

Development of an IoT and AI-Integrated Web Platform for Real-Time River Water Quality Monitoring in Pahang River

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ABSTRACT

River water quality monitoring is essential for supporting environmental protection and early decision-making. However, IoT-based monitoring systems often generate large volumes of sensor data that are stored but not fully transformed into actionable information. This study presents the design and implementation of iSENS-Air, an AI-driven web-based decision support system for real-time river water quality monitoring in the Pahang River area. The system was developed for four monitoring locations, namely Bilut, Telum, Kechau, and Semantan. IoT sensors collect nine water quality parameters, including turbidity, biochemical oxygen demand, dissolved oxygen, chemical oxygen demand, ammonia, total dissolved solids, conductivity, oxidation-reduction potential, and pH. The collected data are stored in a cloud environment and accessed through API-based data retrieval. The platform integrates data preprocessing, water quality classification, risk identification, historical analysis, and AI-generated insight using the OpenAI API. The web dashboard was developed using Next.js to present real-time parameter cards, daily classification summaries, monitoring maps, historical data, and recommended actions. The implemented system demonstrates how raw sensor data can be transformed into interpretable information for river water quality monitoring and preliminary decision support.

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1. INTRODUCTION

River water quality monitoring is an essential activity for supporting environmental protection, public health, and sustainable water resource management [1], [2]. Rivers are often exposed to various pollution sources, including agricultural runoff, domestic wastewater, industrial discharge, and land-use activities around the river basin [3]. Changes in water quality parameters such as turbidity, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, ammoniacal nitrogen, total dissolved solids, conductivity, oxidation-reduction potential, and pH can indicate potential degradation of aquatic environments [4]. In Malaysia, river water quality is commonly interpreted based on water quality classes, where Class I represents water suitable for conservation and minimal treatment, while Class V indicates water that is unsuitable for the defined beneficial uses [5], [6]. Therefore, continuous observation of river water quality is important to detect abnormal conditions and support early decision-making.

Conventional water quality monitoring practices commonly depend on periodic sampling and laboratory analysis [7]. Although laboratory-based assessment provides reliable measurements, it may not be sufficient for capturing rapid changes in water conditions. River pollution events can occur suddenly due to rainfall, discharge activities, or operational disturbances in surrounding areas [8]. As a result, a monitoring approach that only relies on manual inspection may delay the detection of water quality degradation [9]. With the advancement of Internet of Things (IoT) technology, water quality sensors can now be deployed in the field to collect real-time or near-real-time data from river environments. IoT-based monitoring enables continuous data acquisition, remote observation, and faster identification of abnormal water quality patterns [10].

However, the availability of real-time sensor data does not automatically guarantee effective environmental decision-making [11]. In many monitoring projects, large volumes of sensor readings are collected and stored in cloud platforms, but the data are not fully utilized because they are difficult to interpret, fragmented across storage systems, or presented only as raw numerical values. For non-technical users, raw sensor readings may not directly explain whether the river condition is safe, risky, or requires immediate attention. Therefore, a monitoring system should not only collect data but also transform the data into meaningful information through preprocessing, classification, visualization, and interpretation [12].

To address this issue, this study presents the design and implementation of iSENS-Air, an AI-driven web-based decision support system for real-time river water quality monitoring in the Pahang River area. The system focuses on four monitoring locations, namely Bilut, Telum, Kechau, and Semantan. IoT sensors deployed at the river sites collect multiple water quality parameters and transmit the readings to a cloud environment. The stored sensor data are then accessed through an API-based data retrieval mechanism, allowing the web platform to obtain the latest available records for further processing and visualization. The system is developed using Next.js and is designed to provide an interactive dashboard that presents real-time sensor readings, daily water quality classification, historical data analysis, and AI-assisted interpretation.

The proposed platform integrates several functional layers. First, the data acquisition layer receives water quality data from IoT sensors deployed in the river. Second, the data management layer retrieves and organizes sensor records from cloud storage. Third, the preprocessing layer handles raw sensor data cleaning to reduce noise, missing values, and inconsistent readings. Simple machine learning algorithms, such as K-Nearest Neighbors (KNN) and Support Vector Machine (SVM), can be used to support data cleaning and water quality classification. Fourth, the visualization layer presents real-time and historical water quality information through cards, tables, maps, trend summaries, and parameter comparison panels. Finally, the AI-assisted decision support layer uses the OpenAI API to generate natural language insights, including possible pollution contributors, predicted pollution sources, and recommended actions based on the processed water quality patterns. The main contribution of this study is the development of an integrated web-based platform that bridges the gap between raw IoT sensor data and user-oriented water quality decision support. Instead of presenting sensor data as isolated numerical readings, iSENS-Air converts the data into an interpretable monitoring interface with classification, visualization, and AI-generated explanations. This allows users to understand the current river condition, review historical patterns, and obtain preliminary decision support from a single dashboard. Since this study focuses on design and implementation, the evaluation emphasizes system functionality, workflow integration, interface design, and practical usefulness rather than extensive model benchmarking.

