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Smart River Water Level and Quality Surveillance

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ABSTRACT

Effective river surveillance requires more than the presentation of isolated environmental measurements. River stage, water quality, geographic location, observation time, data availability, and the physical context of a monitoring station should be accessible within a unified interface if the information is to support rapid interpretation. This paper presents Smart River Water Level and Quality Surveillance, a software-based Web-GIS environmental monitoring and decision-support platform that integrates hydrological and physicochemical river observations into a station-centric surveillance workflow.

The platform acquires periodically refreshed environmental telemetry from an authoritative government monitoring source and transforms incoming records through station aggregation, parameter normalization, river-name inference, spatial organization, visual condition assessment, and a project-specific weighted composite water-quality score. The dashboard supports twelve hydrological and physicochemical parameters: river stage, water depth, pH, water temperature, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, turbidity, electrical conductivity, nitrate, chloride, and total organic carbon.

The developed system extends conventional telemetry display through interactive Web-GIS navigation, State–River–Station filtering, parameter-level status indicators, station-associated monitoring imagery, responsive desktop/mobile layouts, light and dark themes, multi-tier data failover, printable PDF-compatible environmental monitoring reports, and CSV export. An administrative module allows authorized users to create additional monitoring locations using externally obtained field or laboratory measurements, place stations geographically through a map interface, upload station imagery, manage locally entered records, and perform controlled parameter-response testing.

A processed project snapshot containing 468 telemetry records associated with 40 distinct monitoring stations was used to demonstrate the system workflow. The project also includes a verified archive of 23 station-associated monitoring photographs for visual ground-context support. The platform demonstrates how a software environmental-informatics layer can improve the accessibility, interpretability, resilience, and extensibility of existing river-monitoring information without requiring deployment of an additional independent sensor network.

Keywords: River Monitoring, Water Quality, Water Level, Web-GIS, Environmental Surveillance, River Stage, Environmental Informatics, Composite Water-Quality Score, Decision Support System, Responsive Web Application.

1. Introduction

Rivers are essential components of environmental and human systems. They support drinking-water resources, agriculture, industry, aquatic ecosystems, groundwater interaction, recreation, and regional development. Their condition changes in response to rainfall, seasonal flow variation, wastewater discharge, industrial activity, sediment transport, urbanization, and other natural and anthropogenic influences.

A river cannot be adequately described by one environmental variable. Hydrological observations such as river stage and water depth describe physical conditions, while physicochemical measurements such as pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity, electrical conductivity, nitrate, chloride, total organic carbon (TOC), and water temperature provide complementary information about water-quality conditions.

Conventional river monitoring frequently combines field observation, sample collection, laboratory analysis, and automated station telemetry. Laboratory analysis remains essential because many parameters require controlled analytical procedures. At the same time, periodically refreshed telemetry can increase temporal coverage and provide a more immediate view of changing environmental conditions.

A substantial body of research has therefore focused on Internet of Things (IoT) systems, wireless sensor networks, cellular monitoring nodes, autonomous multiparameter stations, and remote water-quality dashboards. Moreno et al. developed **RiverCore**, an IoT architecture for river-water-level monitoring using fixed/mobile nodes and cellular communication [1]. Adu-Manu et al. demonstrated wireless-sensor-network-based river monitoring with emphasis

on water-quality sensing and communication [2]. Chowdury et al. proposed an IoT-based near-real-time river-water-quality monitoring system integrating sensor acquisition and remote presentation [3]. Teixeira et al. experimentally validated an autonomous IoT monitoring system for water-quality assessment in the Amazon River environment [4]. These studies demonstrate the importance of reliable measurement acquisition and communications.

However, the existence of telemetry does not by itself produce an effective environmental surveillance platform. Once measurements have been generated, additional software problems remain: how to group fragmented parameter records into stations, normalize inconsistent identifiers, infer usable river information, combine hydrological and water-quality variables, present locations geographically, preserve usability during temporary network failures, integrate local observations, and generate interpretable outputs for users.

The present work addresses this software and environmental-informatics problem through **Smart River Water Level and Quality Surveillance**. The proposed system does not deploy a separate Arduino, ESP32, Raspberry Pi, or custom physical sensing network. Existing government-generated telemetry is treated as an upstream environmental-data source, while the contribution of the project lies primarily in **data integration, processing, interpretation, spatial visualization, resilience, administration, and reporting**.

A central objective is to integrate river-stage observation and water-quality surveillance within a single station-centric interface. Hydrological stage and physicochemical condition are commonly viewed in separate contexts, even though both contribute to understanding the state of a river monitoring location. The proposed platform combines these information types while preserving their different interpretations.

The system also supports a second data pathway. If a local river or monitoring point is absent from the automatic upstream network, an authorized administrator can enter measurements obtained through suitable field equipment or laboratory testing, specify the geographic location, and attach monitoring imagery. This allows the platform to represent both network telemetry and administrator-entered local observations while keeping their provenance conceptually distinct.

The central research question is therefore:

How can heterogeneous river telemetry and locally acquired environmental observations be transformed into an integrated, resilient, spatially aware, and user-accessible Web-GIS surveillance platform?

2. Literature Review

2.1 River-Level Monitoring Systems

Moreno et al. developed RiverCore as an IoT architecture for river-water-level observation using cellular communications [1]. The study demonstrates how remote sensing nodes can transmit hydrological information into a server environment. Its contribution is concentrated in field hardware, communications, and telemetry acquisition, whereas the present work focuses primarily on how already-generated environmental information can be normalized, combined, interpreted, and spatially presented.

2.2 Wireless Sensor Networks for Water Quality

Adu-Manu et al. investigated smart river monitoring using wireless sensor networks [2]. Their system emphasized timely monitoring, sensing reliability, communication efficiency, and energy-aware operation. The study demonstrates the importance of multiparameter environmental observation. The Smart River platform follows the principle of multiparameter monitoring while addressing the downstream software layer: station aggregation, GIS navigation, visual interpretation, reporting, and administrative extensibility.

2.3 IoT-Based River-Water Monitoring

Chowdury et al. proposed an IoT-based river-water-quality monitoring system that acquired measurements and delivered them through a remote platform [3]. Their work illustrates that environmental surveillance is more useful when numerical data are transformed into interpretable information rather than exposed only as raw sensor streams. The current platform similarly emphasizes interpretation, although its alerting is presently visual within the dashboard rather than delivered through SMS, e-mail, or push notification.

2.4 Autonomous Monitoring in Complex River Environments

Teixeira et al. presented an autonomous IoT-based water-quality monitoring system validated for Amazon River conditions [4]. Their work highlights the engineering complexity of deploying a complete independent sensing and communications infrastructure. The Smart River platform addresses a complementary research problem: increasing the usefulness of environmental telemetry after it has already been produced by an external monitoring network.

2.5 Near-Real-Time Monitoring in Indian River Contexts

Research on Indian river monitoring has demonstrated the feasibility of periodically refreshed environmental observation. Singh et al. reported river-water-quality monitoring of the Ganga using IoT-related approaches and environmental informatics [5]. Such systems illustrate the value of continuous or periodically refreshed observations while also motivating better mechanisms for integrating spatial context, parameter interpretation, and public-facing visualization.

2.6 Water-Quality Assessment and GIS

Krishan et al. combined water-quality assessment methods with GIS techniques in a study of the Gomti River [6]. GIS is valuable because environmental monitoring is inherently spatial: the meaning of a measurement depends partly on where the observation was made. The proposed platform therefore treats the map as an operational navigation and surveillance component, not as a decorative background [9, 10].

