Water Pollution Analysis and Monitoring System

Project Report submitted to

Indian Institute of Technology, Kharagpur

for the partial fulfillment of award of the degree

of

B.Tech (Hons) in Mining Engineering

by

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under the guidance of

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INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

DECEMBER 2024

CERTIFICATE OF APPROVAL

Date: 28/11/23

Certified that the Project Report entitled **Water Pollution Analysis and Monitoring System** submitted by **Bhuneshwar Netam** to Indian Institute of Technology, Kharagpur, for the partial fulfillment of the award of the degree of B.Tech (Hons.) in the Mining Engineering has been accepted by the examiners and that the student as successfully defended the Project Report in the viva-voce examination held today.

(Supervisor)

(BTP Coordinator) **(Head of the Department)**

DECLARATION

I certify that

a. The work contained in this Project Report is original and has been done by me under the guidance of my supervisor.

b. The work has not been submitted to any other Institute for any degree or diploma.

c. I have followed the guidelines provided by the Institute in preparing the Project Report.

d. I have confirmed to the norms and guidelines given in the Ethical Code of Conduct of the Institute. e. Whenever I have used materials (data, theoretical analysis, figures, and text) from other sources, I have given due credit to them by citing them in the text of the Project Report and giving their details in the references. Further, I have taken permission the copyright owners of the sources, whenever necessary.

Signature of the Student

CERTIFICATE

This is to certify that the Project Report entitled **Water Pollution Analysis and Monitoring System**, submitted by **Bhuneshwar Netam** to Indian Institute of Technology, Kharagpur, is a record of bona fide research work under my supervision and is worthy of consideration for the partial fulfillment of the award of the degree of B.Tech (Hons) in Mining Engineering of the Institute.

Supervisor

ACKNOWLEDGEMENTS

I express my heartfelt gratitude to my thesis advisor, Prof. **Kaushik Dey** for their invaluable guidance and unwavering support throughout this thesis. Their mentorship and encouragement have been instrumental in shaping my research. Thanks to Indian Institute of Technology Kharagpur for its support. I’m deeply thankful to my family for their unwavering belief in me and my friends for their constant motivation and support. To everyone who contributed, seen or unseen, your support made this achievement possible.

Thank You

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Chapter 1: Introduction and Motivation

1.1 Introduction

Water pollution significantly impacts ecosystems and human health, necessitating reliable tools for monitoring and management. This project aims to develop an innovative, web-based application to analyze water pollution parameters, using MongoDB for robust data storage, Node.js for back-end operations, and responsive front-end frameworks for user interaction.

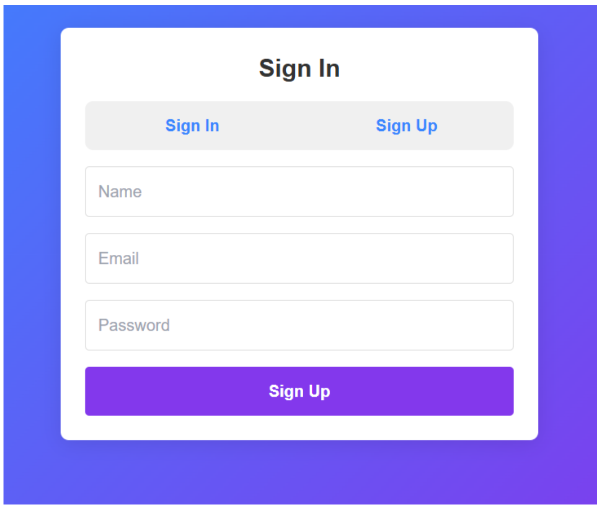
This system provides an integrated platform for storing, managing, and analyzing water quality data, aiding in environmental awareness and decision-making processes.

Water pollution poses a critical threat to ecosystems and human health. This project focuses on developing a web-based platform that monitors water quality through data collection and analysis, intending to raise awareness and aid in pollution management. The system allows users to enter, view, and search water quality data by sample IDs, encompassing various water parameters (e.g., physical, chemical, air quality).

1.2 Motivation

The motivation for this project stems from:

- The pressing need to address the challenges posed by water pollution.
- The lack of accessible, automated tools for analyzing pollution parameters.
- The importance of combining modern technologies to create a user-friendly, scalable system for environmental monitoring.



1.3 Scope of Work

- **Frontend:** Build a responsive interface for data entry and visualization.
- **Backend:** Design robust API endpoints for handling complex data processing.
- **Database:** Use MongoDB for secure and efficient data storage.
- **Integration:** Connect all components for a seamless user experience.

1.4 Objectives

- Implement secure user authentication.
- Provide data entry forms for multiple water quality parameters.
- Enable efficient search functionality for sample IDs.
- Display data interactively, categorized for clarity.

Chapter 2: Literature Review

2.1 Overview of Existing Systems

Existing tools for environmental analysis are often limited by:

- Manual data entry processes.
- Lack of integration between air and water quality parameters.
- Outdated frameworks that hinder scalability and usability.

