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Integrated Smart Filtration & Monitoring System For Water Quality Using IOT

Dr. Vrinda S. Bhalerao
Assistant Professor, Department of Civil Engineering
Guru Gobind Singh College, Nashik. Nashik,
Maharashtra, INDIA.

Siddhi A. Yadav
B.E. Student, Department of Civil Engineering
Guru Gobind Singh College, Nashik. Nashik,
Maharashtra, INDIA.

Pratibha S. Tak
B.E. Student, Department of Civil Engineering
Guru Gobind Singh College, Nashik. Nashik,
Maharashtra, INDIA.

Ashwini Sonwane
B.E. Student, Department of Civil Engineering
Guru Gobind Singh College, Nashik. Nashik,
Maharashtra, INDIA.

***Abstract-* Access to clean and safe water is a fundamental necessity for human health and sustainable development. This research presents the design and implementation of a Smart Filtration System integrated with Internet of Things (IoT) technology for real-time water quality monitoring. The system combines a multi-layer natural filtration unit with embedded sensors to measure key parameters such as pH, turbidity, temperature, TDS, and electrical conductivity. Data is transmitted to a cloud platform for real-time visualization, analysis, and alert generation. The proposed system ensures efficient filtration and continuous monitoring, enabling proactive maintenance and ensuring the delivery of safe and high-quality water for domestic and community use.**

***Keywords-* Smart Filtration, IoT, Water Quality, Real-time Monitoring, Sensors, ESP32, Cloud Platform, Sustainable Water Management**

I. INTRODUCTION

1.1 Introduction to Filtration System

Water purification is a cornerstone of public health and environmental sustainability, especially in regions where access to clean water is limited or compromised by industrial, agricultural, and domestic pollutants. Traditional filtration systems have long relied on mechanical and chemical processes to remove contaminants, but the growing demand for sustainable, low-cost, and decentralized solutions has led to renewed interest in natural filtration media. This report explores a multi-layered filtration system that utiizes sand, gravel, charcoal, as core components. Each layer is selected for its unique physical chemical and biological properties, contributing to a holistic purification process. Coarse gravel and sand serve as the primary mechanical filters, effectively removing suspended solids, silt, and turbidity.

These layers also regulate flow dynamics and prevent clogging in downstream media. Activated charcoal, derived from biomass, provides high adsorption capacity for organic compounds, chlorine, and odor-causing substances. Its renewable nature and local availability make it an ideal choice for sustainable engineering applications. This layer targets microbial contaminants including coliform bacteria, E. coli, and protozoa, reducing the biological load without the need for chemical disinfectants.

The filtration column is designed to optimize contact time, minimize channeling, and maintain consistent flow rates across all layers. Experimental studies and field trials validate the efficacy of this configuration, demonstrating significant reductions in turbidity. microbial count, and chemical residues. The modular design allows for customization based on local water quality challenges, enabling deployment in rural households, community water kiosks, and emergency relief settings. Maintenance protocols are simplified through replaceable cartridges and accessible filter compartments, ensuring long-term usability and minimal operational costs. This natural filtration approach not only aligns with ecological principles but also empowers communities to manage their.