Table 1. Comparison of Related Monitoring Approaches

Capability	RiverCore	Smart River WSN	IoT River WQ System	Amazon IoT System	Proposed Platform
Custom physical sensing	Yes	Yes	Yes	Yes	No additional sensor network
River-stage monitoring	Primary	Limited	Limited	Secondary	Yes
Multiparameter water quality	Limited	Yes	Yes	Yes	Yes
Web-based interface	Yes	Yes	Yes	Yes	Yes
Interactive Web-GIS	Not central	Not central	Limited	Not central	Yes
Existing telemetry reuse	No	No	No	No	Yes
River-name inference	No	No	No	No	Yes
Station imagery integration	No	No	No	Deployment context	Yes
Local field/lab data entry	No	No	No	No	Yes
Custom station creation	No	No	No	No	Yes
Multi-tier application failover	Not central	Not central	Not central	Communication resilience	Yes
PDF-compatible monitoring report	Not central	Not central	Not central	Not central	Yes
CSV export	Research-oriented	Research-oriented	Not central	Research dataset	Yes
Responsive mobile layout	Not primary focus	Not primary focus	Not primary focus	Not primary focus	Yes

The comparison does not imply that the proposed software platform replaces physical sensing research. The reviewed systems and the present work operate at different layers of environmental monitoring. The cited studies primarily emphasize **measurement generation and communication**, while the present project emphasizes **integration, spatial interpretation, accessibility, administration, reporting, and application resilience**.

3. Research Gap, Aim, and Objectives

Environmental monitoring research has substantially advanced sensor design, remote acquisition, and communication. Nevertheless, usability problems remain when data arrive as heterogeneous or fragmented records. Parameters may appear under different aliases, the same station may occur in multiple rows, river names may be embedded in free-text station descriptions, hydrological and water-quality information may be presented separately, and raw numbers may require users to perform manual interpretation.

The project addresses the following gaps:

fragmented parameter-level records may not provide a complete station-level view;

source parameter names may require normalization;

river names may not be available as clean structured fields;

river-stage and water-quality observations may be viewed separately;

raw numerical values may be difficult to interpret rapidly;

monitoring locations require effective geographic representation;

application usability may degrade when a single upstream route is unavailable;

automatic station networks may not include smaller local rivers or community monitoring points;

many dashboards are effectively read-only; and

environmental information may not be easily exported for offline analysis or documentation.

The aim of the work is:

To design and evaluate a responsive Web-GIS environmental surveillance platform that integrates river-stage and water-quality observations into a unified, resilient, spatially interactive, and extensible decision-support environment.

The principal objectives are to:

1. acquire periodically refreshed environmental telemetry;
2. transform parameter-level records into station-centric objects;
3. normalize heterogeneous parameter identifiers;
4. infer river information from station metadata when necessary;
5. integrate hydrological and water-quality observations;
6. implement a simplified project-specific composite assessment;
7. provide parameter-level visual condition coding;
8. implement interactive Web-GIS navigation;
9. associate stations with monitoring imagery;
10. provide resilient telemetry/fallback data acquisition;
11. support administrator-entered field/laboratory observations;
12. provide printable reports and CSV export;
13. preserve usability across desktop and mobile layouts; and
14. identify limitations and future research directions.

4. Proposed System Architecture

The platform is organized as a layered environmental information system. The principal operational sequence is:

Environmental Data Sources → Data Acquisition → Station Aggregation → Parameter Normalization → River Inferencing → Composite/Parameter Assessment → Web-GIS Visualization → Administration → Reporting and Export

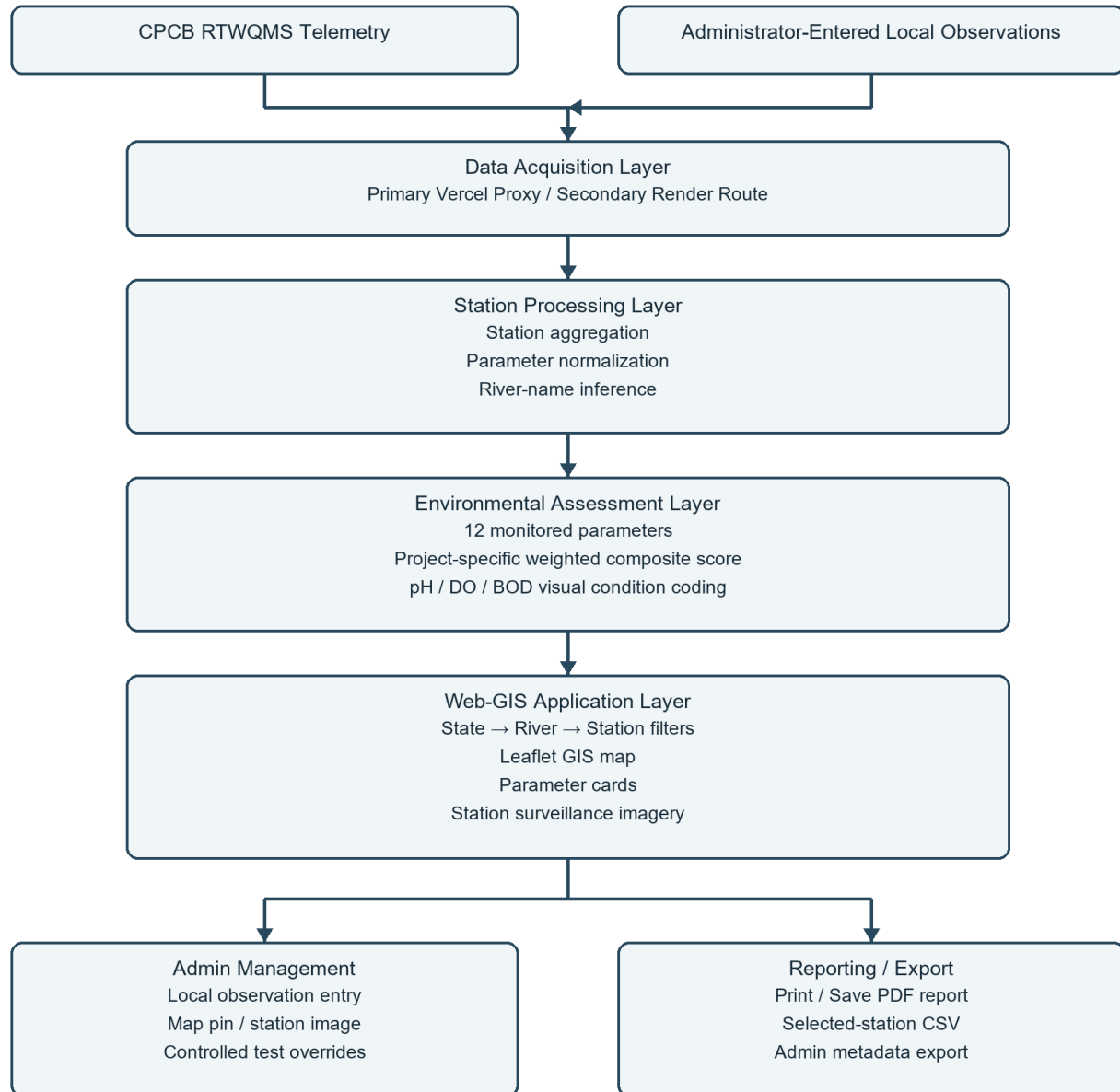
Two data pathways are supported.