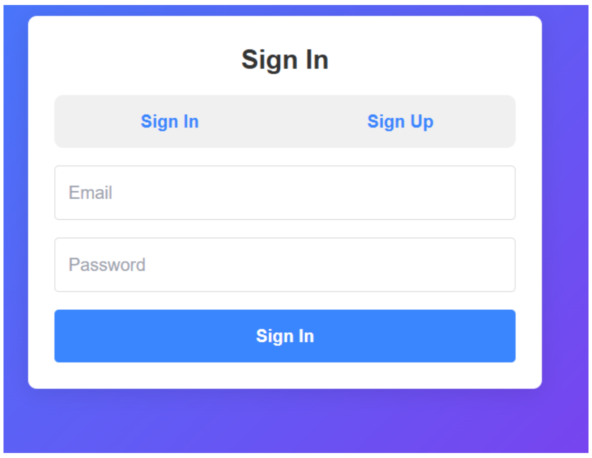
2.2 Key Gaps and Findings

- Absence of a unified platform for environmental parameter analysis.
- Limited usage of modern frameworks and databases for real-time data analysis.
- Inefficient user interfaces, reducing engagement and accessibility.

2.3 Relevance to Current Project

This project addresses these limitations by combining:

- Node.js and MongoDB for backend and database efficiency.
- Tailwind CSS and JavaScript for a responsive, user-friendly front end.



Chapter 3: Materials, Methods, and Experimental Setup

3.1 Materials and Tools Used

Technologies:

- **Node.js**: A JavaScript runtime used for building the back-end server, enabling scalable and efficient event-driven applications.
- **MongoDB**: A NoSQL database chosen for its flexibility in handling complex data structures and scalability for large datasets.
- **Express.js**: A minimal web application framework for Node.js that simplifies the process of building APIs and managing server operations.
- **HTML, CSS (Tailwind CSS), and JavaScript**: Used for creating a responsive and interactive front-end interface.
- **Bootstrap**: Supplementary CSS framework for additional styling and responsiveness in the UI.

Middleware and Libraries:

- **bcrypt**: For password hashing to ensure secure user authentication.
- **JSON Web Token (JWT)**: For secure session management and API authentication.
- **body-parser**: For handling HTTP request data (e.g., JSON and form submissions).
- **Mongoose**: An ODM (Object Data Modeling) library for MongoDB, used for schema definition and query execution.

Hardware and Software Requirements:

- **Operating System:** Linux/Windows/MacOS
- **Node.js Version:** 14+
- **MongoDB:** Cloud-based or local installation
- **Web Browser:** Latest version of Chrome, Firefox, or Edge
- **Development Tools:** Visual Studio Code, Postman for API testing

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3.2 Framework Design and Development

System Architecture: The system is designed with a modular approach for scalability and maintainability. The architecture is divided into three key layers:

1. **Frontend Layer:**

   Provides an interactive user interface for data entry, search, and visualization.

   Built using Tailwind CSS for responsiveness and JavaScript for dynamic functionalities.

2. **Backend Layer:**

   Handles server-side logic, API routing, and communication with the database.

   Node.js and Express.js manage routing, authentication, and data validation.

3. **Database Layer:**

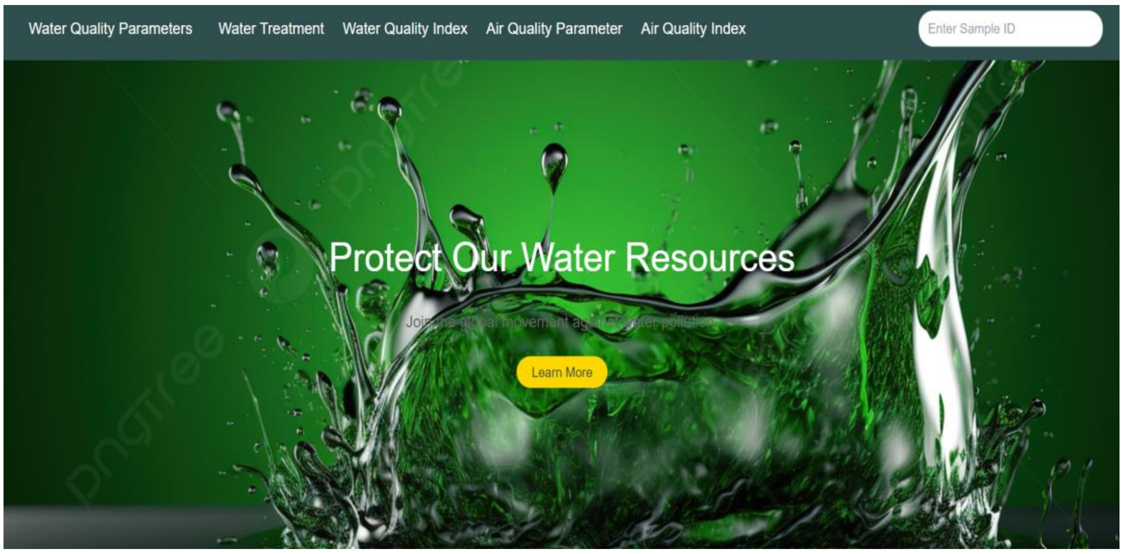
   A centralized repository using MongoDB for storing user and water pollution data.