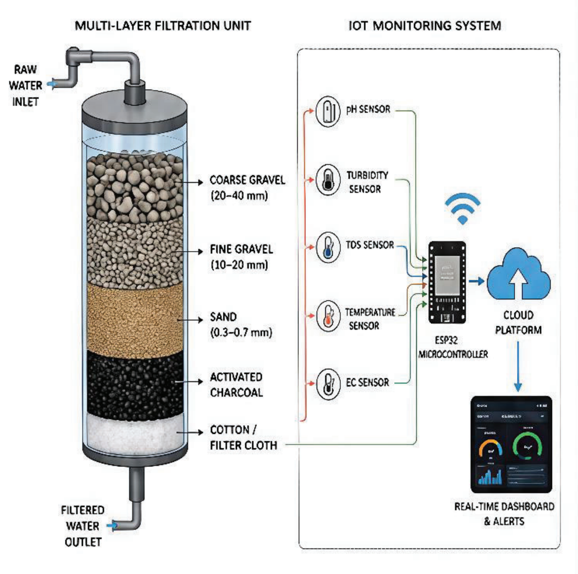

Fig. 1. Smart Filtration System with IoT-based Real-time Monitoring

1.2 Introduction to IoT-Based Real-Time Water Quality Monitoring

While natural filtration systems offer effective purification, their performance can vary based on environmental conditions, filter saturation, and water source variability. To ensure consistent water quality and enable proactive maintenance, this project integrates Internet of Things (IoT) technologies into the filtration framework. IoT-based monitoring transforms passive filtration into an intelligent, responsive system capable of real-time data acquisition, analysis, and control. The architecture comprises a network of sensors embedded within and around the filtration unit, measuring critical water quality parameters such as pH, turbidity, temperature, electrical conductivity, total dissolved solids (TDS), and dissolved oxygen. These sensors are interfaced with microcontrollers like ESP32 or Arduino, which serve as local processing hubs.

Data is transmitted wirelessly via protocols such as LoRa, Wi-Fi, or NB-loT to a centralized cloud platform, where it is visualized through dashboards and analyzed using machine learning algorithms. Edge computing capabilities allow for preliminary data processing at the device level, enabling immediate detection of anomalies such as sudden spikes in turbidity or pH fluctuations. This facilitates real-time alerts, adaptive filtration control, and predictive maintenance scheduling. The system also supports historical data logging, trend analysis, and contamination forecasting, enhancing its utility for long-term water resource management. Cybersecurity measures are implemented through encrypted communication protocols and blockchain-based audit trails to ensure data integrity and prevent unauthorized access. The loT framework is designed to be modular and scalable, allowing integration with GIS platforms for spatial water quality mapping and interoperability with municipal water infrastructure.of concrete bricks.

The excessive usage of the earth materials that are utilized for production of fired bricks results in massive depletion of the natural resources and also high energy consumption. These bricks are also responsible for serious environmental degradation due to the high greenhouse gas emissions. On the other hand, the concrete blocks are considered to be environmentally unfriendly, where they consume large amount of energy and also emit CO_2 and other greenhouse gases. By giving adequate attention to the use of appropriate building materials, effective solutions to the above problems can be developed. Incorporation of industrial and agricultural waste materials in brick production is an efficient method to diminish the environmental pollution, reduce the amount of generated wastes and protect the raw materials from depletion.

Making bricks from agricultural waste supports the idea of a circular economy, where waste is turned into useful products instead of being discarded. These sustainable bricks can also offer practical benefits, such as being lighter in weight, providing better thermal insulation, and potentially lowering costs. In addition, sourcing materials locally can create new opportunities for rural communities and support local economies.

In India, rice husk and sugarcane bagasse are primarily available as waste products from agro-processing industries. Key sources include over 130,000 rice mills (generating ~24 million tons of husk annually) and sugar factories (yielding 120 million tons of bagasse), concentrated heavily in Maharashtra, Uttar Pradesh, Tamil Nadu, Karnataka, and Andhra Pradesh.

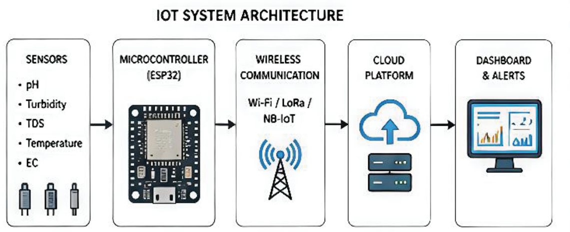

Fig. 2. IoT System Architecture for Real-time Water Quality Mointoring

II. MATERIAL

A. Collection Of Sample

i. Godhavari

Water sample was collected from the The water sample was collected from the Panchavati area of the Godavari River in Nashik. This river is an important water source used for domestic and religious purposesG. A clean plastic bottle was used for the collection. Before collecting the sample, the bottle was rinsed two to three times with the same river water to avoid contamination.The sample was collected from below the surface of the water to prevent floating impurities from entering the bottle. After collection, the bottle was tightly sealed and labeled properly.The collected sample was used to analyze important water quality parameters such as pH, Total Dissolved Solids (TDS), temperature, and turbidity, in order to evaluate the quality of water and the effect of different filtration methods

ii. Hand Pump:

He water sample was collected from a hand pump located in Sahyadri Nagar, CIDCO, Nashik. This source is commonly used by local residents for domestic water needsWater sample was collected from a handpump source using a clean plastic bottle. Before collecting the sample, the handpump was allowed to run for a few minutes to remove stagnant water. The bottle was rinsed two to three times with the same water to avoid contamination.