4.1 Upstream Telemetry Pathway

Periodically refreshed observations are acquired automatically from the CPCB Real-Time Water Quality Monitoring Stations (RTWQMS) data service [8, 14]. The upstream network is the measurement source; the proposed platform operates as the software processing and presentation layer.

4.2 Local Monitoring Pathway

An administrator can add a monitoring location using externally measured field or laboratory observations. This pathway is intended for locally monitored rivers or sampling points that may not exist within the upstream telemetry network.



Periodically refreshed environmental surveillance

Figure 1. Overall architecture of the proposed Smart River Water Level and Quality Surveillance platform, showing upstream telemetry and administrator-entered observations, acquisition, station processing, composite assessment, Web-GIS presentation, administration, and reporting.

5. Data Acquisition and Resilience

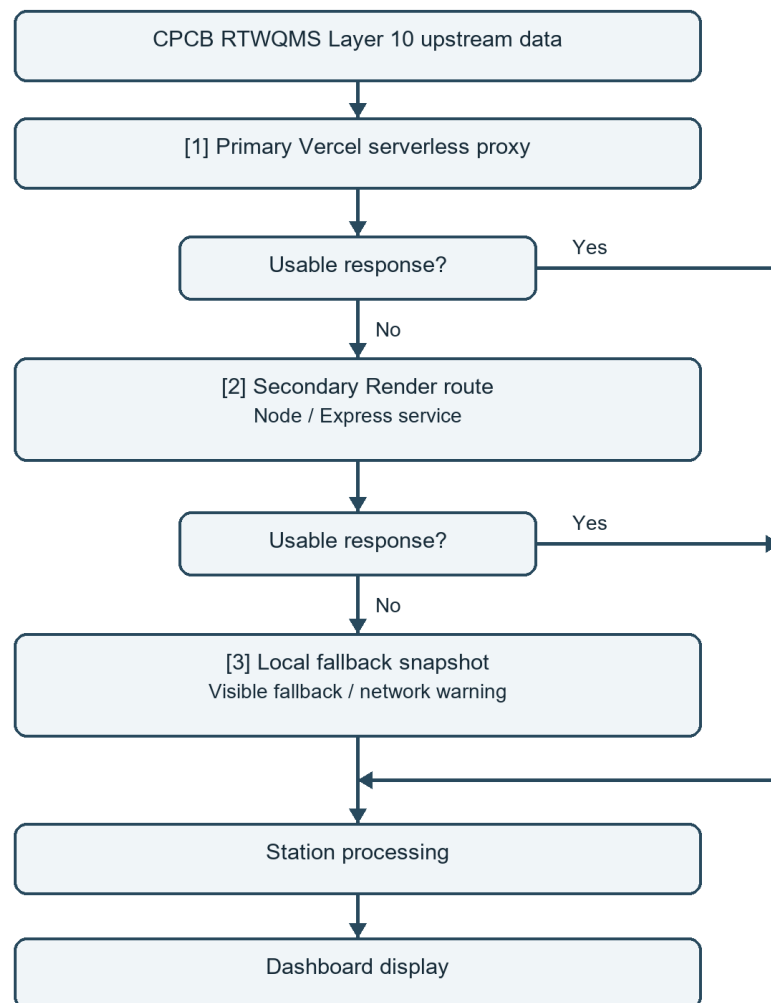
The deployed platform uses a multi-tier acquisition mechanism to reduce complete dependence on one application route. The preferred request is handled through a Vercel serverless proxy. If that route fails to return usable data, a secondary Node.js/Express service hosted on Render can be attempted. If online retrieval is unavailable, the application can load a deterministic local fallback snapshot.

The acquisition order is therefore:

Primary Vercel Proxy → Secondary Render Backend → Local Fallback Dataset

The fallback dataset is intended to preserve interface continuity and demonstrate the monitoring workflow; it is not a replacement for current telemetry. The interface can display a warning or status change when fallback data are active.

The client periodically refreshes the dashboard. A frontend polling interval of approximately 60 seconds should not be interpreted as evidence that every physical upstream station generates a new measurement every 60 seconds. The academically appropriate description is **periodically refreshed** or **near-real-time** monitoring.



Frontend polling does not establish upstream measurement frequency.

Figure 2. Multi-tier data acquisition and failover workflow used to maintain application continuity when the preferred telemetry route is unavailable.

6. Data Processing Methodology

6.1 Station Aggregation

The upstream feed contains measurement-oriented records. A station can therefore appear repeatedly, with separate records corresponding to different environmental parameters. The application groups incoming records by station identity and converts them into station-centric objects.

A processed station object may contain:

station identifier and station code;

station name;

state or union territory;

latitude and longitude;

source timestamp;

inferred river name;

hydrological measurements;

physicochemical measurements; and

application-level assessment outputs.

This step converts a fragmented record stream into a structure suitable for dashboard presentation.

6.2 Parameter Normalization

Environmental parameters can appear under different aliases. The application maps these identifiers into canonical internal names before rendering or calculating the composite score. For example, river stage can be represented by aliases such as “River Stage,” “S,” or “Water Level.” Normalization enables one set of dashboard and calculation rules to operate across source variations.

6.3 River-Name Inferencing

The source feed does not always expose a clean standardized river_name field. The application therefore derives river information from available station metadata using keyword dictionaries, known landmark/location terms, regular-expression rules, and fallback basin labels. This processing supports the State → River → Station navigation hierarchy.

7. Environmental Parameters and Assessment

The public dashboard presents twelve principal hydrological and physicochemical parameters.

Table 2. Monitored Environmental Parameters

No.	Parameter	Typical Display Unit	Monitoring Role
1	Water Level / River Stage	m above MSL	Hydrological-stage observation
2	Water Depth	m	Local water-column depth
3	pH	pH unit	Acidity/alkalinity indicator
4	Water Temperature	°C	Physical water condition
5	Dissolved Oxygen (DO)	mg/L	Aquatic oxygen condition
6	Biochemical Oxygen Demand (BOD)	mg/L	Organic-load indicator
7	Chemical Oxygen Demand (COD)	mg/L	Chemical/organic demand indicator

No.	Parameter	Typical Display Unit	Monitoring Role
8	Turbidity	NTU	Suspended-material indicator
9	Electrical Conductivity	Source-reported conductivity unit	Ionic-content indicator
10	Nitrate	mg/L	Nutrient-related indicator
11	Chloride	mg/L	Chemical indicator
12	Total Organic Carbon (TOC)	mg/L	Organic-carbon indicator

Electrical conductivity is retained in the source-reported conductivity unit because the available source materials do not establish a consistently normalized unit.

7.1 River-Stage Observation

River stage is displayed as elevation relative to Mean Sea Level (MSL). It should not be confused with local water depth. A high MSL value at one geographic location is not inherently more dangerous than a lower value at another because meaningful flood interpretation requires station-specific warning and danger thresholds.

The current implementation does **not** integrate Central Water Commission warning levels, danger levels, Highest Flood Levels, discharge, rainfall-runoff models, or predictive flood forecasting. The correct description is therefore **river-stage monitoring and hydrological-stage observation**, not statutory flood warning.

7.2 Parameter-Level Status Interpretation

The interface provides direct visual interpretation for selected parameters. For CPCB Class-B water-quality criteria for organized outdoor bathing, pH is 6.5–8.5, dissolved oxygen is at least 5 mg/L, and BOD is at most 3 mg/L [7]. These principal criteria are used to support the dashboard’s visual condition coding for pH, DO, and BOD.