   Optimized schemas ensure fast queries and efficient storage.

3.3 Methods

1. Frontend Development:
The frontend focuses on creating a clean and responsive design:

- **Sign-In/Sign-Up Forms:** Interactive forms styled with Tailwind CSS, featuring real-time validation using JavaScript.
- **Data Entry Forms:** Dynamic forms for entering water quality parameters like physical, chemical, and biological properties.
- **Responsive Design:** Ensures usability on various devices through media queries and a mobile-first approach.

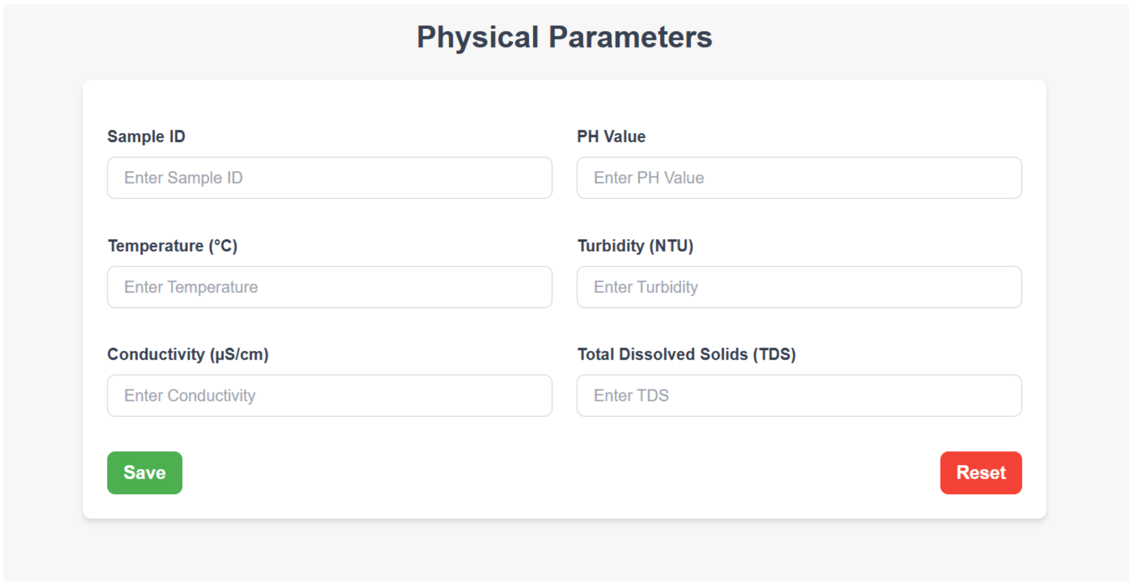


2. Backend Development:
The back-end is built to handle user interactions and provide seamless API endpoints:

- **Authentication:** User authentication is implemented using bcrypt and JWT.
- **API Development:** RESTful APIs manage CRUD (Create, Read, Update, Delete) operations for water pollution data.
- **Error Handling:** Middleware intercepts errors and provides user-friendly responses.

3. Database Design:
MongoDB is used to store structured and semi-structured data:

- **User Schema:** Includes fields for user name, email, and hashed passwords for authentication.
- **WaterData Schema:** Captures details about water parameters (physical, chemical, biological) with unique sample IDs.



4. Integration of Frontend and Backend:

- **RESTful APIs:** APIs connect the front-end forms to the backend logic, facilitating seamless data exchange.
- **AJAX and Fetch API:** Used to send asynchronous requests from the frontend to the backend, ensuring dynamic updates without refreshing the page.

3.4 Experimental Setup

Local Environment Setup:

1. **Backend Server:**

   Install Node.js and required packages (e.g., Express.js, Mongoose, bcrypt, JWT).

   Initialize the server and set up API routes.

2. **Database Configuration:**

   Set up MongoDB on a cloud platform (e.g., MongoDB Atlas) or a local installation.

   Define collections for users and water pollution data.

3. **Frontend Development Environment:**

   Use Visual Studio Code as the IDE.

   Include Tailwind CSS for styling and set up JavaScript files for dynamic behavior.

Testing Environment:

1. **Test Cases:**

   User registration and login flows.

   CRUD operations for water quality parameters.

   Search functionality based on sample IDs.

2. **Validation:**

   Input validation for user forms to prevent invalid or incomplete data entries.

   Backend validation for database operations, ensuring error-free data handling.

3. **Simulation of Real-World Scenarios:**

   Simulated pollutant data inputs to test system performance.