The remainder of this paper is organized as follows. Section 2 describes the proposed methodology, including the study area, system architecture, data pipeline, preprocessing stage, classification process, and web dashboard development. Section 3 discusses the implementation results, including the real-time monitoring interface, historical data visualization, water quality classification, and AI-generated insight. Finally, Section 4 concludes the paper and outlines future work.

2. METHODOLOGY

This study adopts a design and implementation approach to develop iSENS-Air, an AI-driven web-based decision support system for real-time river water quality monitoring. The methodology focuses on the integration of IoT-based water quality sensors, cloud-based data storage, SFTP-based data retrieval, data preprocessing, machine learning-assisted classification, AI-generated interpretation, and web dashboard development. Since the main objective of this study is to present the design and implementation of the system, the evaluation emphasizes system workflow, functional integration, and practical usefulness rather than extensive predictive model benchmarking.

2.1. Study Area and Monitoring Locations

The system was developed for river water quality monitoring in the Pahang River area. Four monitoring locations were included in the implementation, namely Bilut, Telum, Kechau, and Semantan. These locations

were selected as representative monitoring points for observing water quality conditions through deployed IoT sensor nodes. Each monitoring point was designed to collect water quality data continuously and transmit the readings to a cloud storage environment. The monitoring locations are displayed on the web platform through an interactive map interface, allowing users to select a specific river location and open the corresponding monitoring dashboard.

2.2. Overall System Architecture

The overall architecture of the proposed system is shown in Figure 1. The system consists of several main layers: the IoT sensing layer, cloud data storage layer, API-based data retrieval layer, processing and classification layer, AI-assisted decision support layer, and web visualization layer. The IoT sensing layer is responsible for collecting water quality readings from sensors installed in the river. The collected readings are then transmitted and stored in a cloud environment. The web system retrieves the stored sensor data through an API-based mechanism, allowing the platform to access updated sensor records from the cloud environment.

After the data are retrieved, the system performs preprocessing to clean and organize the sensor readings. The cleaned data are then used for water quality classification and risk interpretation. The processed results are displayed through a web dashboard developed using Next.js. In addition, the system integrates the OpenAI API as a natural language interpretation layer to generate user-friendly insights, possible pollution contributors, and recommended actions based on the processed monitoring results.

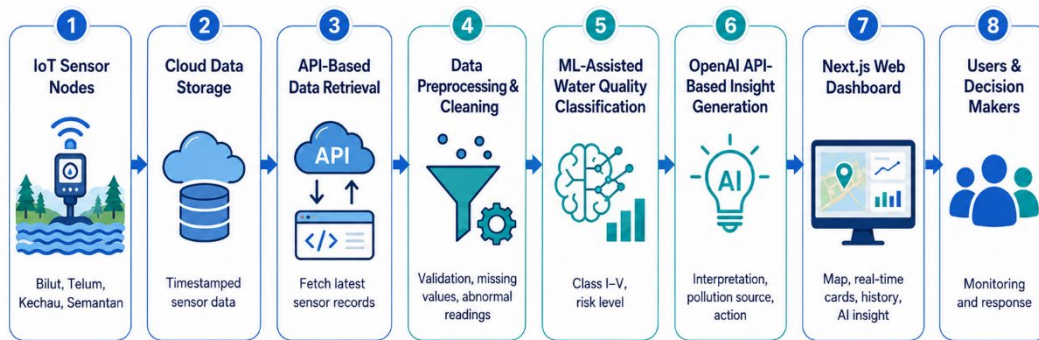


Figure 1. Overall architecture of the iSENS-Air system

2.3. IoT Sensor Data Acquisition

The system receives water quality data from IoT sensors deployed at the selected river monitoring locations. The sensor readings consist of nine water quality parameters, namely turbidity (TR), biochemical oxygen demand (BOD), dissolved oxygen (DO), chemical oxygen demand (COD), ammonia (NH₃), total dissolved solids (TDS), conductivity (CT), oxidation-reduction potential (ORP), and potential of hydrogen (pH). These parameters were selected because they provide important information about the physical and chemical condition of river water.