The interface uses three broad display states:

Green / compliant condition: the evaluated value satisfies the implemented reference condition;

Red / threshold-deviation condition: the value falls outside the implemented reference condition; and

Neutral / monitored condition: the parameter is displayed without a binary regulatory-compliance decision in the current interface.

This distinction is important because drinking-water, ecological, discharge, and surface-water criteria are not interchangeable.

8. Project-Specific Weighted Composite Water-Quality Score

Water-quality indexing has a long methodological history [11,12]. In the present system, however, a project-specific weighted composite score is calculated using nine water-quality parameters. The interface may label this output as a “WQI Score,” but academically it is treated as a project-specific weighted composite water-quality score, not as an official CPCB WQI and not as a standard Weighted Arithmetic Water Quality Index implementation.

Table 3. Composite-Score Weights

Parameter	Weight
Dissolved Oxygen	0.25
Biochemical Oxygen Demand	0.20
pH	0.15

Parameter	Weight
Chemical Oxygen Demand	0.10
Turbidity	0.08
Electrical Conductivity	0.07
Nitrate	0.05
Chloride	0.05
Total Organic Carbon	0.05
Total	1.00

For available parameters, the overall score is calculated as:

$$Q = \text{round}\left(\frac{\sum W_i q_i}{\sum W_i}\right)$$

where W_i is the configured parameter weight and q_i is the corresponding project-specific sub-score. If a participating parameter is missing, its weight is removed from the denominator used for available measurements.

The application categories are:

Table 4. Application Composite-Score Categories

Score Range	Application Category	Display Color
80–100	Good	Green
60–79	Moderate	Amber
40–59	Poor	Orange
0–39	Critical	Red

These categories are application-level interpretation classes and must not be represented as statutory CPCB Classes A–E.

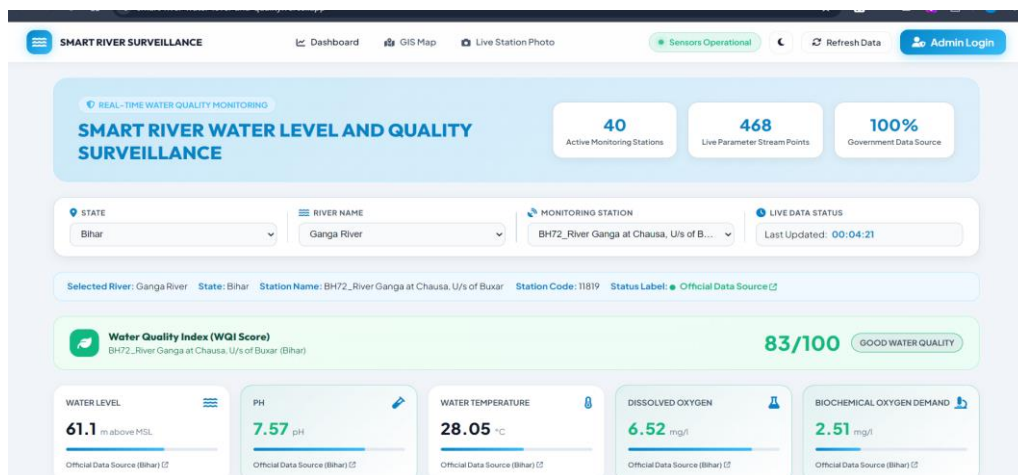


Figure 3. Public monitoring dashboard showing station selection, station metadata, project-specific composite water-quality score, and environmental parameter cards.

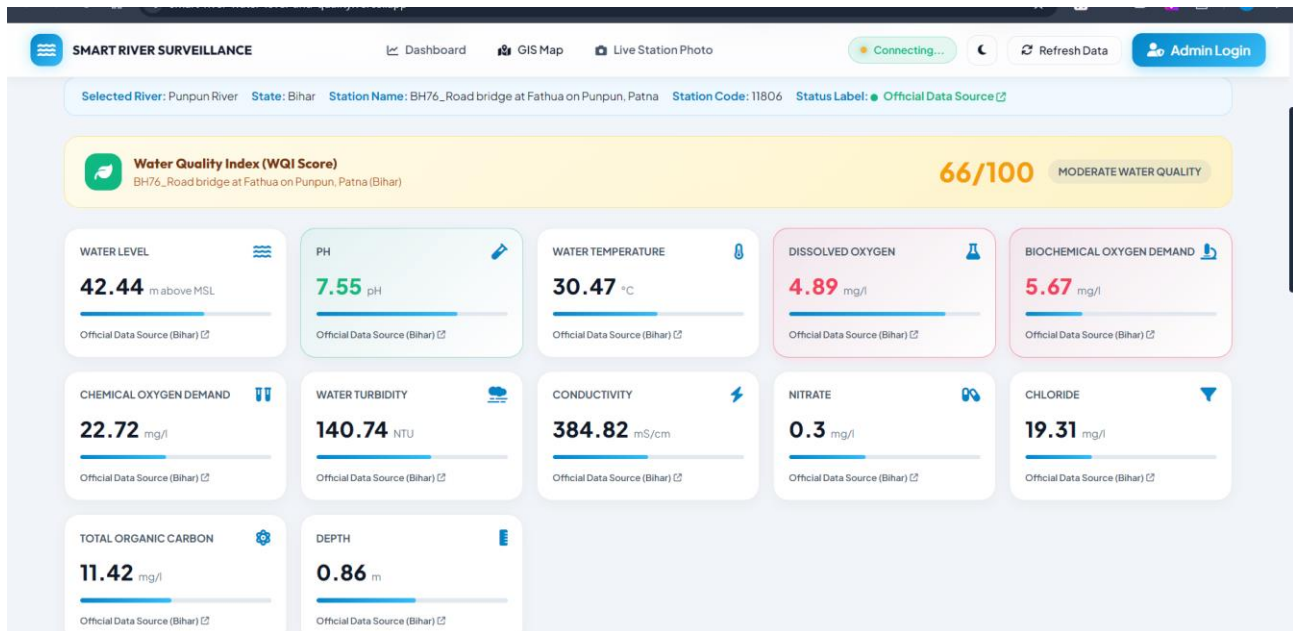


Figure 4. Visual decision-support mechanism demonstrating an application-level Moderate composite score together with parameter-specific compliant and threshold-deviation states.

The color-coded figure demonstrates why individual parameter interpretation and the overall composite score should be kept separate. A station may receive a Moderate composite score while specific parameters simultaneously show compliant or threshold-deviation conditions.

9. Web-GIS and Station Surveillance Imagery

9.1 Interactive Web-GIS

The geographic module uses Leaflet.js with OpenStreetMap tiles. Each monitoring station is represented using available coordinates and map markers. Users can navigate using State → River → Station filters or by selecting a station marker directly.

When the selected station changes, the interface updates the geographic position, station metadata, river-stage information, water-quality cards, composite score, status indicators, and station-associated photograph. The map therefore functions as an operational navigation component rather than a static illustration.

9.2 Station Surveillance Imagery / Ground-Context Verification

The platform incorporates station-associated still photographs to provide physical context alongside telemetry and geographic information. The supplied project archive contains **exactly 23 station photographs**. These images cover different monitoring environments and installation contexts, including floating platforms, bridge-associated sites, fixed monitoring enclosures, and solar-panel-equipped installations.

When a user selects a station with a mapped photograph, the image is shown together with station metadata. Station-code mapping, local image assets, caching/preloading behavior, and fallback handling are used to improve image availability.

