International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Jal Suchak: An Automated Solution for Heavy Metal Pollution Index Data Management and Analysis

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Abstract:
Groundwater contamination caused by heavy metals poses a significant risk to public health and environmental sustainability. Existing groundwater quality assessment approaches are largely manual, fragmented, and lack real-time analytical and visualization capabilities. This paper proposes Jal Suchak, an automated groundwater quality assessment platform that computes Heavy Metal Pollution Indices (HMPI) using WHO standards and performs health risk analysis for both adults and children. The research methodology integrates data preprocessing, pollution index computation, health risk modeling using Chronic Daily Intake (CDI) and Hazard Quotient (HQ), and geospatial analysis for hotspot identification. The system is implemented using a web-based architecture with analytical and visualization modules, along with an intelligent chatbot powered by a

Retrieval-Augmented Generation (RAG) model for interactive querying. Experiments conducted on real groundwater datasets demonstrate accurate pollution classification, effective risk identification, and clear visual interpretation through dashboards and spatial maps. The results confirm that Jal Suchak significantly reduces manual effort, improves analytical accuracy, and provides actionable decision support, thereby contributing a scalable and integrated solution for groundwater pollution monitoring and management.

Keywords: Groundwater Quality Assessment, Heavy Metal Pollution Index, Health Risk Analysis, Geospatial Visualization, Environmental Monitoring, Intelligent Chatbot, Decision Support System.

I. INTRODUCTION

Groundwater contamination caused by heavy metals is a critical environmental and public health issue, mainly resulting from industrialization, agricultural activities, and improper waste disposal. Toxic metals such as lead, arsenic, cadmium, and chromium are non-biodegradable and pose severe health risks through long-term exposure. Existing studies in the literature have widely used pollution indices such as Heavy Metal Pollution Index (HPI), Metal Index (MI), and Contamination Degree (Cd) to assess groundwater quality; however, most approaches rely on manual or offline computation, lack integrated health risk assessment, and provide limited visualization and decision support. These limitations introduce challenges in handling large datasets, ensuring computational accuracy, managing data inconsistencies, and enabling timely identification of contamination hotspots, thereby motivating the need for an automated and scalable solution.

This paper proposes Jal Suchak**,** an automated groundwater quality assessment platform that integrates pollution index computation, health risk analysis for adults and children, and geospatial visualization within a unified system. The platform preprocesses groundwater datasets, computes standardized pollution indices and risk metrics, and presents results through interactive dashboards, spatial maps, and automated alerts. An intelligent chatbot further enables users to query pollution and risk insights interactively. The system is evaluated using realworld groundwater datasets, demonstrating effective classification of contamination levels, clear identification of high-risk regions, and improved interpretability of results. Overall, Jal Suchak contributes a comprehensive, efficient, and data-driven decision-support framework for sustainable groundwater monitoring. The remainder of this paper is organized to review related work, describe the proposed methodology and implementation, present experimental results, and conclude with future directions.

II. LITERATURE REVIEW / SURVEY

Groundwater contamination caused by heavy metals has become a serious environmental and public health concern in many regions of the world. Researchers have developed various techniques to evaluate water quality and determine the level of contamination using pollution indices, statistical models, and spatial analysis methods. These approaches aim to simplify the interpretation of complex water quality datasets and support effective environmental monitoring and management.

The following studies provide the foundation for the proposed Jal Suchak system.

Elsiddig et al. (2023) [1] proposed an improved Heavy Metal Pollution Index (HPI) model for assessing water contamination levels. The HPI method integrates the concentrations of multiple heavy metals into a single index value based on assigned weight factors and permissible limits. Their study demonstrated that the HPI model provides an effective way to evaluate the overall impact of heavy metals on water quality. However, the process involves multiple mathematical calculations and manual data processing, which can become complex and time-consuming when analyzing large datasets.