Each sensor reading is stored with a timestamp to support real-time monitoring and historical analysis. The timestamp is important because the dashboard provides current parameter values, daily summaries, and historical trends. By continuously collecting these parameters, the system enables users to observe changes in river water conditions over time rather than relying only on periodic manual inspection.

2.4. Cloud Storage and API-Based Data Retrieval

The raw data generated by the IoT sensors are stored in a cloud environment. To access the stored data, the iSENS-Air platform uses an API-based data retrieval mechanism. The API enables the web system to request updated sensor records from the cloud and integrate them into the dashboard. The retrieved data are then parsed, validated, and prepared for further processing in the system.

The API-based approach was selected because it provides a flexible and scalable connection between the cloud data storage and the web application. Instead of manually downloading sensor records, the web system can automatically request the latest available data and update the dashboard accordingly. This allows the platform to provide real-time or near-real-time information based on the most recent sensor readings. The use of an API also supports better integration with web technologies, making it suitable for a dashboard developed using Next.js.

2.5. Data Cleaning and Preprocessing

Raw sensor data may contain missing values, duplicated records, inactive sensor readings, inconsistent timestamps, or abnormal values caused by sensor disturbance. Therefore, data cleaning is an important step before the readings are displayed or interpreted. The preprocessing stage includes timestamp organization, parameter selection, missing value checking, duplicate removal, and validation of sensor readings. Inactive parameters are also identified so that the dashboard can clearly distinguish between available and unavailable sensor data.

Simple machine learning methods can also be applied to support data cleaning and quality assessment. In this implementation, algorithms such as K-Nearest Neighbors (KNN) and Support Vector Machine (SVM) are considered suitable because they are relatively lightweight and practical for structured sensor data. KNN can be used to support similarity-based data validation, while SVM can be applied to classify water quality status based on selected parameter patterns. The purpose of this stage is not to develop a complex prediction model, but to improve the usability of sensor data before it is presented to users.

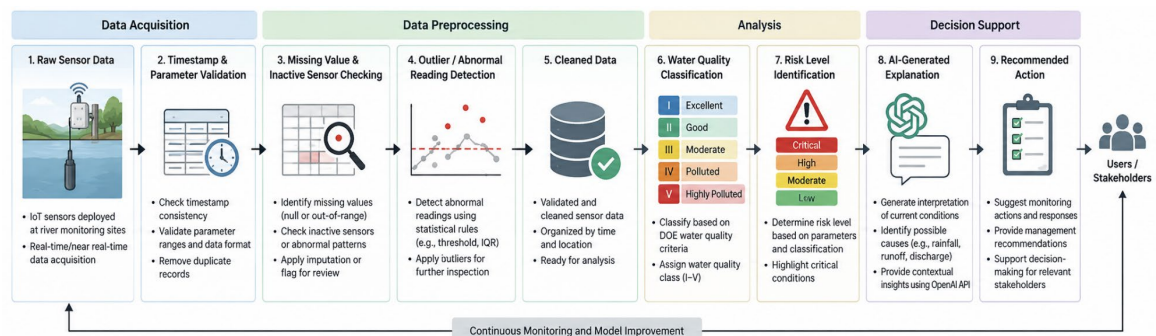


Figure 2. Data processing and AI-assisted decision support workflow

2.6. Water Quality Classification and Risk Assessment

After the preprocessing stage, the cleaned sensor data are used to classify the water quality status. The classification process considers the measured values of the nine parameters and compares them with predefined water quality criteria. The system provides a daily water quality summary and assigns a class label, such as Class I to Class V, depending on the condition of the monitored river water. The system also presents a risk status, such as low risk, moderate risk, high risk, or critical risk, to help users understand the severity of the current condition.

The classification result is designed to be interpretable. For example, if one parameter exceeds the acceptable threshold, the system identifies the limiting parameter that contributes to the final classification. This is important because users need to know not only the final water quality class, but also the parameter that influences the classification. In the dashboard, this information is displayed in the daily water quality summary section, where the system explains the overall class, risk level, and dominant parameter affecting the water quality status.