The sample was then collected carefully and the bottle was tightly sealed to prevent any external contamination. Proper labeling was done after collection.

iii. oring Water :

The water sample was collected from a borewell located at Gajanan Park Apartment, Dnyaneshwar Nagar, Saraf Nagar, Nashik. This source represents groundwater used for daily household activities Water sample was collected from a boring (borewell) source using a clean plastic bottle. Before collecting the sample, the water was allowed to flow for a few minutes to remove stagnant water from the pipeline.

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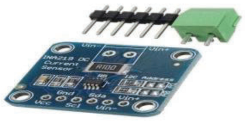
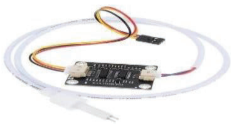
iv. pH Converter



The pH sensor Module consist of pH sensor also called as pH probe and a signal conditioning board which gives an output which is proportional to the pH value and can be interfaced directly to any Micro-controller. The pH sensor components are usually combined into one device called a combination pH electrode. The measuring electrode is usually glass and quite fragile. Recent developments have replaced the glass.

V. TDS Converter & Sensor



TDS (Total Dissolved Solids) Sensor and Converter,

The TDS (Total Dissolved Solids) Sensor is a key component used to measure the concentration of dissolved solids (such as minerals, salts, and impurities) present in water. It provides an estimate of the water purity level and is an essential parameter in water quality monitoring systems.

VI. Turbidity Sensor:

The Turbidity Sensor measures the turbidity of fresh-water or seawater samples in NTU (Nephelometric Turbidity Units) the standard unit used by most water collection agencies and organizations. Its small, sleek design and simple setup make it easy to use at the collection site. In addition to water quality .

VII. Temperature

The Dallas Temperature Sensor is a 1-wire programmable Temperature sensor from maxim integrated. It is widely used to measure temperature in hard environments like in chemical solutions, mines or soil etc. The constriction of the sensor is rugged and also can be purchased with a water proof option making the mounting process easy. It can measure a wide range of temperature from -55°C to +125° with a decent accuracy of ±5°C. Each sensor has a unique address and requires only one pin of the MCU to transfer data so it a very good choice for measuring temperature at multiple points without compromising much of your digital pins on the microcontroller.

III. METHODOLOGY

3.1 Methodology By Flow Chart:

1. System Design: Design of multi-layer filtration unit and selection of sensors.
2. Fabrication: Construction of filtration column with locally available materials.
3. Sensor Integration: Integration of sensors with ESP32 microcontroller.
4. Data Transmission: Real-time data transmission to cloud using Wi-Fi.
5.Data Visualization: Development of dashboard for real-time monitoring.
6. Testing & Analysis: Performance evaluation of filtration and monitoring system.

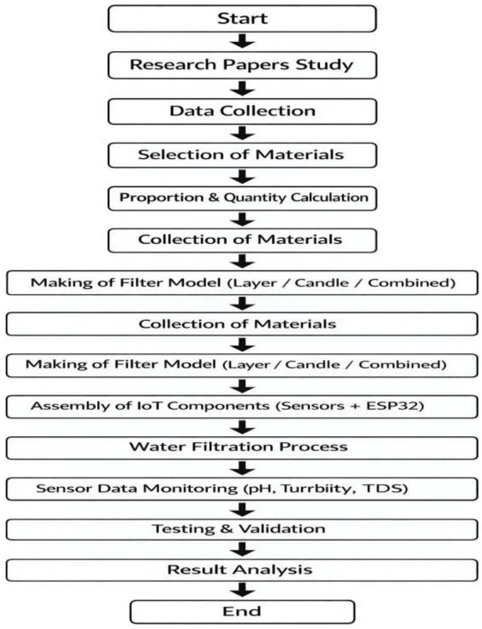
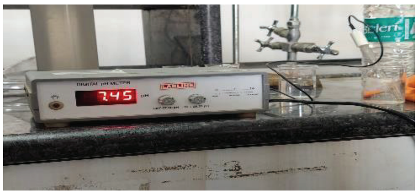


Fig.3.1.Methodology By Flow Chart

pH Meter

The pH meter is used to measure the acidity or alkalinity of water. The pH scale ranges from 0 to 14, where values below 7 indicate acidic nature, 7 indicates neutral, and above 7 indicates alkaline nature.