Anitha et al. (2022) [2] conducted a study on groundwater pollution assessment using the Heavy Metal Pollution Index and Metal Index methods. Their research applied these indices to evaluate groundwater samples and classify polluted zones based on contamination levels. The study demonstrated that pollution indices can effectively summarize complex environmental data and provide reliable indicators of water quality. Nevertheless, the approach mainly relies on manual data processing and lacks automated tools for efficient computation and visualization.

Ahmad Badeenezhad et al. (2021) [3] introduced the application of Monte Carlo Simulation for water quality risk assessment**.** This probabilistic technique evaluates uncertainty in environmental datasets and improves the reliability of pollution analysis by accounting for variability in measurement values. The study showed that Monte Carlo methods can significantly enhance risk estimation in water quality assessment. However, the implementation of such probabilistic models requires advanced technical knowledge and computational expertise.

Narayanan et al. (2020) [4] proposed a GIS-based groundwater pollution mapping approach using spatial interpolation techniques. Their research focused on identifying contamination hotspots by visualizing the spatial distribution of heavy metals in groundwater sources. The use of Geographic Information Systems improved the ability to monitor pollution patterns across large geographic areas. Despite these advantages, the system primarily focuses on spatial analysis and does not include automated pollution index computation.

Chakraborty and Patra (2019) [5] performed a statistical analysis of heavy metal contamination in groundwater using correlation and statistical modeling methods. Their research examined relationships between different heavy metals and environmental parameters to identify possible sources of contamination. The study provided valuable insights into groundwater pollution patterns. However, the analysis lacks integrated visualization platforms and automated systems for efficient pollution index evaluation.From the above studies, it is evident that several techniques exist for analyzing groundwater contamination, including pollution indices, statistical analysis, probabilistic modeling, and spatial mapping. Although these approaches provide valuable insights into water quality conditions, many existing systems rely on manual calculations, fragmented tools, and limited visualization capabilities. These limitations highlight the need for an automated and integrated platform for groundwater pollution assessment.

A. Summary of Literature

The literature review indicates that pollution indices such as the Heavy Metal Pollution Index (HPI) and Metal Index are widely used methods for evaluating groundwater contamination caused by heavy metals. These indices simplify the interpretation of complex water quality parameters by combining multiple variables into a single numerical value, making it easier to assess overall pollution levels.

Several studies have also utilized statistical analysis, probabilistic modeling, and GIS-based spatial analysis to improve groundwater quality assessment. These methods help identify contamination patterns, estimate uncertainty in environmental datasets, and detect pollution hotspots across different geographic regions.

However, several limitations are consistently observed across existing systems:

- Manual and complex calculations for pollution indices
- Lack of automated data processing and analysis tools
- Limited visualization and reporting mechanisms
- Difficulty in handling large environmental datasets
- Absence of centralized platforms for groundwater quality monitoring

These limitations highlight the need for an automated and integrated environmental monitoring system capable of performing pollution index calculations, analyzing large datasets, and presenting results through interactive visualization tools.

The proposed Jal Suchak system addresses these challenges by automating the computation of pollution indices, enabling efficient groundwater quality analysis, and providing userfriendly visualization and reporting features for environmental researchers and decision-makers.

III. PROPOSED SYSTEM

Jal Suchak is an intelligent groundwater quality assessment platform designed to analyze heavy metal contamination in water sources using pollution index methods. The system aims to simplify the process of groundwater quality evaluation by providing an automated and user-friendly platform for environmental monitoring. Traditional groundwater pollution assessment often involves manual calculations and fragmented analytical tools, making the process time-consuming and prone to errors.

Users interact with the system through a web-based interface where groundwater quality datasets can be uploaded. These datasets typically contain concentrations of various heavy metals such as lead, cadmium, chromium, iron, and zinc. Once the data is uploaded, the backend processing module performs data validation, preprocessing, and pollution index computation.