2.7. AI-Generated Insight and Decision Support

The system integrates the OpenAI API to generate natural language insights from the processed water quality data. The AI component does not replace the sensor measurement, preprocessing, or classification process. Instead, it acts as an interpretation layer that converts structured analytical results into readable explanations. The input to the AI component includes the latest parameter values, daily classification result, risk level, historical trend summary, limiting parameter, and selected statistical information from the recent monitoring period.

The AI-generated output includes a short interpretation of the water quality condition, likely main contributors, predicted source of pollution, and recommended action. For example, if BOD values are consistently high, the system may generate an explanation indicating possible organic pollution and recommend further inspection or immediate intervention. This feature is intended to help users understand the meaning of the data more quickly, especially users who may not be familiar with technical water quality parameters.

2.8. Web-Dashboard Development

The iSENS-Air dashboard was developed using Next.js and designed as a web-based monitoring and decision support platform. The dashboard consists of several main interfaces: the landing page, monitoring map, real-time water quality assessment page, daily summary panel, AI decision support section, historical data analysis section, and raw data table. The landing page introduces the system and provides access to the monitoring map. The monitoring map displays the available river monitoring locations and allows users to select a specific area.

After a monitoring location is selected, the user is directed to the detailed dashboard page. This page displays the latest sensor readings using parameter cards. Each card shows the parameter name, value, unit, and status. The daily summary panel presents the water quality class, risk level, and short explanation of the dominant parameter. The AI decision support section provides a seven-day interpretation, likely contributors, predicted source of pollution, and recommended action. The historical analysis section allows users to select a date range and review parameter trends, threshold exceedance indicators, and tabular sensor records.

2.9. System Workflow

The complete system workflow begins when IoT sensors collect water quality data from the selected river monitoring locations. The sensor readings are uploaded to cloud storage and accessed by the web system through an API-based data retrieval mechanism. The retrieved data are then cleaned, validated, and organized based on timestamp and parameter type. After preprocessing, the system performs water quality classification and risk assessment. The processed output is then sent to the AI interpretation module to generate natural language insight. Finally, the results are displayed on the Next.js dashboard in the form of maps, parameter cards, classification summaries, historical charts, and tables.

3. RESULTS AND DISCUSSION

3.1. Implementation of the Isens-Air Web Dashboard

The implementation result of the proposed system is a web-based dashboard called iSENS-Air, which was developed to support real-time river water quality monitoring and AI-assisted decision support. The dashboard integrates IoT sensor data, preprocessing results, classification outputs, and natural language interpretation into a single platform. The system was designed to enable users to access river water quality information from four monitoring locations, namely Bilut, Telum, Kechau, and Semantan.

The dashboard interface consists of several functional components, including a monitoring map, real-time water quality cards, a daily classification panel, an AI decision support section, a historical data analysis panel, and a raw data table. These components were implemented to transform raw sensor readings into an interpretable monitoring interface. The overall implemented interface can be presented either as a combined dashboard view or as separate feature-based figures. The monitoring map interface is shown in Figure 3, while the real-time parameter display and daily classification panel are shown in Figure 4. The AI-assisted interpretation module is presented in Figure 5, and the historical visualization and raw data review components are shown in Figure 6.

3.2. Monitoring Map and Location Selection

The monitoring map interface serves as the entry point to the system. As shown in Figure 3, the map displays the available monitoring areas and allows users to select a river location for further inspection. This interface is important because it connects the spatial aspect of river monitoring with the analytical dashboard. Instead of requiring users to manually search for station data, the map allows direct interaction with the monitoring points.

The map also provides a simple risk-oriented overview through marker visualization and legend categories such as low risk, moderate risk, high risk, critical risk, and inactive or unavailable data. This helps users quickly identify which river location requires more attention. From a usability perspective, the map-based interface improves accessibility because users can navigate the monitoring system spatially rather than only through tables or menu navigation.