In drinking water, the acceptable pH range is 6.5 to 8.5. The pH meter works using an electrode that detects hydrogen ion concentration in water and displays the result digitally.

Sample Water	*pH*
Godavari River	5.3
Borewell	5.5
Handpump	5.7

Turbidity Meter

The turbidity meter measures the clarity of water by detecting suspended particles. It is expressed in NTU (Nephelometric Turbidity Units). For safe drinking water, turbidity should be less than 5 NTU, and ideally below 1 NTU. The instrument works by passing light through the sample and measuring the scattering effect caused by particles.

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Sample Water	*Turbidity (NTU)*
Godavari River	89%
Borewell	75%
Handpump	89%

TDS Meter (Total Dissolved Solids)

The TDS meter measures the amount of dissolved solids such as salts, minerals, and impurities present in water. It is expressed in ppm (parts per million).

Sample Water	*TDS (ppm)*
Godavari	189
Borewell	140
Handpump	65

The ideal TDS level for drinking water is 50–150 ppm, while values up to 500 ppm are acceptable. The meter works by measuring the electrical conductivity of water and converting it into TDS value.

Making Of Prototypes :

From all the tests that were carried out on the samples collected well water was considerably more amongst all the amples. Therefore, prototypes were thus made keeping in view to reduce the ardness of water.

PROTOTYPE :

Total number of layers 5 (Bottom to Topall the Layers) Layer Number 1: Cotton
Layer Number 2: Sand
Layer Number 3: Charcoal
Layer Number 4: Fine Aggregates
Layer Number 5: Coarse Aggregates

IoT OF FINAL MODEL MATERIALS USED:

- Turbidity Sensor
- ESP-32 (Espressif Systyem)
- Temperature Sensor
- 16×2 LCD Screen
- pH Converte
- TDS Converter & Sensor
- pH Sensor
- Main Switch

Natural Layer & Ceramic Laayer Model:

The combined filter is a more advanced system that uses both natural layer filtration and ceramic filtration together. In this model, water first passes through the natural layers (aggregates, sand, and charcoal), where large and medium impurities areemoved. After that, the artially filtered water passes through the ceramic candle, which removes very fine particles and microorganisms. This combination provides better filtration compared to using a single method. It improves water clarity, removes bad odor, and reduces harmful bacteria, making the water much safer. Although it takes slightly more time for filtration, the quality of output water is higher. Therefore, the combined filter is the most effective among the three methods used in this project.

Natural Filter:

The natural layer filter is made using different natural materials such as aggregates (small stones), natural sand, activated charcoal, hard coal, and wooden charcoal. These materials are arranged in layers inside the upper bucket. Each layer performs a specific function in the filtration process. The aggregates remove large suspended particles like dust and debris, while the sand

Ceramic Filter:

The ceramic filter uses a ceramic candle as the main filtering element. The ceramic material has very small pores that can trap fine particles, bacteria, and microorganisms present in water. When water passes through the ceramic candle, it undergoes micro-filtration, which improves the quality of water significantly.This type of filter is more effective than the natural layer filter in removing harmful microbes. It provides cleaner and safer water for drinking purposes.

Water Quality Analysis of Different Water Sources (Before) :

This table shows the analysis of different water sources such as river, handpump, and boring water. The parameters tested include pH, Total Dissolved Solids (TDS), temperature, and turbidity. These parameters help in determining the quality and suitability of water for domestic use. The variation in values indicates the difference in water quality from different sources.

S.No.	Water Source	pH	TDS (ppm)	Temperature (°C)	Turbidity (%)
1	River	5.3	189	30°C	89%
2	Handpump	5.7	65	30°C	89%
3	Boring	5.5	140	28°C	75%

Table.1 Water Quality Analysis of Different Water Sources Before

Lab Test Of After Filteration.