The system calculates the Heavy Metal Pollution Index (HPI) to evaluate the overall level of contamination in groundwater samples. The computed index values are then interpreted to determine whether the water quality is safe or polluted. The platform further enhances usability by presenting results through graphical visualizations and analytical reports that allow users to easily interpret pollution levels.

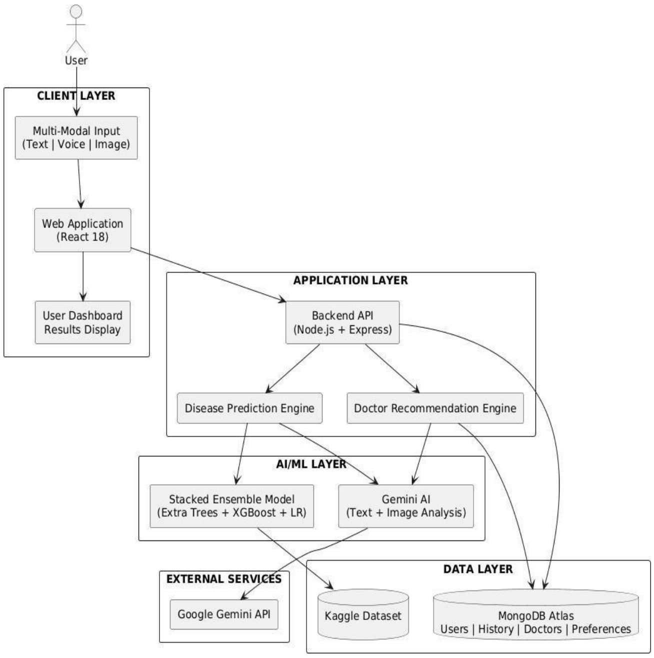
Overall, Jal Suchak provides an automated and scalable solution for groundwater quality monitoring, enabling researchers, environmental analysts, and policymakers to assess water contamination levels efficiently.

A. System Architecture

The architecture of Jal Suchak consists of several interconnected components including the user interface, backend processing system, pollution index calculation module, visualization module, and database storage system.

The frontend interface allows users to upload groundwater quality datasets through a simple and interactive web interface. The backend processing module receives the uploaded dataset and performs validation checks to ensure the data format and parameters are correct.

After validation, the preprocessing module cleans and structures the dataset by organizing heavy metal concentration values required for pollution index computation. These processed values are then passed to the pollution index



calculation module, which calculates the Heavy Metal Pollution Index (HPI) using standard formulas.

The computed index values are stored in the system database and forwarded to the visualization module. The visualization component generates graphical outputs such as charts, pollution indicators, and summary reports that help users understand groundwater contamination levels more effectively.

B. System Modules

Jal Suchak consists of multiple functional modules that collectively perform groundwater pollution analysis and visualization.

1) User Authentication and Data Management Module

This module manages user registration, login, and session handling. User credentials are securely stored in the system database and authentication mechanisms ensure secure access to the platform. This module also enables users to store and access historical groundwater analysis records.

2) Data Input and Validation Module

This module allows users to upload groundwater quality datasets containing heavy metal concentration values. The system verifies the dataset structure and validates the input parameters to ensure accuracy and consistency before further analysis.

3) Data Preprocessing Module

The preprocessing module organizes and cleans the uploaded dataset. It removes missing values, standardizes parameter formats, and converts the raw dataset into a structured format suitable for pollution index computation.

4) Pollution Index Calculation Module

This module calculates the Heavy Metal Pollution Index (HPI) based on the concentration of heavy metals in the groundwater sample. The HPI method combines multiple parameters into a single index value using weight factors and permissible limits. The final index value indicates the overall level of groundwater contamination.

5) *Visualization and Reporting Module*

The visualization module converts computed pollution index values into graphical representations such as charts, pollution indicators, and summary reports. These visual outputs allow users to quickly interpret groundwater quality conditions and identify potential environmental risks.

6) *Database Storage Module*

All uploaded datasets and computed results are stored securely in the database. This enables users to retrieve historical analysis records and track groundwater quality changes over time.