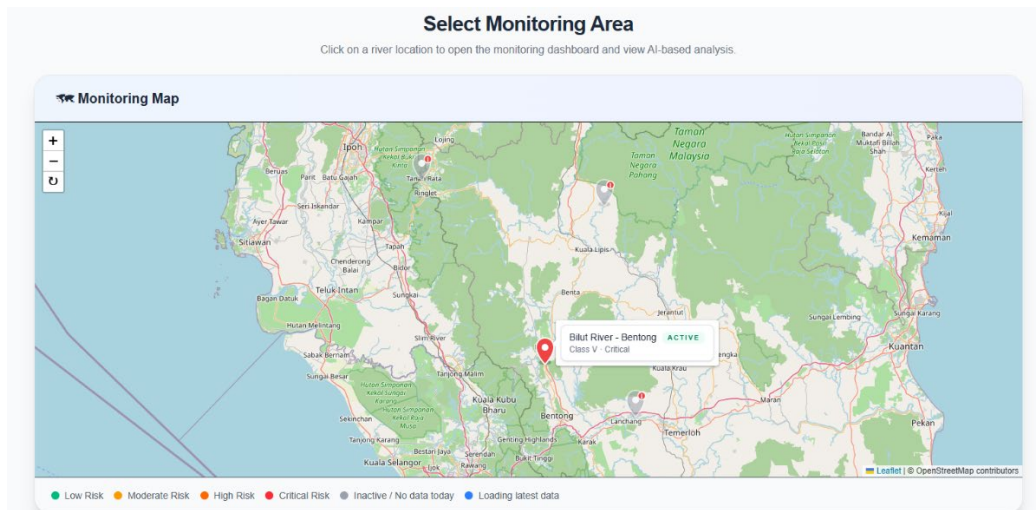


Figure 3. Monitoring map and location selection interface of the iSENS-Air dashboard for accessing river water quality monitoring stations

3.3. Real-Time Water Quality Display and Daily Classification

After a monitoring location is selected, the system displays the real-time water quality dashboard. As shown in Figure 4, the dashboard presents the latest sensor readings using parameter cards for turbidity (TR), biochemical oxygen demand (BOD), dissolved oxygen (DO), chemical oxygen demand (COD), ammonia (NH₃), total dissolved solids (TDS), conductivity (CT), oxidation-reduction potential (ORP), and pH. Each card presents the parameter name, latest value, measurement unit, and status. Parameters that are unavailable or inactive are also clearly labelled, which is useful for transparency in real-time monitoring.

In addition to the parameter cards, the dashboard includes a daily classification panel that summarizes the water quality condition for the selected location. The panel displays the water quality class and a risk label, such as critical risk, based on the processed sensor data. The summary also identifies the limiting parameter that drives the classification result. This feature is useful because users do not only see numerical readings, but also receive a concise interpretation of the overall water quality condition.

The real-time display and daily classification panel demonstrate the practical value of the proposed system. In conventional monitoring systems, raw sensor data may be difficult to interpret directly. In contrast, iSENS-Air presents both detailed parameter values and a high-level summary, making the information easier to understand by both technical and non-technical users.

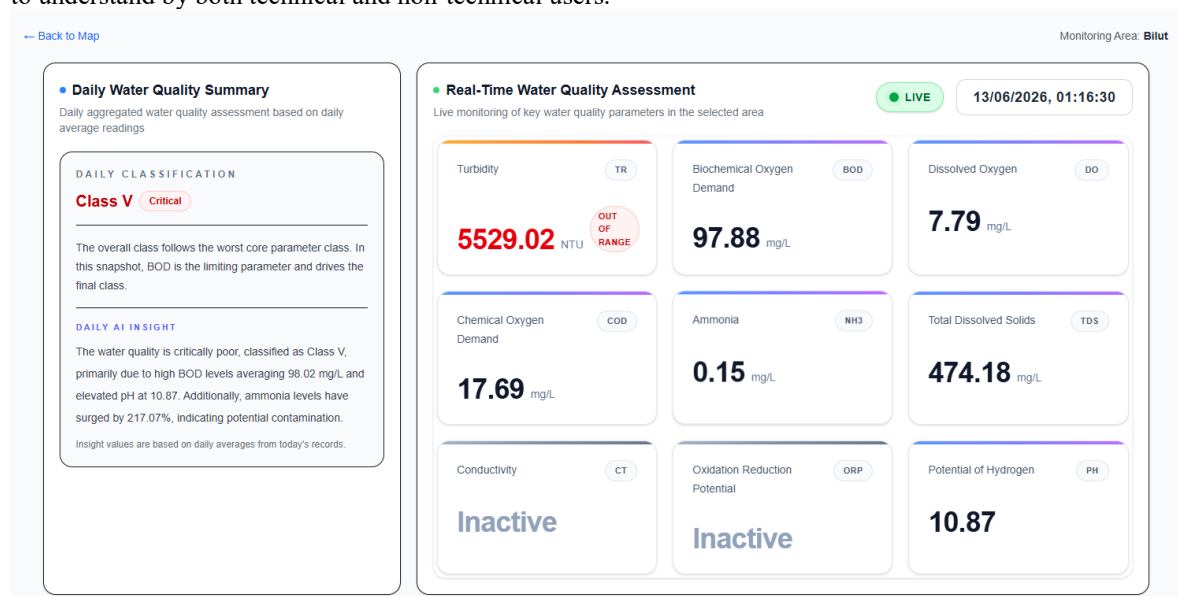


Figure 4. Real-time water quality dashboard showing parameter cards and the daily water quality classification panel for the selected monitoring location

