Annexure-I: Technology Details

वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद
CSIR-INDIA

1. Introduction

"CSIR HAR-GHAR-JAL Smart Water Measurement and Monitoring Suite" is an IoT-enabled framework developed by JJM and CSIR to demonstrate and deploy innovative, cost-effective, and intelligent technologies for measuring and monitoring water service delivery in rural settings, ensuring safe and sustainable water resource management at pilot locations.

This framework provides an end-to-end solution for measuring water quantity, quality, and regularity. It offers both off-the-shelf, commercially available and CSIR-developed water technologies integrated with future-proof communication protocols and technologies for SMART rural water management. The major work packages involved in the proposed project include Sensor Systems, IoT, Cloud & Data Analytics, and Dashboard & Visualization aimed at developing and demonstrating SMART water measuring and monitoring systems for rural settings in India.

The CSIR's developed IoT-enabled framework will overcome obstacles hindering the PAN-India upscaling of IoT-based water management through sensor innovations and cost reduction. The availability of such an indigenous sensor system will lead to a drastic cost reduction (40-50%) and decrease downtime caused by outages/breakdowns of the sensors. Additionally, it will facilitate local repair and replacement support, unlike imported sensors.

After successfully implementing the framework for pilot studies at the lab scale - CSIR aims to transfer its expertise to MSMEs, consultancy firms, government organisations, etc., possessing engineering and scientific knowledge, a strong financial background, and sufficient experience in implementing large-scale end-to-end IoT solutions. CSIR has decided to issue a non-exclusive license for three years to replicate this expertise nationwide.

2. About CSIR

The Council of Scientific and Industrial Research (CSIR) is India's premier national R&D organisation, dedicated to scientific research and technological innovation across various domains. Among its many labs, The Central Scientific Instruments Organisation (CSIO) specialises in developing advanced scientific instruments and technologies. The Central Salt & Marine Chemicals Research Institute (CSMCRI) focuses on research in areas related to salt, marine chemicals, and marine biotechnology. The Central Electronics Engineering Research Institute (CEERI) is renowned for contributing to electronics and electrical engineering research. The Central Mechanical Engineering Research Institute (CMERI) is dedicated to

research in mechanical engineering and related fields. The National Environmental Engineering Research Institute (NEERI) conducts environmental science and engineering research.

In the developed IoT-enabled framework water monitoring solution, CSIO developed IoT nodes and Gateways. Further, CSIO, CSMCRI and CEERI have developed sensor systems to ensure accurate data collection. CMERI has contributed to the cloud solution, facilitating data storage and analysis. NEERI has conducted sensor calibration and developed the dashboard for data visualisation. Additionally, CEERI has designed and implemented the power system to ensure the uninterrupted operation of the IoT infrastructure. Together, these institutions' contributions form a comprehensive and integrated approach to IoT-enabled water service delivery monitoring solutions, addressing various aspects of data collection, analysis, and management for enhanced efficiency and performance.

3. About CSIR's- HAR-GHAR-JAL-IoT-enabled Integrated Water Service Delivery Measurement and Monitoring Suite

The CSIR's IoT-enabled Water Service Delivery Monitoring Suite comprises five modules. Details of five modules are provided below:

Module 1: Sensor Systems (Developed by CSIO, CSMCRI, NEERI): This module focuses on indigenous sensor systems customised for measuring and monitoring water quality and quantity in piped-water distribution systems. It employs transduction schemes, including electrochemical and optical principles, adaptable to various scenarios (flow by/flow-through/immersed).

Module 2: IoT (Developed by: CSIO): This module connects sensor nodes/Remote Terminal Units (RTUs) to cluster data loggers, then to central data loggers/gateways, following a star-of-star topology. Central data loggers transmit data to state clouds, which are then forwarded to the central Cloud.

Module 3: Cloud and Data Analytics (Developed by CMERI): This module manages data collection and transmission to the Cloud, adhering to data standards and communication protocols. Using AI/ML it performs basic analytics such as descriptive statistics about various water quality and quantity parameters.