C. Advantages of the Proposed System

The proposed Jal Suchak system offers several advantages compared to traditional groundwater pollution assessment methods.

First, the system automates the calculation of pollution indices such as the Heavy Metal Pollution Index, eliminating the need for complex manual calculations.

Second, the platform enables efficient processing of large environmental datasets, making it suitable for large-scale groundwater monitoring.

Third, graphical visualizations improve the interpretation of pollution levels and help users easily understand groundwater quality conditions.

Fourth, centralized data storage enables users to maintain historical records for long-term environmental analysis.

Finally, the user-friendly interface and automated analysis pipeline make Jal Suchak an effective tool for researchers, environmental agencies, and policymakers involved in groundwater quality management.

IV. METHODOLOGY

The methodology of Jal Suchak describes the systematic process through which groundwater quality data is analyzed to determine pollution levels. The system follows a structured workflow that integrates data preprocessing, pollution index computation, and visualization techniques.

A. Data Acquisition and Preprocessing

The first step in the system involves collecting groundwater quality datasets that contain concentrations of heavy metals such as lead, cadmium, chromium, iron, and zinc.

Once the dataset is uploaded, the system performs preprocessing operations including:

- Removal of missing or inconsistent data values
- Standardization of parameter units
- Structuring the dataset for index calculation

This preprocessing stage ensures that the dataset is suitable for accurate pollution index computation.

B. Heavy Metal Pollution Index Calculation

The Heavy Metal Pollution Index (HPI) is used to evaluate the overall quality of groundwater contaminated by heavy metals.

The index is calculated using the following formula: $HPI = (\sum W_iQ_i) / (\sum W_i)$
Where:

- W_i = Unit weight of the ith parameter

Q_i = Sub-index of the ith parameter The sub-index Q_i is calculated as:
$Q_i = ((M_i - I_i) / (S_i - I_i)) \times 100$

Where:

- M_i = Measured concentration of the ith metal
- I_i = Ideal value of the ith parameter
- S_i = Standard permissible limit of the ith parameter
- The calculated HPI value represents the overall pollution level of the water sample.

C. Pollution Level Classification

After computing the HPI value, the system classifies groundwater quality based on predefined thresholds.

Typical classification includes:

- $HPI < 100 \rightarrow$ Safe water quality
- $HPI \geq 100 \rightarrow$ Polluted water

This classification helps users quickly determine whether groundwater sources are safe for consumption.

D. Data Visualization and Interpretation

The calculated pollution index values are presented through graphical visualizations such as charts and pollution indicators.

These visualizations allow users to:

- Understand groundwater contamination levels
- Identify polluted regions
- Compare different water samples

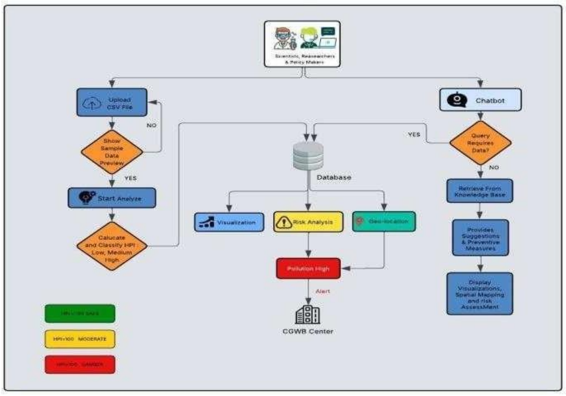
The visualization module simplifies complex environmental data into easily interpretable graphical outputs.

System Workflow

Jal Suchak operates through a structured processing pipeline that converts groundwater datasets into pollution assessment reports.

The workflow consists of the following steps:

1. Users upload groundwater quality datasets.
2. The system validates and preprocesses the dataset.
3. Heavy metal concentrations are extracted from the dataset.
4. The Heavy Metal Pollution Index is calculated.
5. Pollution levels are classified based on HPI thresholds.
6. Visualization graphs and reports are generated.
7. Results are displayed to the user through the web interface.
8. Analysis records are stored in the system database.