3.4. AI-Assisted Decision Support Output

One of the main features of iSENS-Air is the AI-assisted decision support section, which is shown in Figure 5. This section converts processed sensor data into natural language explanations. The AI-generated output includes a short interpretation of recent water quality patterns, likely main contributors, a predicted source of pollution, and a recommended response. This feature was designed to address a common limitation of monitoring systems in which sensor readings are available but not easily understandable by end users.

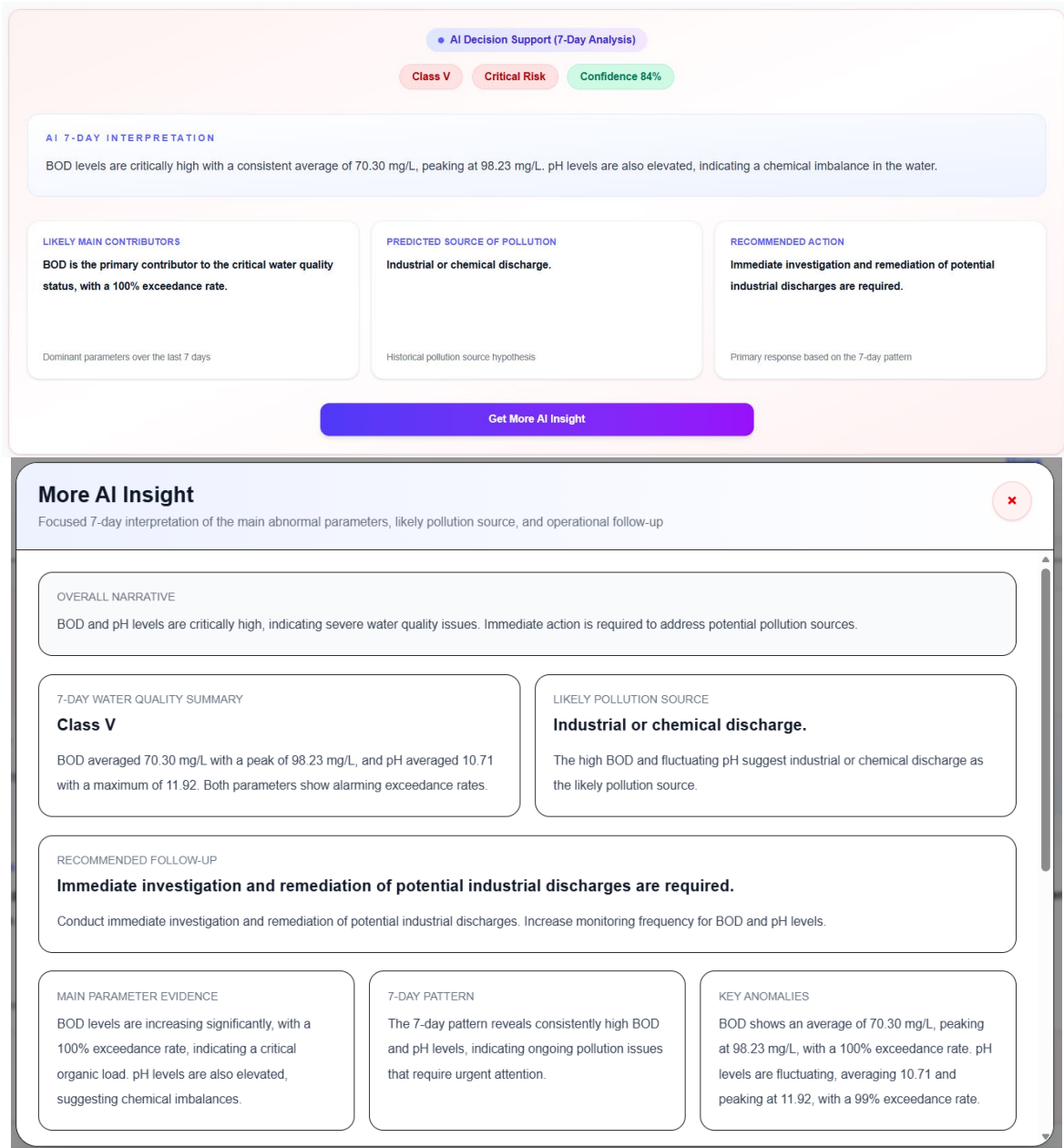


Figure 5. AI-assisted decision support section showing the seven-day interpretation, likely pollution contributors, predicted pollution source, and recommended action