   Stress testing database queries for efficiency under heavy loads.

Deployment and Testing Tools:

- **Postman:** For API testing to ensure proper routing and data exchange.
- **Browser DevTools:** For inspecting front-end performance and debugging.
- **Jest or Mocha:** For unit testing critical backend functions.

3.5 Additional Experimental Considerations

Performance Testing:

- Evaluating system responsiveness with large datasets.
- Analyzing API response times for real-time updates.

Security Testing:

- Testing for vulnerabilities such as SQL injection (even though MongoDB is used).
- Verifying JWT expiration and renewal processes.

Cross-Browser and Device Compatibility:

- Ensuring functionality across multiple browsers (e.g., Chrome, Firefox) and devices (e.g., mobile, tablet, desktop).

User Feedback and Iterations:

- Conducting usability tests with mock users to identify improvement areas in the UI/UX design.
- Iteratively enhancing features based on feedback.

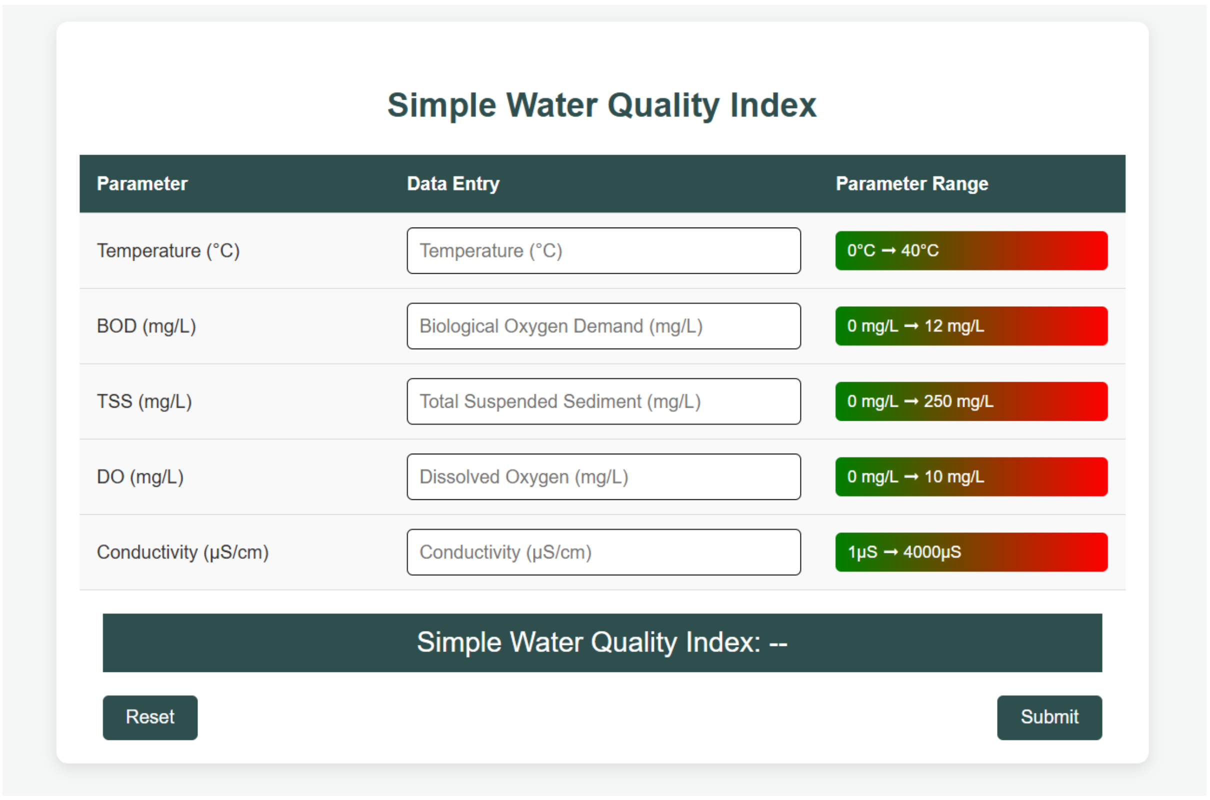
Chapter 4: Work Done So Far (Results and Discussion)

4.1 Frontend Development

User Interface Design: The frontend emphasizes user-friendly interactions with a clean and responsive design using **HTML**, **CSS (Tailwind CSS)**, and **JavaScript**. The primary pages developed are:

- **Sign-In/Sign-Up Pages:** These allow secure user authentication.

  - *Design Features:* Styled with Tailwind CSS for consistency and modern aesthetics.
  - *Dynamic Behavior:* JavaScript is used for client-side validation and toggling between sign-in and sign-up forms.
- **Main Dashboard:** Displays water quality data in a structured table format.
  - *Interactive Elements:* Data categorized into physical, chemical, and biological parameters.
  - *Responsive Layout:* Designed to adapt seamlessly to various screen sizes.