Although the website labels this feature “**Live Station Monitoring Photo**,” the current implementation should be interpreted as periodically refreshed or station-associated **still imagery**, not as continuous CCTV or live-video streaming.

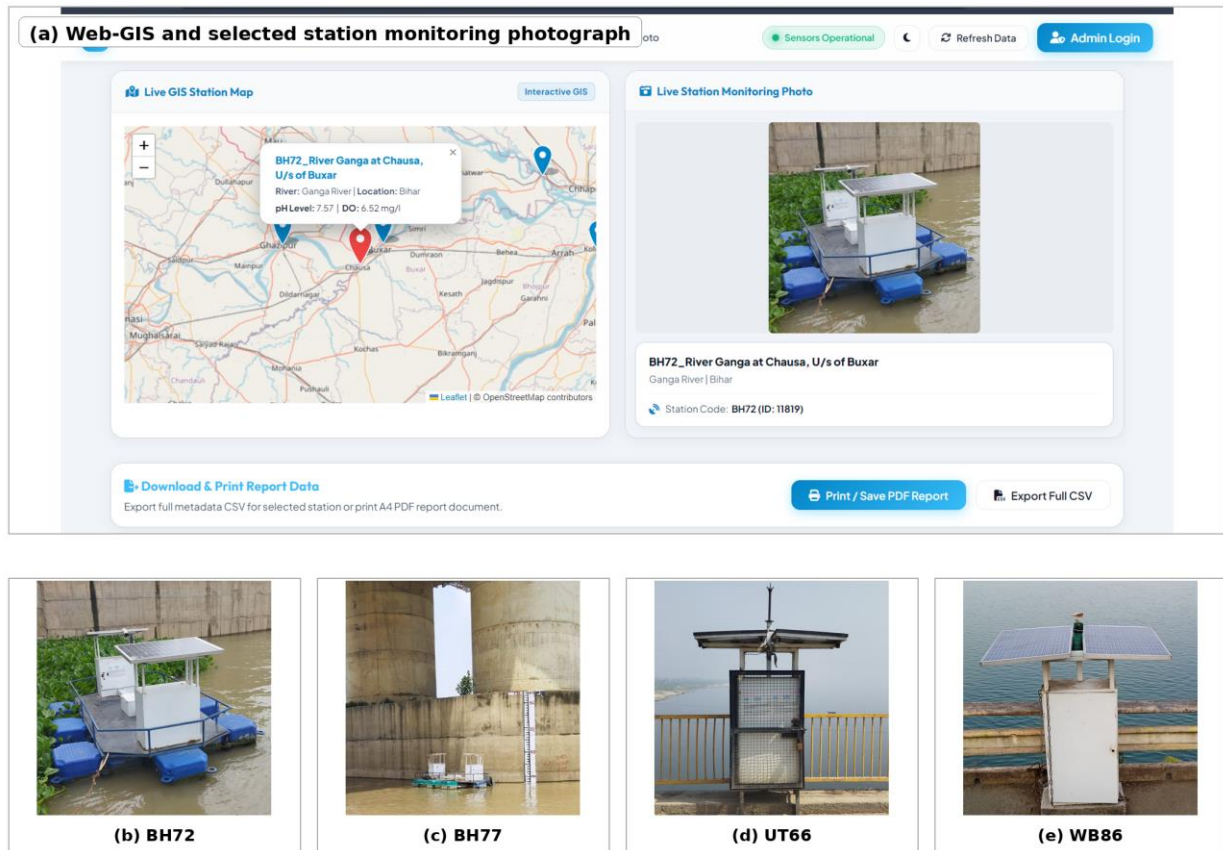


Figure 5. Station-centric spatial and visual surveillance: (a) integrated Web-GIS and selected station monitoring photograph; (b–e) representative monitoring-station photographs selected from the 23-image station archive, illustrating different physical monitoring environments and installation configurations.

10. Administrative Monitoring Module

The Admin Panel extends the project beyond a read-only monitoring dashboard. Its functions include administrative access, local river-test entry, custom river and station management, map-based coordinate selection, twelve-parameter entry, image upload or image URL entry, directory management, local parameter overrides, and administrative export.

10.1 Local Field/Laboratory Observation Entry

A useful scenario is a river, tributary, or community sampling point that is not represented in the upstream automatic telemetry network. An authorized administrator can obtain measurements externally using appropriate field equipment or laboratory testing and then enter the resulting observations into the platform.

A typical workflow is:

1. collect or obtain a representative river sample;
2. conduct appropriate field or laboratory measurements;
3. open the Admin Panel;
4. enter river, state/city, station/testing-spot, and station-code information;
5. select geographic coordinates using the interactive map;
6. enter available monitored parameter values;
7. upload a station/sampling-location photograph or supply an image URL; and

8. publish the custom observation/station into the local application view.

This produces a hybrid information model:

Upstream Government Telemetry + Administrator-Entered Field/Laboratory Observations

The platform itself does not validate whether the external sampling and laboratory method is scientifically sufficient. Reliability still depends on sampling protocol, analytical method, calibration, instrumentation, and quality assurance. A future provenance model should therefore store laboratory name, instrument, calibration, operator, analytical method, observation timestamp, and verification status.

10.2 Controlled Scenario Testing

Administrator overrides may also be used for controlled what-if or stress-testing of the interface. For example, DO can be reduced or BOD increased to confirm that parameter status colors, composite score behavior, map popups, and interface synchronization respond correctly. Such overrides do not modify the upstream CPCB dataset.

The screenshot displays the 'Add New India River Water Testing Entry' form within the SMART RIVER SURVEILLANCE application. The interface includes a top navigation bar with links for 'Public Dashboard' and 'Admin Control Panel', and a status bar indicating 'Admin Authenticated'. The main form area is titled 'SMART RIVER WATER LEVEL AND QUALITY SURVEILLANCE' and features three summary cards: '14 Managed Rivers', '6 States Covered', and '40 Active Stations'. Below these, there are tabs for 'Add India River Water Test', 'Rivers Directory', 'States Directory', and 'All Registered Stations'. The 'Add India River Water Test' tab is active, showing a form to 'Add New India River Water Testing Entry'. The form includes fields for 'RIVER NAME' (e.g., Kanhan River / Nag River), 'STATE / CITY' (e.g., Nagpur, Maharashtra), 'STATION / TESTING SPOT NAME' (e.g., Kanhan Intake Spot), and 'STATION CODE (ID)' (e.g., NGP_KANHAN_01). There is a section for 'LIVE STATION MONITORING PHOTO UPLOAD' with options to upload a file or enter a web image URL. A map is provided for selecting a river pin spot, with a tooltip indicating 'Selected River Pin Spot' and coordinates (Lat 21.1458, Lng 79.0882). Below the map, there is a section for 'Tested Water Quality & Level Readings (12 CPCB Parameters)' with input fields for various parameters: Water Level (m above MSL), pH (pH), Water Temperature (°C), Dissolved Oxygen (mg/l), Biochemical Oxygen Demand (mg/l), Chemical Oxygen Demand (mg/l), Water Turbidity (NTU), Conductivity (uS/cm), Nitrate (mg/l), Chloride (mg/l), Total Organic Carbon (mg/l), and Depth (m). A large blue button at the bottom of the form reads 'Publish Tested River Data & GIS Map Pin to Live Dashboard'.

Figure 6. Administrative interface for creating a locally monitored river station using externally measured observations, map-based coordinates, station imagery, and environmental parameter entry.