Module 4: Dashboard and Visualisation (Developed by NEERI): This module designs a web-based dashboard presenting data from sensors, field testing kits, and other sources in interactive charts and graphs. Customised for stakeholders at various levels, it integrates metadata, sensor data, and geo-data.

Module 5: Power Systems (Leads: CEERI) This module deploys power sources selected based on location, node power requirements, and ROI. Solar, battery, or charging modules power the network entirely.

More information about each of the modules is given in section 5 (Technical Specifications).

4. Features of JJM - CSIR - Har Ghar Jal

- Use of comprehensive in-house and off-the-shelf sensors, including pH, Turbidity, salinity, TDS, residual chlorine, nitrate, fluoride, and arsenic sensors, which have been tested, developed and demonstrated at lab-level
- All sensor performance is calibrated to ensure accurate and reliable data collection for smart water service delivery measurement and monitoring.
- IoT-RTUs-Gate ways facilitates seamless connectivity and data transmission between sensor nodes and central systems for IoT-enabled solutions.
- Cloud and data analytics solutions enable efficient data collection, storage, and analysis for informed decision-making in water management.
- A GIS-enabled web-based dashboard presents data from sensors, field testing kits, and other sources in interactive charts and graphs.
- Indigenous RISK-PiNET package for Pipe Condition Assessment, Contamination Risk Assessment, Replacement planning of Water Distribution network with Cost estimation
- Vulnerability assessment to fail - High, Medium, Low
- Performance index of the network and suggestions to improve service delivery
- Estimation of Contamination risk in each pipe - High, Medium, Low

5. Technical Specifications

The following specifications are included in the CSIR's-HAR-GHAR-JAL integrated water service delivery measurement and monitoring suite –comprising Sensor-nodes, Gateways, Cloud & Analytics, and Dashboard-visualization for measuring and monitoring quality, quantity and regularity.

Component 1: Ground Water Level Sensor (GWLS)

Lead Lab - CSMCRI

Groundwater water level sensors measure the static pressure of water proportionally to the water level in water bodies like tanks, wells, or tube wells. The water level measurement is based on a piezoresistive silicon element, and level information is transformed into standard current output linearly. It can be submerged directly into the water where the water column between the sensor head and water head is measured. The sensor offers reliable performance and can be used in outdoor applications.

Specifications (GWLS)	
Feature	**Principle:** Piezoresistive; The sensor offers reliable performance and can be used in outdoor applications.
Power Supply	10-30 VDC
Level Range	upto 100m
Accuracy	±0.25 % FS;
Operating temperature range	20 to 40°C
Output	4-20 mA
Sensor MoC	SS 316 diaphragm
Electrical	2-wire connection
Calibration and Testing	Calibration at the time of installation & periodic maintenance.
Protection	IP68

Applications	• Water level measurement in tanks, wells, and tube wells • Water level and control applications • Domestic tank water level monitoring and control • Pressure / Level measurement in tanks	

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Component 2: Optical Liquid Switch

Lead Lab - CSMCRI

Optical liquid switch is useful for detection of either absence or presence of water (clear or turbid) or monitor water level. The change in state from presence to absence of water or vice-a-versa triggers relay contact changeover-suitable for control application and also for remote audio/visual indication. The LED illuminated cap provides information on the absence of water locally; OFF – presence, ON – absence. It is a self-contained small device and can be used in any application or process directory employing water service.