The AI component acts as an interpretation layer rather than a primary classification engine. The water quality class and risk level are derived from the processed sensor data, while the OpenAI API is used to provide user-friendly explanations. This distinction is important because it ensures that scientific measurements remain the basis of the assessment, while AI improves the readability and communicative value of the results.

From the implementation results, the AI decision support section adds contextual meaning to the monitoring output. For example, when BOD values remain high over a selected period, the system can highlight BOD as the likely dominant contributor to poor water quality, suggest a possible pollution source, and provide

a preliminary action recommendation. This makes the dashboard more useful as a decision support tool rather than only a monitoring interface.

3.5. Historical Data Analysis and Raw Data Review

The dashboard also provides a historical data analysis section and a raw data table, as shown in Figure 6. The historical analysis interface allows users to select a date range and review summarized trends from past sensor data. Instead of showing only the most recent reading, the system presents a broader context through trend highlights, parameter comparisons, and threshold exceedance indicators. This feature is useful for understanding whether a water quality issue is temporary, recurring, or worsening over time.

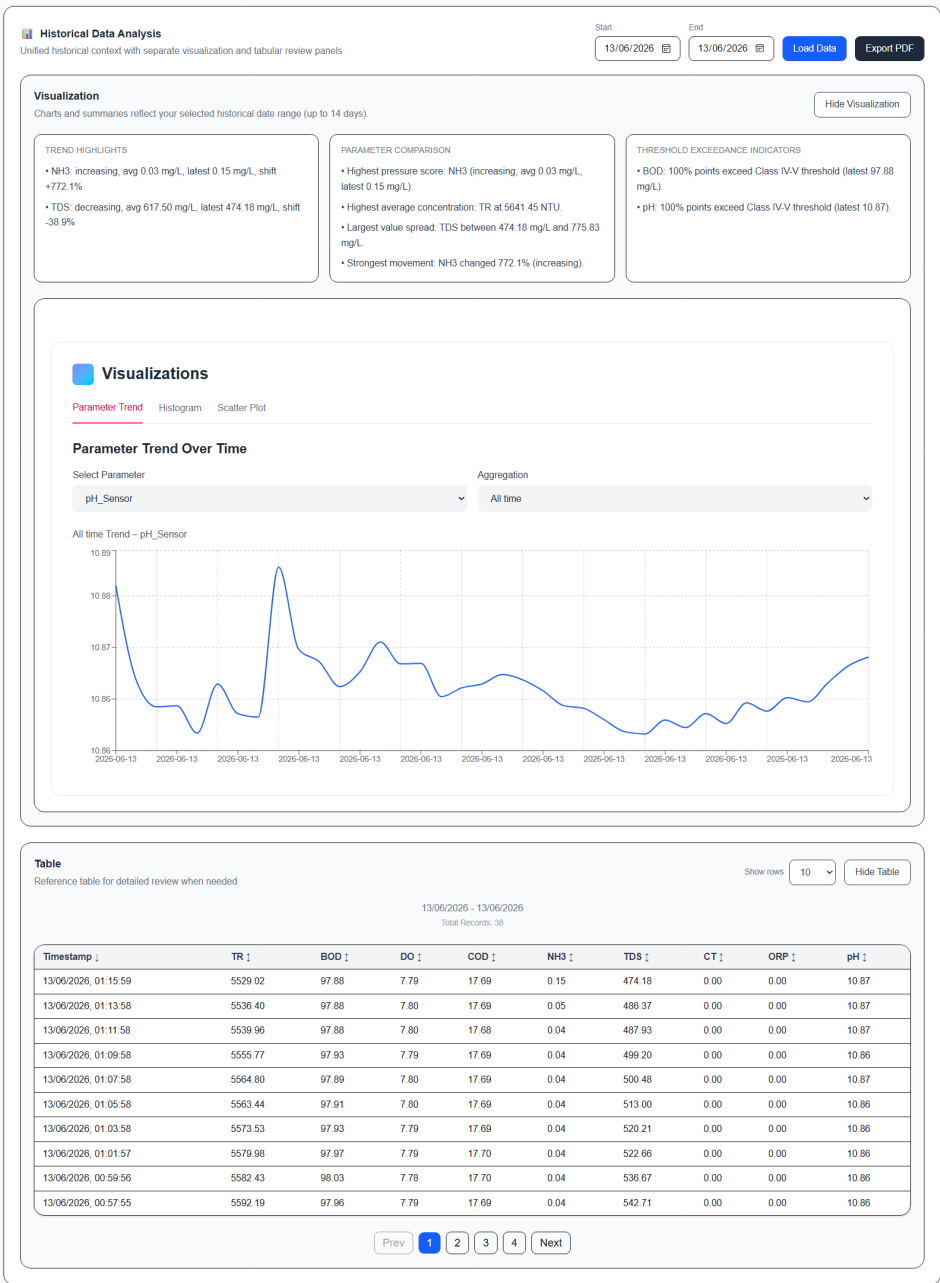


Figure 6. Historical data analysis and raw data review interface showing summarized trends, parameter comparisons, threshold indicators, and timestamped sensor records

The raw data table complements the summarized analysis by allowing users to inspect the original processed sensor records. This is important because some users may require detailed timestamped values for verification, reporting, or further analysis. By combining summarized historical interpretation with direct

tabular access, the system balances readability and transparency. This part of the implementation shows that iSENS-Air is not limited to current monitoring alone. It also supports retrospective review, which is valuable for identifying recurring patterns and building a broader understanding of river water quality dynamics.

3.6. Discussion

The implementation results indicate that iSENS-Air successfully integrates multiple components into a single monitoring platform. The system connects IoT-based sensing, cloud-based data retrieval, preprocessing, classification, AI-assisted interpretation, and web-based visualization. This integration is important because, in many practical monitoring settings, the main challenge is not only collecting data but also transforming the data into understandable information for decision-making.

A key strength of the system is its layered design. The monitoring map supports location-based access, the real-time parameter cards provide direct observation of current conditions, the daily classification panel summarizes the water quality status, the AI decision support section offers natural language interpretation, and the historical analysis feature supports further review of past observations. Together, these components improve the usability of river water quality monitoring data.

