DEVELOPMENT OF SENSOR FOR FLUORIDE DETECTION IN WATER AND EXPERIMENTAL STUDY ON FLUORIDE REDUCTION USING NANOPARTICLE INDUCED SOIL ADSORBENT

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Introduction:

Fluoride, a naturally occurring mineral, plays a dual role in human health—essential in trace amounts for preventing dental caries, yet hazardous when consumed in excess. With fluoride contamination in drinking water becoming a significant global concern, particularly in regions with high groundwater fluoride concentrations, the need for reliable detection and efficient removal methods is more pressing than ever. Excessive fluoride exposure has been linked to serious health conditions including dental and skeletal fluorosis, as well as potential disruptions to the endocrine and nervous systems.

This project focuses on the **development of a sensor for fluoride detection in water** and an **experimental study on fluoride reduction using nanoparticle-induced soil adsorbent**. Traditional fluoride detection methods can be complex and time-consuming, highlighting the need for portable, sensitive, and cost-effective alternatives for real-time monitoring of fluoride levels.

In parallel, effective fluoride removal techniques are essential for ensuring safe water. Among various technologies, **adsorption stands out** for its cost-effectiveness, environmental compatibility, and simplicity. This study explores an innovative approach using **nanoparticle-enhanced soil adsorbents**, which offer improved efficiency by increasing the surface area and reactivity of natural materials.

This integrated approach combines smart detection with sustainable purification strategies, contributing to safer drinking water and improved public health in fluoride-affected regions.

Figure 1: Stages of Dental Fluorosis.

Objectives:

- To develop a reliable, cost-effective, user-friendly and portable sensor for fluoride detection.
- To assess rapid fluoride detection capability of sensor and validate accuracy through extensive field testing.
- To optimize data management and enable real-time monitoring of fluoride levels through integrated data logging, digital reporting and wireless connectivity.
- To conduct experimental study to assess nanoparticles induced soil adsorbents for reducing fluoride in water.

Methodology:

Procedure of Building Sensor Module:

- A suitable TDS sensor is selected and calibrated using standard solutions to ensure accurate measurements.
- A circuit diagram is designed to connect the sensor to the Arduino board, considering power supply, analog input pin, and ground connections. The components are physically wired according to the diagram.

- Arduino code is written to read the analog voltage output from the TDS sensor, Convert it to Fluoride content value using a calibration curve and send the processed data to the NodeMCU via serial communication.

- The NodeMCU is configured with the Wi-Fi ssID and password using the appropriate library and functions. Serial communication is established with the Arduino to receive the Fluoride content data converted from the TDS value.

- Code is written to formnat the received TDS data into a suitable format of fluoride content values and send it to a specified server or cloud platform using HTTP requests.

- The sensor's accuracy is tested by measuring solutions with known TDS values and comparing the results. The reliability of data transmission is tested by monitoring the received data on the server or cloud platform. Stable Wi-Fi connectivity is ensured.

- The sensor and NodeMCU are securely mounted in the desired location. A reliable power source is provided. A web interface or mobile app is set up to visualize and monitor real-time Fluoride data. Data logging is implemented to store historical data for analysis.

Procedure of Preparation of Nanoparticles Adsorbents:

- Soil samples are collected from a specific location and alumina nanoparticles size and purity are procured.

- Adsorbent granules are prepared by mixing the collected soil samples and alumina nanoparticles.

- Experiments are conducted to optimize the adsorption process by varying parameters like adsorbent dosage and contact time.

- Batch adsorption experiments are performed to study the effect of adsorbent dosage and contact time on adsorption.

Result and Conclusion:

Samples were initially tested using the sensor and these results were subsequently validated and compared against measurements obtained by spectrophotometer after addition of zirconyl chloride solution to each sample to develop the necessary color complex which is required for the spectrophotometer measurement.

Fluoride sensor reading as 0.1 mg/L for sample 2

Spectrophotometer reading as 0.6932 mg/L for sample 2

Figure2: Samples being tested under sensor and validated under Spectrophotometer.

The samples are identified by a nearby value, allowing for direct comparison of the results obtained from the sensor and the spectrophotometer for each corresponding sample. This side-by-side presentation facilities an assessment of correlation and potential discrepancies between the two analytical methods when applied to the same sample set, thereby providing justification for the sensor derived data.

The fluoride removal studies by adsorption were conducted in 500 ml of 6 numbers of beakers containing the fluoride solution. In these beaker adsorbent granules with varying dosage were added. Then the water was tested at an interval of every 10 minutes for a period of 60 minutes. The initial and final fluoride concentration in the test sample was determined at an interval of 10 minutes and is tabulated and graph is prepared.

