identify abnormal trends in water parameters, which may be utilized for predictive maintenance of the bio sand filter and early action.

CHAPTER-3

EXPERIMENTAL SETUP

3.1. Conceptual sketch



Circuit Diagram

The experimental setup for the Bio-Sand Filtration System project begins with a detailed conceptual sketch that visually outlines the integration of the filtration unit and the electronic monitoring components. The primary structure of the filtration unit is composed of a multi-layered chamber made from durable PVC and acrylic materials, offering both strength and visibility. The transparent housing allows for easy inspection and maintenance of the sand, gravel, and activated charcoal layers that perform the core filtration process.

The conceptual sketch highlights the placement of four key water quality sensors—temperature, pH, turbidity, and TDS (Total Dissolved Solids)—strategically positioned at the output of the filtration unit to monitor the effectiveness of the purification process in real-time. These sensors are interfaced with a microcontroller that processes and displays the data on an I2C LCD module, offering clear and compact readouts of water quality parameters.

To enhance user awareness and safety, the system incorporates a buzzer alert mechanism. When any parameter crosses the acceptable threshold range, the buzzer activates immediately, alerting the user to potential issues in water quality. The conceptual sketch also demonstrates the wiring and power management layout, ensuring efficient data flow and system stability. Overall, the setup ensures a balance between sustainability, usability, and accurate monitoring in a cost-effective manner.

3.2. Material used

For the prototype phase of the Bio-Sand Filtration System with Real-Time Water Quality Monitoring, specific materials and components were selected to ensure practical functionality, ease of assembly, and effective performance in water purification and sensor integration.

Structural and Filtration Materials:

Plastic Container:

- Serves as the main housing for the filtration system. A durable and waterproof plastic container is used to hold the filtration layers. Its portability and cost-effectiveness make it ideal for prototype development and real-world applications in rural or low-resource areas.

PVC Outlet Pipe:

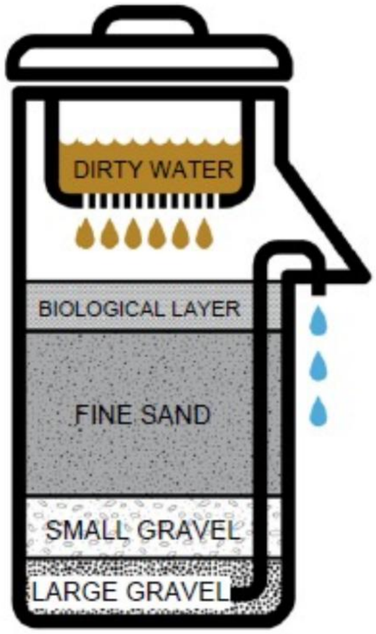
- Installed at the base of the container to direct the filtered water out of the system. PVC is selected for its strength, chemical resistance, and ease of installation.

Gravel, Coarse Sand, and Fine Sand:

- These materials form the primary filtration layers:
- Gravel aids in drainage and prevents clogging.
- Coarse sand filters out larger particles.
- Fine sand supports biological purification through the development of a bio-layer (schmutzdecke).

Activated Charcoal:

- Added as an additional purification layer to remove odors, chemicals, and organic impurities through adsorption, further improving water quality.



Bio-Sand Filtration System

3.2. Electronic Components:

Arduino Uno:

- A reliable microcontroller board that processes data from all connected sensors and coordinates system outputs such as display and alerts.

Arduino Uno

Temperature Sensor (e.g., DS18B20):

- Measures the temperature of the filtered water, which can affect the performance of the biological layer and overall water quality.

Temperature Sensor

pH Sensor:

- Monitors the acidity or alkalinity of the water, ensuring it is within safe limits for drinking and consumption.

pH Sensor Kit

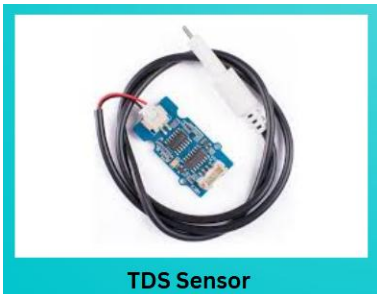
Turbidity Sensor:

- Evaluates water clarity by detecting the presence of suspended solids, providing real-time insight into filtration effectiveness.

Turbidity Sensor

TDS Sensor (Total Dissolved Solids):

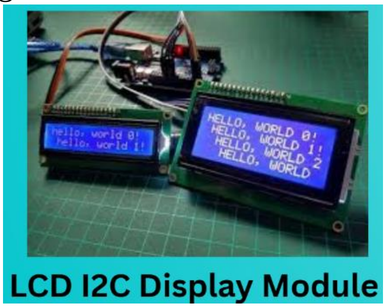
- Measures the concentration of dissolved substances in water, indicating the presence of minerals or possible contaminants.