11. Responsive Interface and Theme Adaptation

The platform was designed for desktop, laptop, tablet, and mobile access using responsive CSS layouts, grid behavior, and media queries. On narrower screens, navigation remains accessible, parameter cards stack, the GIS/imagery split layout collapses vertically, and report controls remain available.

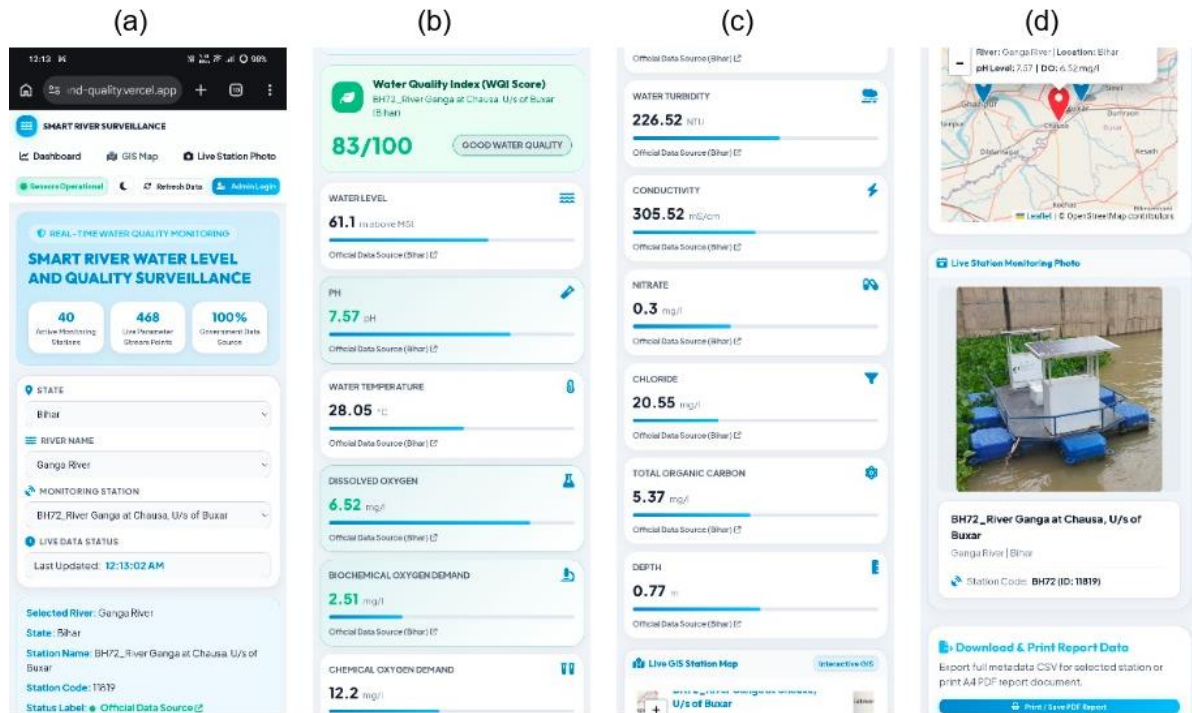


Figure 7. Responsive mobile implementation of the Smart River surveillance platform showing adaptive navigation, environmental parameter cards, GIS mapping, station imagery, and reporting controls. Panels (a–d) reproduce the mobile view from top to bottom.

The application also supports light and dark themes. Theme preference changes the interface presentation without changing the environmental data or calculations.

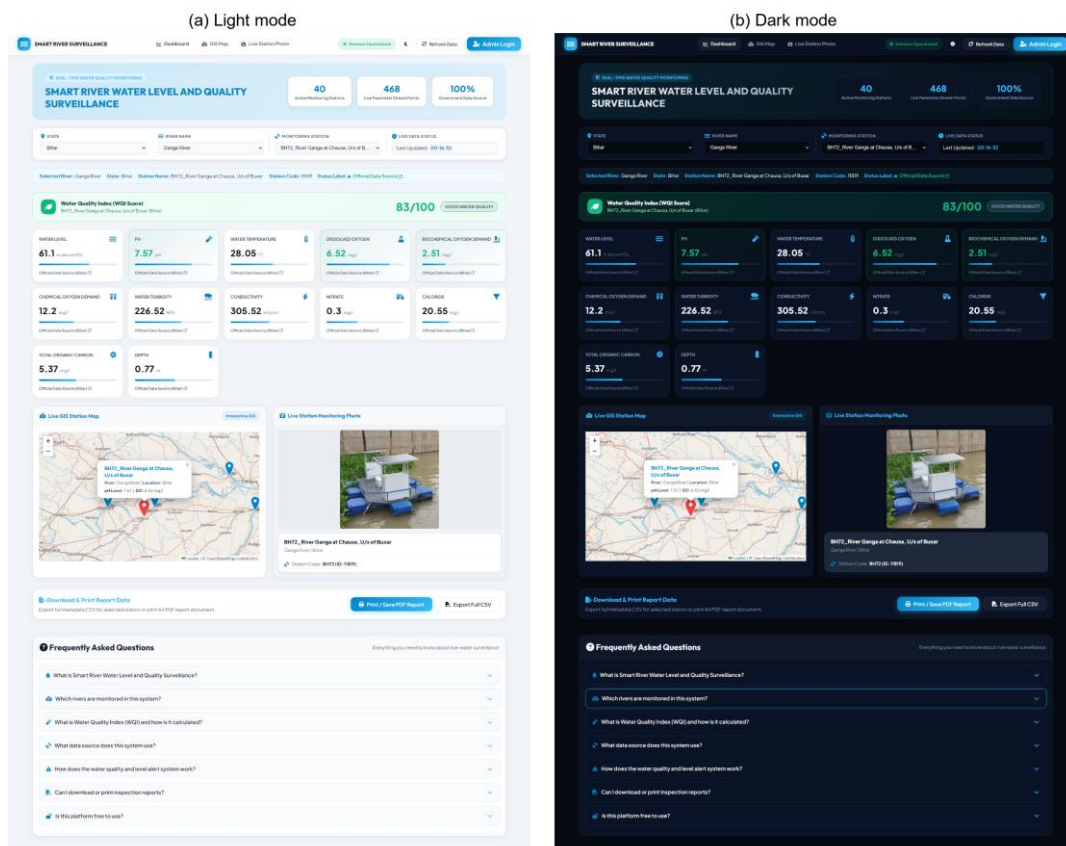


Figure 8. Light and dark interface modes demonstrating theme adaptability while preserving the same monitoring functionality and information hierarchy.

12. Reporting and Data Export

12.1 Dashboard-Generated Environmental Monitoring Report

The public interface includes a **Print / Save PDF Report** function. The implementation invokes the browser's native print workflow and uses print-specific CSS to hide unnecessary interactive elements and create an A4-oriented monitoring report. A user can print the result or select the browser's "Save as PDF" option.

The report contains selected station information, inspection timestamp, river/location information, the application-level composite score, and environmental parameter values. It is a **dashboard-generated environmental monitoring report** and should not be described as an official regulatory certificate.