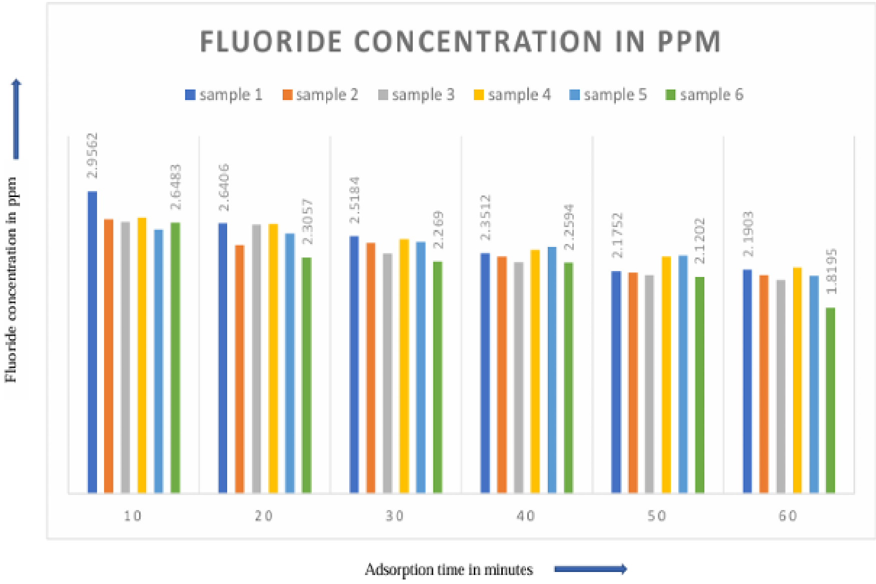

Figure 3: Variation in fluoride concentrations.

In conclusion, the project highlights the potential of combining sensor-based detection with nanoparticle-induced soil adsorbents for effective fluoride monitoring and removal. While promising results were achieved, further comparative analysis with traditional methods is needed. Field applicability, especially in rural settings, and interference from co-ions require deeper investigation. Optimization of granule composition can further enhance defluoridation efficiency. The project sets a strong foundation for scalable, low-cost water treatment solutions.

Project Outcome & Industry Relevance:

- The project delivers a **low-cost, portable fluoride detection sensor** for real-time monitoring of water quality.
- A **nanoparticle-induced soil adsorbent** is developed for effective, eco-friendly fluoride removal from drinking water.
- The solution is especially useful for **rural and resource-limited areas** where access to lab testing is limited.
- It meets the **industrial need** for affordable water purification and monitoring technologies in fluoride-affected regions.
- Stakeholders like **municipal bodies, NGOs, and water supply programs** can use this system for regular water quality management.

- The project contributes to **environmental engineering and public health** and shows strong potential for future development and commercialization.

Working Model vs. Simulation/Study:

This project involved the **development of a physical working model** rather than being a purely theoretical study or simulation. A practical fluoride detection system was designed and implemented using a TDS sensor integrated with an Arduino and NodeMCU microcontroller. The sensor was calibrated using standard solutions to ensure accurate measurement of fluoride concentration based on a derived calibration curve.

Hardware components were physically connected following a designed circuit diagram, and custom Arduino code was written to process sensor readings and convert them into fluoride values. These values were transmitted via the NodeMCU to a cloud server using Wi-Fi, enabling real-time monitoring and data logging. A web or mobile interface was also developed for easy visualization of the fluoride levels.

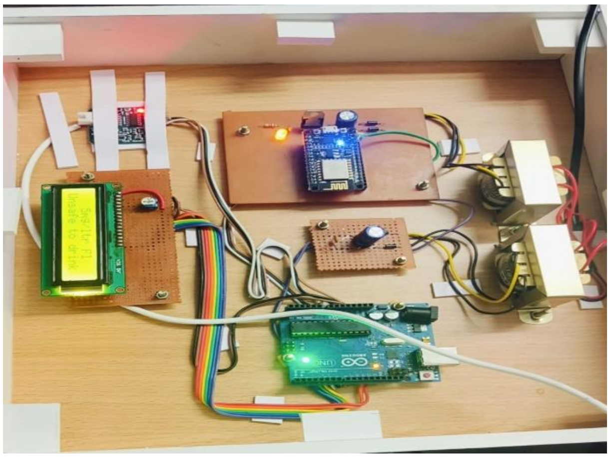

Figure 4: Senor Setup.

Additionally, a **physical fluoride removal setup** was prepared using nanoparticle-induced soil adsorbents, and experimental testing was carried out to assess its efficiency. The combined detection and removal system represents a fully functional model with direct real-world applicability, showcasing both practical hardware implementation and environmental application.

Project Outcomes and Learnings:

- Sensor calibration and integration taught us the importance of precision in hardware interfacing and the need for accurate data conversion techniques (TDS to fluoride values).

- Wireless communication and IoT setup provided hands-on experience in real-time data transmission, cloud integration, and remote monitoring.

- Experimental analysis with soil and nanoparticles enhanced our understanding of adsorption principles, material optimization, and environmental chemistry.

- We gained insight into practical challenges such as interference from other ions, power supply management, and data reliability in real-world applications.

- The project fostered problem-solving, teamwork, and interdisciplinary learning, combining electronics, environmental engineering, and data science.

Future Scope:

The future scope of this project includes:

1. A **comparative study** of traditional, sensor-based, and adsorbent-based fluoride detection and removal methods can be undertaken to evaluate their performance in terms of sensitivity, efficiency, cost, and real-world feasibility.
2. The sensor developed can be tested further for **field applicability**, especially in rural and fluoride-affected areas, to assess its usability, durability, and performance in non-laboratory environments.
3. Further research is needed to study the **interference caused by co-existing ions** (like chloride, sulfate, and nitrate) in water, which can affect the accuracy of fluoride detection.
4. The **composition of the nanoparticle-induced soil adsorbents** can be optimized by experimenting with different ratios of red soil, black soil, and alumina nanoparticles to improve fluoride removal capacity.
5. The **scalability** of the adsorbent-based fluoride removal method should be explored to assess its potential use in community-scale or decentralized water treatment systems.