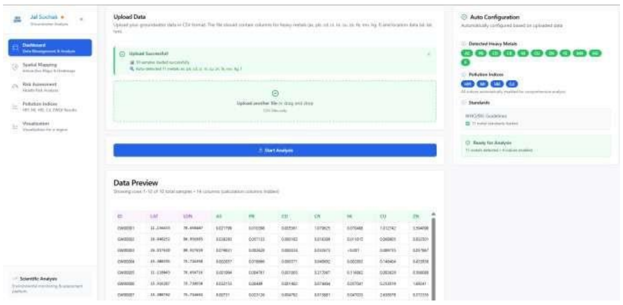


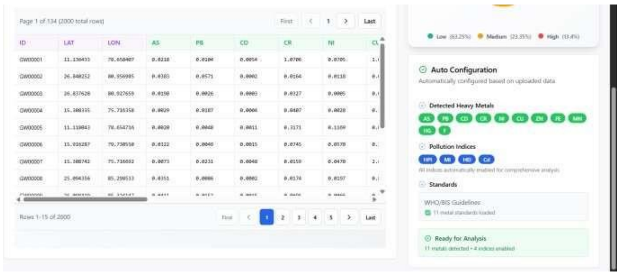
V. RESULTS AND DISCUSSION

This section presents the experimental results and performance evaluation of the proposed Jal Suchak system. The evaluation focuses on groundwater quality assessment, heavy metal pollution analysis, and geospatial visualization of contamination levels. The system was tested using groundwater sample datasets containing concentrations of heavy metals such as lead, cadmium, iron, copper, and zinc. The platform processes these values and computes pollution indicators such as the Heavy Metal Pollution Index (HPI) to determine overall water quality. The generated outputs include groundwater quality classification, pollution level indicators, geospatial mapping of contamination, and graphical visualizations for improved interpretation and decisionmaking.

A. Heavy Metal Pollution Index Calculation

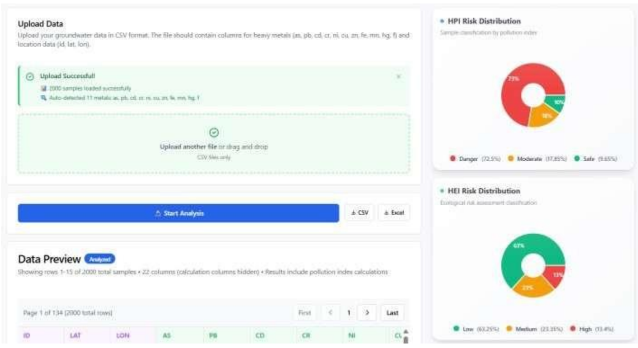
The system calculates the Heavy Metal Pollution Index (HPI) using concentration values of different heavy metals obtained from groundwater samples. The automated calculation module processes the input data and computes the index value to determine the level of pollution in each groundwater sample. This automation eliminates manual computational errors and improves efficiency in groundwater quality analysis.





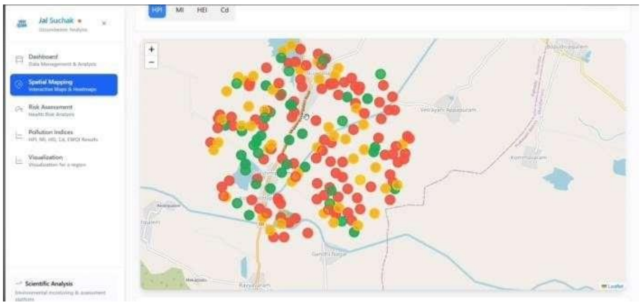
B. Groundwater Quality Assessment Results

The Jal Suchak system successfully analyzes groundwater samples and classifies them into categories such as safe, moderately polluted, and highly polluted based on the calculated HPI values. This classification helps identify areas where groundwater quality is suitable for drinking and areas where contamination exceeds permissible limits. The system therefore supports early detection of groundwater pollution and assists authorities in implementing corrective measures.