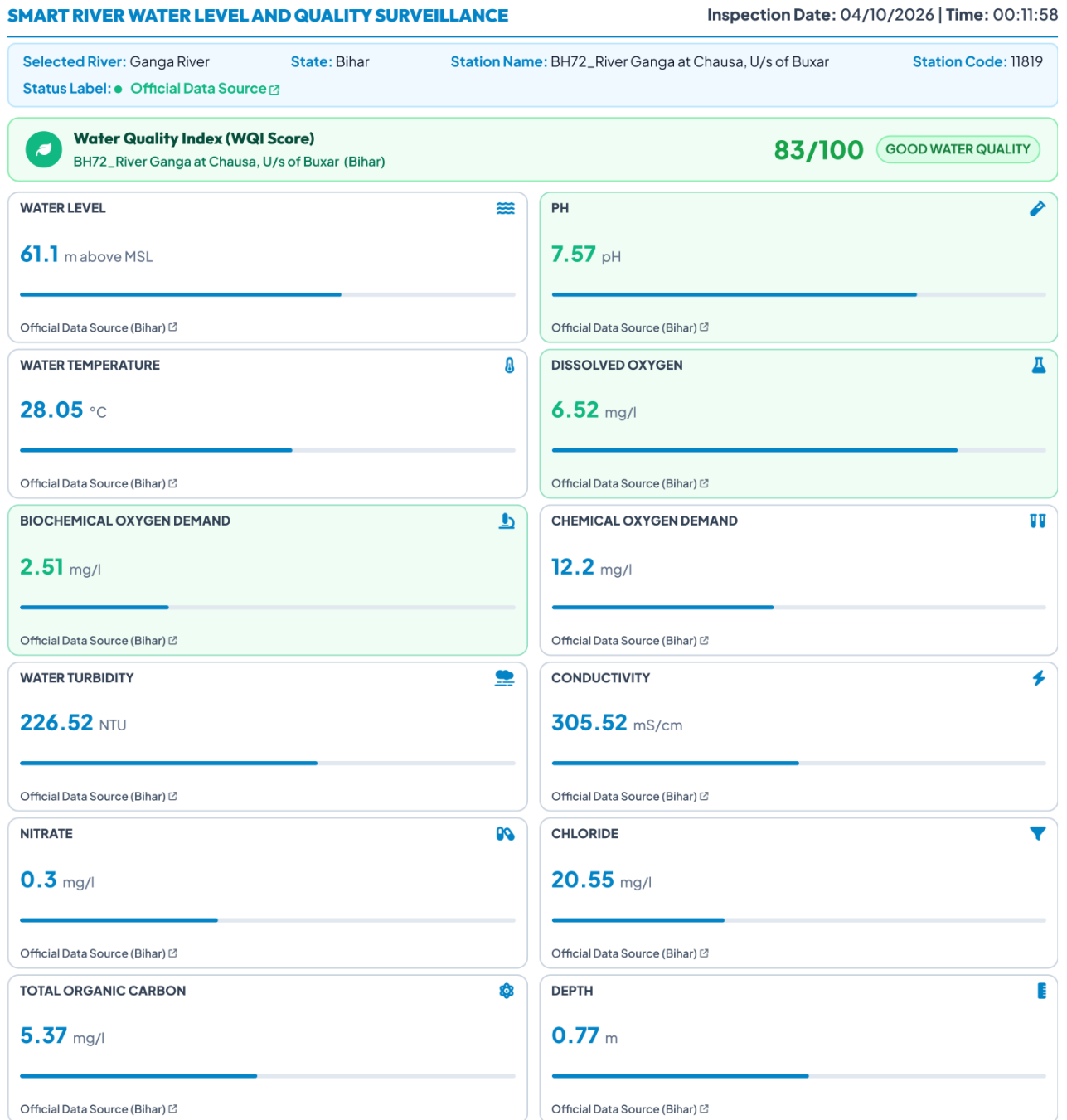


Figure 9. Dashboard-generated environmental monitoring report containing station metadata, the project-specific composite assessment, river-stage information, and monitored water-quality parameters.

12.2 CSV Export

The public dashboard supports CSV export for the currently selected station. Exported information can include station/location metadata, parameter name, value, unit, timestamp, and source/status information. Administrative functionality provides broader metadata or station-management export. CSV output can be used subsequently in spreadsheet or analytical tools such as Excel, Python/Pandas, R, or SPSS.

13. Evaluation Methodology and Results

13.1 Functional Evaluation

The implemented system was evaluated by verifying whether each major software capability was operational within the project environment.

Table 5. Functional Evaluation of the Developed Platform

Function	Evaluation Result
Environmental telemetry retrieval	Implemented
Station aggregation	Implemented
Parameter normalization	Implemented
River-name inference	Implemented
Twelve environmental parameter cards	Implemented
River-stage observation	Implemented
Project-specific composite score	Implemented
Parameter color coding	Implemented
Web-GIS mapping	Implemented
State–River–Station filtering	Implemented
Station imagery	Implemented
23-image station-photo archive	Verified in supplied project assets
Light/dark themes	Implemented
Responsive mobile/desktop layout	Implemented
Multi-tier failover	Implemented
Print/Save-PDF report	Implemented
Selected-station CSV export	Implemented
Local river-test entry	Implemented
Custom station creation	Implemented
Controlled parameter testing	Implemented

Function	Evaluation Result
SMS/e-mail/push notification	Not implemented
CWC statutory flood thresholds	Not implemented
Persistent genuine historical time-series database	Not implemented

13.2 Evaluated Snapshot

The processed project snapshot contains **468 telemetry records across 40 distinct monitoring stations**. The following numerical summary was reported in the technical project dossier.

Table 6. Dossier-Reported Summary of the Analyzed Project Snapshot

Parameter	Minimum	Maximum	Reported Snapshot Mean
Water Level	12.40 m MSL	284.15 m MSL	68.42 m MSL
pH	6.82	8.45	7.64
Dissolved Oxygen	3.12 mg/L	8.95 mg/L	6.48 mg/L
Biochemical Oxygen Demand	1.40 mg/L	6.80 mg/L	2.74 mg/L
Turbidity	12.4 NTU	490.0 NTU	145.8 NTU
Water Temperature	24.8 °C	33.5 °C	29.8 °C
Composite Score	52	91	76.4

The values in Table 6 are dossier-reported analyzed snapshot values. The underlying processed CSV was unavailable for independent verification; the summary therefore does not constitute a recalculation from raw observations.

The dossier further reported that approximately 87.5% of summarized DO observations were at or above 5 mg/L and approximately 75% of summarized BOD observations were at or below 3 mg/L. These percentages must be interpreted only as claims about the analyzed project snapshot, not as nationwide assessments of Indian rivers.

13.3 Interpretation of River-Stage Results

The wide river-stage range reflects differences in station elevation and gauge context. A water-surface elevation of 200 m MSL at one station is not inherently more dangerous than 20 m MSL at another. Meaningful flood interpretation requires local station thresholds. Consequently, the primary result of the hydrological module is the successful integration of river-stage observation into the same workflow as water-quality monitoring.

13.4 Interpretation of Water-Quality Results

The project snapshot contains both relatively favorable and potentially concerning individual observations. The key software result is that these differences are exposed immediately through visual parameter states and the composite score. For example, the supplied color-coded dashboard screenshot demonstrates a Moderate composite score while pH is displayed in a compliant state and DO/BOD are shown as threshold-deviation conditions.

13.5 Composite-Score Results

The dossier-reported project-specific composite score ranged from **52 to 91** with a reported mean of **76.4**. Under the application's own classification scheme, a value of 76.4 lies in the Moderate category. Since the score uses project-specific weights and sub-score functions, it must be interpreted as application-level decision support rather than a statutory water-quality classification.

14. Discussion

The developed platform demonstrates that environmental-monitoring engineering does not end at the sensor or telemetry layer. Raw observations require processing and contextualization before they become useful to a broad range of users.