Simple Water Quality Index

Parameter	Data Entry	Parameter Range
Temperature (°C)	Temperature (°C)	0°C → 40°C
BOD (mg/L)	Biological Oxygen Demand (mg/L)	0 mg/L → 12 mg/L
TSS (mg/L)	Total Suspended Sediment (mg/L)	0 mg/L → 250 mg/L
DO (mg/L)	Dissolved Oxygen (mg/L)	0 mg/L → 10 mg/L
Conductivity (µS/cm)	Conductivity (µS/cm)	1µS → 4000µS

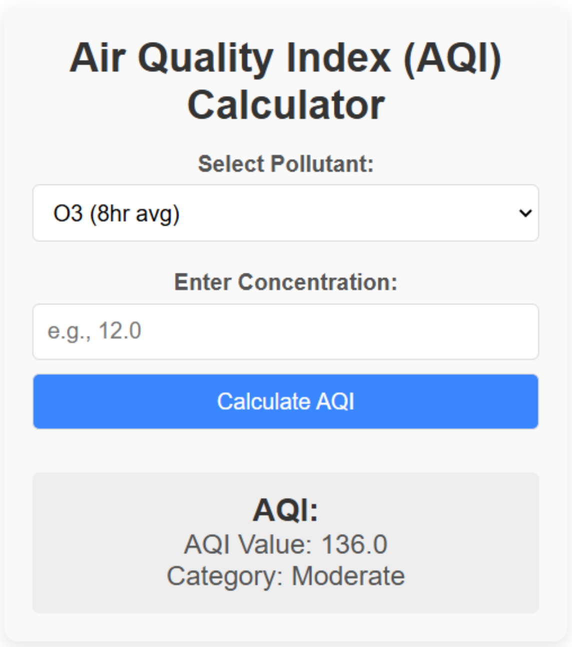
Simple Water Quality Index: --

Search Functionality:

- A search form enables users to retrieve data by **Sample ID**.
- Utilizes JavaScript's Fetch API to send requests to the backend and dynamically update results without a full page reload.

Challenges in Frontend Development:

- **Issue:** Cross-browser compatibility resulted in inconsistent layouts.
  - *Solution:* Incorporated Bootstrap and tested designs in multiple browsers (Chrome, Firefox, Edge).
- **Issue:** Maintaining responsiveness across diverse screen sizes.
  - *Solution:* Tailwind CSS utility classes and media queries were extensively applied.


Air Quality Index (AQI) Calculator

Select Pollutant: O3 (8hr avg)

Enter Concentration: e.g., 12.0

AQI:
AQI Value: 136.0
Category: Moderate

4.2 Backend Development

The backend is developed using **Node.js** with **Express.js**, ensuring modularity, scalability, and efficient routing.

API Endpoints:

1. **Authentication APIs:**
   - *Sign-Up Endpoint:* Handles user registration with bcrypt for password hashing.
   - *Login Endpoint:* Authenticates users and issues JWT tokens for session management.
2. **Data APIs:**
   - *Create Endpoint:* Accepts pollutant data from users and stores it in MongoDB.
   - *Read Endpoint:* Fetches water quality data by Sample ID.
   - *Update/Delete Endpoints:* Enable modifying and removing data entries.

Middleware Implementation:

- **Authentication Middleware:** Verifies JWT tokens for protected routes.
- **Error Handling Middleware:** Returns standardized error messages for invalid inputs or server errors.

Performance Enhancements:

- Optimized database queries to handle large datasets efficiently.
- Implemented pagination for data retrieval to improve load times on the main dashboard.

Challenges in Backend Development:

- **Issue:** Efficiently integrating bcrypt and JWT for secure authentication.
  - *Solution:* Modularized authentication logic and thoroughly tested it with different scenarios.
- **Issue:** Handling invalid data entries during database operations.
  - *Solution:* Implemented extensive validation both at the schema and API levels.

4.3 Database Design and Functionality

The database schema was carefully designed to accommodate the project's requirements, using **MongoDB** for scalability and flexibility.

Schemas Defined:

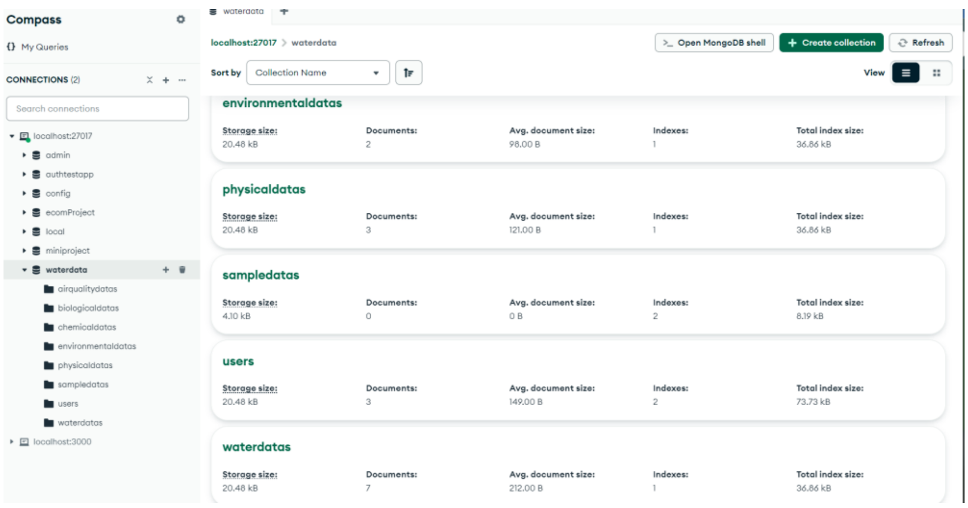
1. **User Schema:**
   - Fields: name, email, password (hashed).
   - Function: Securely stores user credentials and facilitates authentication.
2. **WaterData Schema:**
   - Fields: sampleID, physicalParams, chemicalParams, biologicalParams, timestamp.
   - Function: Organizes water quality data into categories for easier access and analysis.

Database Operations:

- **Insertion:** Pollutant data is added via backend APIs, ensuring unique sample IDs.
- **Retrieval:** Queries are optimized to fetch relevant data quickly based on user input (e.g., Sample ID).
- **Validation:** Data integrity is maintained through Mongoose schema validations.

Challenges in Database Design:

- **Issue:** Handling large volumes of data and ensuring fast retrieval times.



Collection	Storage size:	Documents:	Avg. document size:	Indexes:	Total index size:
environmentaldatas	20.48 kB	2	98.00 B	1	36.86 kB
physicaldatas	20.48 kB	3	121.00 B	1	36.86 kB
sampledatas	4.10 kB	0	0 B	2	8.19 kB
users	20.48 kB	3	149.00 B	2	73.73 kB
waterdatas	20.48 kB	7	212.00 B	1	36.86 kB

Chapter 5: Conclusion and Future Work

5.1 Conclusion

This project successfully addresses the critical challenge of monitoring water quality through a comprehensive web-based application. By integrating cutting-edge technologies such as **Node.js**, **MongoDB**, and **Tailwind CSS**, the system provides a reliable and scalable platform for analyzing and managing water pollution data.

Achievements:

1. **Frontend Development:**
   - Delivered a responsive and user-friendly interface, ensuring compatibility across devices and browsers.
   - Implemented interactive forms for data entry, visualization, and search functionality.
2. **Backend Functionality:**
   - Developed a secure and modular server-side system, capable of handling authentication, data validation, and CRUD operations efficiently.
   - Integrated robust APIs for seamless communication between the frontend and backend.
3. **Database Design:**
   - Created a scalable schema that organizes water quality data into logical categories.
   - Ensured data integrity and quick retrieval through indexing and validation mechanisms.
4. **Secure Authentication System:**
   - Established secure user authentication with **bcrypt** for password hashing and **JWT** for session management.
5. **Pollutant Analysis and Visualization:**
   - Designed algorithms to categorize pollutants and associate them with health implications.
   - Displayed data dynamically in an organized table format for user convenience.

Overall, the project achieved its primary goal of creating a platform that not only monitors water pollution but also aids in raising awareness and promoting data-driven decision-making for environmental management.

5.2 Challenges Addressed

1. **Data Validation and Security:**
   - Ensuring accurate and secure storage of user credentials and pollutant data.
   - Addressed by employing robust validation methods at both frontend and backend levels.
2. **System Integration:**
   - Seamlessly connecting the frontend and backend while maintaining performance and usability.

    - Achieved through RESTful API design and efficient middleware implementation.
3. **User Experience:**
    - Designing a platform that balances technical functionality with ease of use.
    - Overcame through iterative feedback and the adoption of modern frontend frameworks.

5.3 Limitations

Despite its successes, the project has a few limitations that present opportunities for future enhancements:

1. **Limited Real-Time Capabilities:**
    - The system currently lacks real-time monitoring features, such as live updates from sensors or external APIs.
2. **Restricted Data Visualization:**
    - The platform does not yet include advanced graphical representations like trend charts or heatmaps.
3. **Manual Data Entry Dependency:**
    - Relies on users to input data manually, which could lead to inconsistencies or delays in data collection.

5.4 Future Work

Building on the current progress, several areas have been identified for improvement and expansion:

1. Real-Time Data Integration:

- **Objective:** Enable live monitoring of water quality data using IoT devices or external APIs.
- **Implementation:**
    - Integrate sensor networks for automatic data collection.
    - Develop real-time synchronization mechanisms to update the database dynamically.

2. Advanced Data Visualization:

- **Objective:** Enhance the platform's analytical capabilities with graphical insights.
- **Implementation:**
    - Use libraries like **Chart.js** or **D3.js** to display data trends over time.
    - Add heatmaps for spatial representation of pollution levels across regions.