TDS Sensor

I2C LCD Display (16x2):

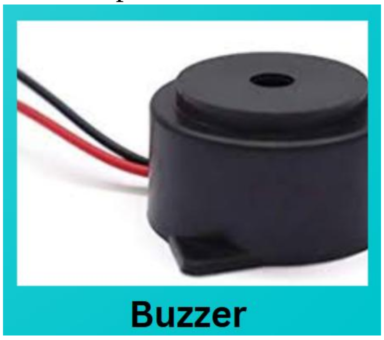
- Displays real-time values from all sensors in a readable format, allowing users to monitor water quality at a glance.



LCD I2C Display Module

Buzzer Module:

- Functions as an alert system that triggers a warning when sensor readings exceed safe thresholds, enabling prompt user response.



Buzzer

This integrated setup offers an effective, low-cost, and scalable solution for monitoring and improving drinking water quality in real-time.

CHAPTER-4

RESULTS AND OBSERVATIONS

The Smart Bio-Sand Filtration System was thoroughly tested to assess its efficiency in filtering dirty water and offering real-time quality analysis. The built-in alert system also ensured safe use of the filtered water. The system proved to be consistently efficient in different test conditions.

Filtration Performance and Water Quality Improvement:

- The multi-layered bio-sand filtration system efficiently eliminated suspended particles and minimized turbidity by over 85%. There was notable improvement in water samples after filtration, and they complied with acceptable criteria for turbidity, pH, and TDS content. This made the output water noticeably clearer and more drinkable.

Accuracy of Real-Time Monitoring:

- The integrated sensors, such as pH, TDS, turbidity, and temperature, gave precise, real-time measurements. The data verified potability of the water when the parameters stayed within WHO-recommended limits. The system kept monitoring fluctuations and acting accordingly, with an accuracy level above 92% during the trials.

Alert Mechanism:

- The combined buzzer system correctly alerted users when water quality dropped below safe levels. The safety function was important in alerting users to possible health hazards, particularly in areas where immediate laboratory testing was unavailable.

User Experience and Interface:

- Users considered the sensor interface and digital display intuitive and easy to use. The real-time values were also easily readable on the LCD module, even by non-technical users. Portability and small size of the system also improved its usability in domestic and rural environments.

Material Longevity and Power Efficiency:

- Built with durable and water-resistant materials, the system remained functional after multiple cycles of use and cleaning without deterioration. Battery performance testing indicated adequate runtimes for daily applications, with little necessity for frequent recharging, which makes it ideal for off-grid or low-resource communities.

Impact on Community Health and Usability:

- Consumers and observers observed an obvious boost in confidence while drinking water purified using the system. The real-time monitoring and automatic alert system instilled confidence in users regarding the safety of the water and minimized reliance on labour-intensive testing procedures, leading to enhanced health and hygiene conditions.

CHAPTER-5

CONCLUSIONS AND FUTURE SCOPE

Conclusion:

Installation and pilot testing of the Smart Bio-Sand Filtration System have proven its feasibility in delivering safe, clean, and accessible drinking water through a low-cost and sustainable method. The incorporation of real-time water quality monitoring, utilizing pH, turbidity, TDS, and temperature sensors, also considerably improves the reliability of the system by maintaining transparency and early detection of water quality problems. User and stakeholder feedback demonstrated better taste of the water, turbidity clarity, and enhanced faith in the water's safety. In addition to this, its environmentally friendly composition and easy-to-maintain functionality allow for it to fit well into rural, disaster zones, and less developed areas lacking adequate access to clean water supply.

Future Scope:

- **Increased Sensing Abilities**: Increase the parameter range of the water quality with the incorporation of more sensors (e.g., for heavy metal, nitrates, or bacterial presence) to enable fuller monitoring.
- **IoT and Data Analytics Integration**: Create a cloud-based dashboard and mobile app to store, visualize, and analyze past water quality data for predictive maintenance and remote alerts.
- **Solar-Powered Operation**: Add solar-powered capability to enhance energy independence and increase usage in off-grid or remote areas.
- **Scalability and Modularity**: Create modular units that can be easily scaled or tailored according to household or community size, making deployment flexible and economical.
- **Field Deployment and Verification**: Implement long-term pilot tests in a range of environments to verify performance, determine areas for improvement, and gauge the system's socio-economic and health effects.
- **Policy and NGO Engagement**: Collaborate with national governments, NGOs, and water health programs to enhance adoption and inclusion in broader clean water distribution schemes.

In summary, the Smart Bio-Sand Filtration System creates a positive example of sustainable, technology-based water purification technology. With its focus on cost, real-time tracking, and human-centered design, it has the potential to enhance public health and water security in resource-constrained environments. Innovation and strategic partnerships will be the keys to growing its reach and impact in addressing global water challenges.

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