The Smart River workflow performs the following transformation:

raw records → station objects → normalized parameters → inferred river organization → application-level interpretation → geographic visualization → user interaction → report/export.

One contribution is the convergence of hydrological and physicochemical information within one interface. River stage provides physical hydrological context, while the water-quality parameters describe chemical and physical water conditions. Their integration produces a broader station-level view while preserving the fact that these variables have different regulatory and scientific interpretations.

A second contribution is spatial integration. Users are not limited to a flat table of stations; they can navigate by geography, river, station, or map marker. This improves the relationship between environmental data and the physical place at which measurements were produced.

The color-coded parameter mechanism reduces interpretation effort for selected parameters. Instead of requiring users to compare every pH, DO, or BOD value with a separate reference table, the interface provides immediate visual cues. At the same time, parameters without an implemented binary rule remain neutral, avoiding an unsupported claim of universal regulatory compliance.

The station-imagery module adds another layer of context. The verified 23-image archive demonstrates that monitoring photographs are associated with multiple station environments rather than a single illustrative location. These still images can help users understand the physical monitoring context, although they should not be confused with live CCTV streams.

The multi-tier data-acquisition strategy addresses an application-availability problem. If one preferred route is unavailable, a secondary service or local snapshot can maintain interface continuity. The fallback mode is therefore an application-resilience mechanism, not a claim that the underlying environmental measurements remain current during an upstream outage.

The Admin Panel extends the platform beyond a fixed read-only viewer. It allows local field/laboratory observations to be represented when automatic telemetry is unavailable for a location. This capability is potentially useful for educational institutions, municipalities, laboratories, or community monitoring programs, provided that future deployments implement stronger provenance and verification controls.

For research integrity, the platform should maintain a clear distinction among **government-originated telemetry**, **administrator-entered field/laboratory observations**, **fallback snapshot data**, and **controlled simulation/override values**. Future database design should encode this provenance explicitly.

15. Key Contributions

The principal contributions of the developed work are:

1. **Unified river-stage and water-quality surveillance** within a single station-centric interface.
2. **Station aggregation** that converts fragmented measurement records into coherent monitoring-station objects.
3. **Parameter normalization** for heterogeneous source aliases.
4. **River-name inferencing** for building usable State–River–Station navigation from imperfect metadata.
5. **Interactive Web-GIS navigation** synchronized with station filters and station data.
6. **Project-specific weighted composite assessment** for simplified multiparameter interpretation.
7. **Parameter-level visual condition coding** for selected CPCB Class-B reference parameters.
8. **Station surveillance imagery / ground-context verification** supported by a verified 23-photo archive.
9. **Multi-tier application resilience** through primary, secondary, and local fallback routes.
10. **Hybrid monitoring capability** that allows upstream telemetry to be supplemented by locally measured field/laboratory observations.
11. **Administrative what-if testing** without modifying the upstream source dataset.
12. **Responsive desktop/mobile operation** and light/dark theme support.
13. **Dashboard-generated printable environmental monitoring reports.**
14. **CSV export** for offline analysis and documentation.

16. Limitations

The current implementation has several limitations.

First, the freshness of network telemetry depends on the upstream monitoring infrastructure and its availability. The platform can preserve interface continuity through fallback data but cannot create new physical measurements during an upstream outage.

Second, a persistent historical time-series database is not currently integrated. The application primarily operates on the latest available snapshot. Any deterministic or generated trend values present in development code should not be represented as genuine historical measurements.

Third, the project does not integrate CWC warning level, danger level, Highest Flood Level, discharge, rainfall, hydrodynamic routing, or predictive flood forecasting.

Fourth, external alert channels such as SMS, e-mail, WhatsApp, mobile push notification, or webhooks are not implemented. Current warnings are visual within the dashboard.

Fifth, biological parameters such as fecal coliform and total coliform are not part of the current automated parameter workflow.

Sixth, the composite score is project-specific and should not be presented as an official CPCB WQI or standardized WAWQI.

Seventh, administrator authentication and local data storage are prototype-level. Custom station information, image changes, and parameter overrides may rely on browser-local storage rather than a centralized multi-user database.

Eighth, administrator-entered observations are only as scientifically reliable as the external field/laboratory method used to generate them. The platform presently does not enforce laboratory QA/QC or complete measurement provenance.

Finally, accessibility can be improved further through more complete ARIA semantics, focus management, keyboard interaction testing, and formal accessibility evaluation.

17. Future Scope

17.1 Persistent Historical Time-Series Storage

A centralized database should store each incoming observation with source metadata and timestamp. This would enable genuine hourly, daily, monthly, seasonal, and long-term trend analysis.

17.2 CWC Hydrological Integration

Future development could integrate station-specific warning levels, danger levels, Highest Flood Levels, discharge, and rainfall information where authoritative interfaces permit. This would allow river-stage values to be interpreted relative to local hydrological thresholds.

17.3 Predictive Analytics

After a sufficiently long and verified historical dataset has been accumulated, predictive models could investigate DO depletion, BOD increases, turbidity anomalies, pollution events, or hydrological changes. Predictive claims should only be introduced after validation against genuine historical observations.

17.4 Automated External Alerts

Critical conditions could eventually trigger controlled SMS, e-mail, mobile push notifications, or authorized webhooks.

17.5 Centralized Local-Data Management

Administrator-entered local monitoring stations should be moved from browser-local storage into a centralized database with user roles and audit history.

17.6 Measurement Provenance

Local observations should store sample ID, sampling date/time, operator, laboratory, analytical method, instrument, calibration information, uploaded laboratory report, and verification status.

17.7 Stronger Authentication and Auditability

Future deployments should use server-side authentication, password hashing, role-based authorization, secure sessions, and immutable administrative audit logs.

17.8 Satellite and Remote-Sensing Integration

Remote-sensing information could supplement point observations with broader spatial environmental context.

17.9 Institutional and Community Monitoring

Universities, laboratories, municipalities, and authorized citizen-science programs could contribute verified local observations through a moderated submission workflow.

17.10 Progressive Web Application

A PWA or dedicated mobile application could support offline caching, improved field navigation, and selected notification features.

18. Conclusion

This research presented **Smart River Water Level and Quality Surveillance**, a software-based Web-GIS environmental monitoring and decision-support platform designed to integrate hydrological and physicochemical river observations within one station-centric interface.

The project demonstrates that meaningful engineering value can be created after environmental measurements have already been generated. The platform performs station aggregation, parameter normalization, river-name inferencing, project-specific composite assessment, geographic visualization, parameter-level visual interpretation, station-imagery integration, resilient data retrieval, administrative data management, reporting, and CSV export.

A major contribution is the integration of river stage and water quality into a common monitoring workflow. The Web-GIS provides geographic context while State–River–Station filters make distributed monitoring locations easier to navigate. Parameter cards and the composite score simplify interpretation while preserving the distinction between individual threshold conditions and overall application-level classification.

The verified 23-image station archive strengthens the physical-context component of the platform by associating environmental records with representative station imagery. The Admin Panel further extends the system by supporting locally measured river observations, custom station creation, map-based placement, image management, and controlled scenario testing.

The system also maintains important technical boundaries. It does not claim an independent physical sensor deployment, does not provide statutory flood forecasting, does not currently provide automated off-site emergency notifications, does not provide genuine historical time-series analysis, and does not present its project-specific composite score as an official CPCB regulatory index.

Within these boundaries, the developed platform demonstrates a practical approach for transforming heterogeneous environmental observations into an accessible, resilient, geographically organized, extensible, and user-oriented river-surveillance environment.

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