LAB TEST – WATER QUALITY ANALYSIS

1) WITHOUT FILTRATION

Water Type	pH	Conductivity (TDS) (µS/cm)	Turbidity
1. River	7.30	00.8	00.7
2. Handpump	7.88	00.5	01.2
3. Boring	7.45	00.7	00.4

2) WITH NATURAL FILTER

Water Type	pH	Conductivity (TDS) (µS/cm)	Turbidity
1. River	7.20	00.7	00.7
2. Handpump	7.50	00.6	00.4
3. Boring	7.20	00.7	00.4

3) WITH CERAMIC CANDLE

Water Type	pH	Conductivity (TDS) (µS/cm)	Turbidity
1. River	7.15	00.7	00.0
2. Handpump	7.40	00.5	00.1
3. Boring	7.20	00.7	00.0

4) WITH NF + CERAMIC CANDLE

Water Type	pH	Conductivity (TDS) (µS/cm)	Turbidity
1. River	7.40	00.8	00.0
2. Handpump	7.10	00.5	00.0
3. Boring	7.20	00.3	00.1

Table.2.Water Quality Different Water Lab Testing

Water Quality Analysis of Different Water Sources After

1. With Natural Filter

Sample	pH	TDS	Temp (°C)	Turbidity (NTU)
River	5.7	100	28	00.3
Handpump	6.4	140	29	00.2
Boring	5.5	177	29	00.1

2. With Ceramic Candle

Sample	pH	TDS	Temp (°C)	Turbidity (NTU)
River	6.4	97	30	00.1
Handpump	5.9	148	29	00.9
Boring	6.9	93	28	00.2

3. With NF + Ceramic Candle

Sample	pH	TDS	Temp (°C)	Turbidity (NTU)
River	6.0	108	29	00.6
Handpump	7.3	121	30	00.3
Boring	7.4	209	30	00.4

Table.3 Water Quality Analysis of Different Water Sources

IV. RESULT

The present study was conducted to analyze and compare the quality of different water sources, namely River water, Handpump water, and Boring water, before and after applying various filtration techniques such as Natural Filter, Ceramic Candle Filter, and the combined method of NF + Ceramic Candle.

Sr. No.	Characteristic Requirement	Acceptable Limit	Permissible Limit (In Absence of Alternate Source)	Method of Test (IS 3025)	Remark
1.	pH Value	6.5–8.5	No relaxation	Part 11	Should be neither too acidic nor too alkaline
2.	Turbidity (NTU, Max)	1	5	Part 10	Indicates clarity of water
3.	Total Dissolved Solids (mg/L, Max)	500	2000	Part 16	Affects taste and indicates dissolved impurities

Initial Lab Analysis (Without Filtration)

The laboratory test of raw water samples indicated that all three water sources had pH values within the permissible range (7.30 – 7.88), showing slightly alkaline nature. However, turbidity levels were comparatively higher, particularly in handpump water (1.2), which indicates the presence of suspended impurities and makes the water unsuitable for direct consumption. Conductivity (TDS) values also confirmed the presence of dissolved solids in all samples.

Performance of Filtration Methods

Natural Filter

After filtration using a natural filter, minor improvements were observed in water quality. The pH remained almost neutral (7.2 – 7.5), but there was no significant reduction in turbidity, especially in river water. This indicates that natural filtration alone is not sufficient for proper purification.

Ceramic Candle Filter

The ceramic candle filter showed considerable improvement in water clarity, as turbidity was reduced significantly (0.0 – 0.1). The pH values remained stable and within the desirable range. This method proved to be effective in removing suspended particles and improving the visual quality of water.

NF + Ceramic Candle

The combined filtration method demonstrated the best overall performance among all techniques. It resulted in:
Minimum turbidity (almost 0.0) in most samples
Balanced pH values (7.1 – 7.4), which is ideal for drinking water Improved reduction in TDS, especially in boring water. This method ensures both physical and chemical purification of water.

V. CONCLUSION

- From the experimental analysis of different water samples (River, Handpump, and Boring water), it is concluded that water quality significantly improves after applying filtration techniques. The initial lab test results showed that although the pH values were within the acceptable range, the presence of turbidity and dissolved impurities made the water unsuitable for direct consumption.
- Among the different filtration methods used, the **Natural Filter** provided only basic purification with minimal reduction in turbidity. **The Ceramic Candle**
-
- Filter showed better performance by effectively reducing turbidity and improving water clarity. However, it had limited impact on dissolved impurities.
- The **combined filtration method (NF + Ceramic Candle)** proved to be the most effective technique. It showed maximum improvement in all parameters, including:
- **Near-zero turbidity,** indicating clear water
- **Balanced pH (7.1 – 7.4)**, suitable for drinking
- **Better reduction in TDS,** ensuring removal of dissolved impurities
- Therefore, it can be concluded that the **NF + Ceramic Candle method is the most suitable and efficient filtration technique** for improving water quality and making it safe for drinking purposes.

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