3. Role-Based Access Control:

- **Objective:** Introduce different access levels for users and administrators.

- **Implementation:**
  - Admin roles to manage data, review user submissions, and generate reports.
  - User roles to view and analyze data relevant to their permissions.

4. AI-Powered Predictive Analytics:

- **Objective:** Use machine learning models to predict future pollution levels.
- **Implementation:**
  - Train models using historical data to identify trends and potential risks.
  - Provide actionable insights, such as areas requiring immediate attention.

5. Enhanced User Experience:

- **Objective:** Make the system more intuitive and accessible.
- **Implementation:**
  - Add multilingual support to cater to a broader audience.
  - Implement voice-assisted navigation for accessibility.

6. Cloud Hosting and Scalability:

- **Objective:** Migrate the system to a cloud platform for global accessibility and scalability.
- **Implementation:**
  - Host on platforms like **AWS**, **Azure**, or **Google Cloud**.
  - Use **Docker** containers and **Kubernetes** for efficient scaling and deployment.

7. Integration with Government and Environmental Agencies:

- **Objective:** Provide data-sharing capabilities for regulatory compliance and policymaking.
- **Implementation:**
  - Create APIs that allow agencies to access pollution data in real time.
  - Develop reporting tools to generate insights for policy decisions.

8. Expanded Database Coverage:

- **Objective:** Broaden the range of pollutants and environmental parameters tracked by the system.
- **Implementation:**
  - Collaborate with environmental researchers to identify additional parameters.
  - Update schemas and APIs to accommodate new data categories.

5.5 Broader Implications

The successful implementation of this project has the potential to significantly impact both environmental monitoring and public health:

- **Awareness and Education:** Educating users about the harmful effects of pollution through accessible data and insights.
- **Policy Advocacy:** Providing actionable data to aid in the formulation of effective environmental policies.
- **Sustainability:** Empowering communities to track and mitigate pollution, fostering sustainable practices.

5.6 Summary

The project has laid a strong foundation for a scalable and impactful water pollution analysis platform. While it has successfully addressed key challenges, the proposed future enhancements aim to transform the system into a comprehensive environmental monitoring tool. By embracing advanced technologies and expanding its scope, this platform has the potential to make significant contributions to global sustainability efforts.

  - ritical fields like sampleID and optimized queries for performance.

4.4 Integration of Frontend and Backend

The integration ensures seamless communication between the user interface and server-side functionalities through **RESTful APIs**.

Key Features Integrated:

1. **Dynamic Data Submission:**
   - Frontend forms use Fetch API to send data to the backend.
   - Responses are parsed and displayed dynamically without refreshing the page.
2. **Search and Display:**
   - Users can search for specific sample data by entering Sample ID.
   - Results are categorized and presented in a clean tabular format.
3. **Validation and Error Handling:**
   - Client-side: Real-time feedback on invalid inputs.
   - Server-side: Detailed error messages returned to the frontend for user guidance.

4.5 Results Achieved

1. **Functional Frontend:**
   - Fully designed user interface with interactive forms for user authentication and data input.
   - Responsive layout compatible with both mobile and desktop devices.
2. **Secure Backend:**
   - Successfully implemented authentication using bcrypt and JWT.
   - Reliable APIs for CRUD operations on water pollution data.

3. **Efficient Database:**
    - Robust schemas for structured data storage and quick retrieval.
    - Sample ID-based indexing improved search functionality performance.
4. **Integrated System:**
    - Frontend and backend communicate seamlessly through APIs, providing a smooth user experience.

4.6 Discussion

Strengths of the Current System:

- **Scalability:** Modular design allows for easy future expansions, such as adding more pollutant parameters or integrating additional APIs.
- **User Experience:** The responsive design and organized data display enhance usability across devices.
- **Security:** Authentication mechanisms ensure user data safety and privacy.

Challenges and Solutions:

1. **Frontend Challenges:**
    - Problem: Maintaining consistency across browsers.
    - Solution: Used Bootstrap and performed rigorous cross-browser testing.
2. **Backend Challenges:**
    - Problem: Optimizing APIs for large datasets.
    - Solution: Query optimization and pagination were implemented.
3. **Database Challenges:**
    - Problem: Handling invalid or incomplete data entries.
    - Solution: Added schema-level validation and error handling.

Lessons Learned:

- Importance of modular design for scalability.
- Need for rigorous testing in both frontend and backend to catch edge cases.
- Value of user feedback for refining the interface and overall system functionality.

Chapter 5: Conclusion and Future Work

5.1 Conclusion

This project successfully addresses the critical challenge of monitoring water quality through a comprehensive web-based application. By integrating cutting-edge technologies such as **Node.js**, **MongoDB**, and **Tailwind CSS**, the system provides a reliable and scalable platform for analyzing and managing water pollution data.