C. Geospatial Mapping of Groundwater Contamination

To better understand the spatial distribution of groundwater pollution, the system integrates geospatial mapping techniques. The analyzed data is plotted on geographic maps to visually represent contamination levels across different regions. This spatial visualization helps identify pollution hotspots and patterns of heavy metal contamination. Geospatial mapping enables environmental researchers and policymakers to easily monitor regional groundwater quality and prioritize areas that require remediation.



D. *System Interface and Workflow*

The Jal Suchak platform provides a user-friendly interface where users can upload groundwater sample data along with location information. The system processes the data, calculates pollution indices, and displays the groundwater quality results along with geospatial maps and graphical outputs. This integrated workflow simplifies groundwater pollution assessment and improves accessibility for environmental monitoring agencies and researchers.

E. *Data Visualization and Analysis*

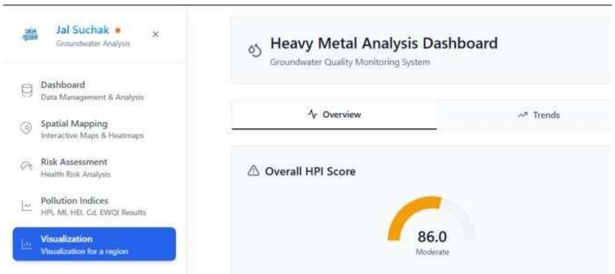
The platform also provides graphical representations such as charts and plots to visualize heavy metal concentration levels and pollution indices. These visualizations allow users to easily compare contamination levels across different samples and observe trends in groundwater quality. Such visual analysis simplifies the interpretation of complex environmental data.

F. *System Interface and Workflow*

The Jal Suchak platform provides a user-friendly interface where users can upload groundwater sample data along with location information. The system processes the data, calculates pollution indices, and displays the groundwater quality results along with geospatial maps and graphical outputs. This integrated workflow simplifies groundwater pollution assessment and improves accessibility for environmental monitoring agencies and researchers.

G. *Overall System Performance*

The experimental results demonstrate that the Jal Suchak system effectively automates groundwater pollution analysis while integrating pollution index computation, geospatial mapping, and visualization tools. The system significantly reduces the complexity of traditional groundwater quality assessment methods and provides a comprehensive platform for monitoring heavy metal contamination. These results indicate that the proposed system can support environmental authorities and researchers in making data-driven decisions for groundwater management and pollution control.



VI. CONCLUSION

This research presented Jal Suchak**,** an automated groundwater pollution assessment platform designed to evaluate heavy metal contamination using the Heavy Metal Pollution Index method. The system integrates data processing, pollution index computation, and visualization tools to provide an efficient solution for groundwater quality monitoring.

By automating the calculation of pollution indices, the system reduces manual effort and improves the accuracy of environmental data analysis. The visualization features further enhance usability by presenting complex data in an easily interpretable format.

Overall, Jal Suchak provides a scalable and user-friendly solution for groundwater pollution assessment, supporting researchers, environmental organizations, and policymakers in monitoring water quality and making informed environmental decisions.

VII. FUTURE WORK

The Jal Suchak system can be further enhanced with several improvements to increase its capabilities and practical usability.

Future work may include integrating machine learning models to predict groundwater pollution trends based on historical datasets. The system can also be extended to include additional water quality indices such as Water Quality Index (WQI) and Metal Index (MI).

Furthermore, integration with real-time sensor-based water monitoring systems can enable continuous data collection and automated pollution analysis. Incorporating GIS-based visualization may also allow spatial mapping of groundwater contamination across geographic regions.

Developing a mobile application and deploying the platform on scalable cloud infrastructure can further improve accessibility and support large-scale environmental monitoring applications.

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