However, the current study focuses on system design and implementation, and therefore some limitations remain. First, the system has not yet been evaluated through extensive user testing or formal usability analysis. Second, the machine learning stage is implemented in a practical and lightweight manner rather than as a highly optimized predictive model. Third, the AI-generated insight depends on the quality of the processed input data and should be interpreted as preliminary decision support rather than a replacement for expert judgment. Future work may include usability evaluation, broader field validation, and enhancement of predictive and interpretive modules.

Overall, the results demonstrate that iSENS-Air provides a practical web-based platform for converting real-time IoT sensor data into interpretable river water quality information. The system shows strong potential for supporting continuous monitoring and preliminary environmental decision-making in the Pahang River area.

4. CONCLUSION

This study presented the design and implementation of iSENS-Air, an AI-driven web-based decision support system for real-time river water quality monitoring in the Pahang River area. The system was developed to support four monitoring locations, namely Bilut, Telum, Kechau, and Semantan, by integrating IoT-based water quality sensors, cloud data storage, API-based data retrieval, data preprocessing, water quality classification, AI-generated interpretation, and a Next.js web dashboard. Through this integration, raw sensor readings from nine water quality parameters can be transformed into more accessible information, including real-time parameter cards, daily water quality classification, risk status, historical data summaries, and raw data tables. The implemented dashboard demonstrates that river water quality data can be presented in a more understandable and practical form for monitoring and preliminary decision-making.

The main contribution of this study is the development of an integrated monitoring platform that bridges the gap between sensor data collection and user-oriented decision support. Instead of only displaying numerical sensor readings, iSENS-Air provides contextual interpretation through classification results, visual summaries, and AI-assisted insights, including possible pollution contributors, predicted pollution sources, and recommended actions. However, since this study focuses on system design and implementation, further work is required to conduct extensive usability evaluation, validate the classification results with expert assessment, and improve the machine learning component using larger historical datasets. Future development may also include mobile access, automated alerts, predictive modelling, and broader deployment across additional river monitoring stations.

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During the preparation of this manuscript, the authors used ChatGPT to assist with grammar checking, language refinement, sentence restructuring, and improving the clarity of the manuscript. The authors carefully reviewed, edited, and verified all AI-assisted outputs and take full responsibility for the accuracy, integrity, and final content of the manuscript.

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