Achievements:

1. **Frontend Development:**
    - Delivered a responsive and user-friendly interface, ensuring compatibility across devices and browsers.
    - Implemented interactive forms for data entry, visualization, and search functionality.
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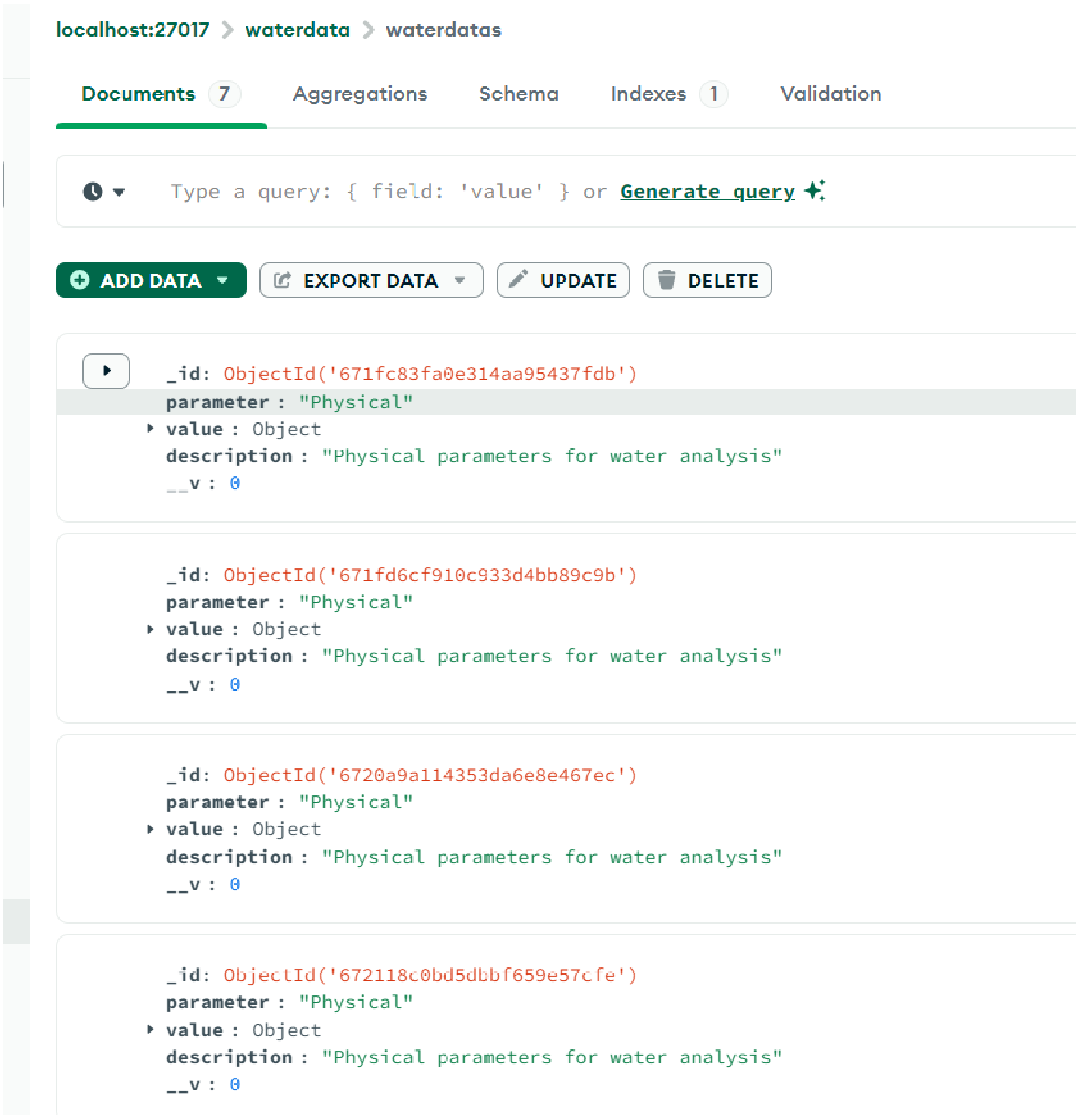
localhost:27017 > waterdata > waterdatas
Documents 7
Aggregations
Schema
Indexes 1
Validation
Type a query: { field: 'value' } or Generate query
ADD DATA
EXPORT DATA
UPDATE
DELETE

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parameter : "Physical"
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__v : 0

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parameter : "Physical"
value : Object
description : "Physical parameters for water analysis"
__v : 0
```

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- **Awareness and Education:** Educating users about the harmful effects of pollution through accessible data and insights.
- **Policy Advocacy:** Providing actionable data to aid in the formulation of effective environmental policies.
- **Sustainability:** Empowering communities to track and mitigate pollution, fostering sustainable practices.

5.6 Summary

The project has laid a strong foundation for a scalable and impactful water pollution analysis platform. While it has successfully addressed key challenges, the proposed future enhancements aim to transform the system into a comprehensive environmental monitoring tool. By embracing advanced technologies and expanding its scope, this platform has the potential to make significant contributions to global sustainability efforts.