	Specifications (Chlorine Sensor)
Feature	• Low cost • Low power demand • Compact design • No calibration/adjustment required • Pipe end-connection • Water proof • Easy installation • Suitable for various applications
Body / connection	CPVC / ¾″ SCH 40
Operating pressure	up to 2 Bar
Operating temperature	5°C to 60°C
Response time	< 1s
Repeatability	±1mm
Electronics	Hermetically sealed
Local indication	Red LED for absence of water
Output	Potential free relay contact 250Vac/220Vdc @ 2A
Power consumption	< 0.2 W at 5 Vdc
Operating Voltage	+5 - 6 Vdc

Electrical connection	Supply: red/black Output: green/yellow/blue
Applications	• Over-flow detection in tanks/reservoirs/pans/dams • Low-level or high-level monitoring with warning/control in tanks, salt farms • Empty pipe/blockage detection in water/drainage pipelines • Water level warning on vehicles • Alarm in events of water flow over bridge/road or under-pass for traffic management and safety • Water-level monitoring and alarm in open canal/stream/open drainage for vicinal population safety • Warning of high tides in coastal areas • Telecom outdoor stations, electrical substation, tunnels, basements for rainwater ingress alarm • Domestic appliances based on water application

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Component 3: Chlorine Sensor

Lead Lab - CSIO

The chlorine sensor measures residual chlorine concentration in water without using any additive reagent using a three-electrode setup. The sensor works by submerging this three-electrode setup into a sample, measuring the concentration with a high resolution and accuracy. The concentration is derived using a linear transformation of the current values received at a characteristic voltage. It is suitable for use in outdoor environments.

Specifications (Chlorine Sensor)	
Feature	**Principle:** Reagent Free, No Waste-stream Amperometric Chlorine Analyzer; **Reference Electrode:** Ag/AgCl**, Counter Electrode:** Platinum, **Working Electrode:** Gold
Power Supply	12 VDC
Measuring Range	0 to 1 mg/L
Resolution	0.1 mg/L
Accuracy	±5 % FS;
Response Time	< 2 Min
Operating temperature range	20 to 40°C
Body Type	**Shell material:** ABS thermoplastic polymer
Calibration and Testing	Calibration at the time of installation & periodic maintenance.
Applications	• Water supply contamination monitoring (domestic and industrial). • Disinfection Monitoring. • Control of Chlorine Dosage. • Compliance Monitoring. • Early Warning System to safeguard public health due to anomalies in the disinfection process.

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Component 4: Fluoride Sensor

Lead Lab - CSIO

Derived from fluorine, Fluoride is a common element in our surroundings and can be found in food, personal hygiene products, and drinking water. Although excessive fluoride intake (especially from drinking water) can cause dental and skeletal fluorosis and pose serious health hazards globally, it also strengthens teeth enamel and prevents cavities. Ensuring access to safe drinking water and protecting public health requires effective monitoring and mitigation measures. The World Health Organization has set the maximum permissible limit in drinking water at 1.5 mgL-1. Given these facts, accurately determining fluoride ions in water is paramount.

CSIR-CSIO developed a Fluoride sensing system that measures the photocurrent generated by the fluorescence from a fluorine-containing sample with Boron-doped Carbon dots. The photocurrent is linearly proportional to the concentration of Fluoride in the sample. The Fluoride sensing system comprises an optical assembly (a light source, sample holder, and detector unit) and an embedded circuit design which uses a microcontroller chip to control the sensor operation. An optical transducer is used to convert the fluorescence intensity into electrical signals. The change in the concentration of Fluoride in the sample results in a change in the detector's output. These variations are then linearised and calibrated in concentration (ppm). The final result regarding fluoride concentration is displayed on the touch screen for a given sample under measurement. The sensing system is operated with a small sample requirement of 1mL in a quartz fluorescence cuvette. Due to fast response time, the sensing system could be used for large-scale field applications.

Specifications (Fluoride Sensor)	
Feature	**Principle:** Optical- Fluorescence **Light Source:** UV-LED; **Detector:** Photodiode; **Sample Cell:** Quartz fluorescence cuvette 10 mm path length **Sample Volume Required:** 1 ml

	Measurement Mode: Offline
Power Supply	12 VDC
Measuring Range	5 to 50 mg/L
Resolution	5 mg/L
Accuracy	±2 % FS;
Response Time	< 10 Sec
Operating temperature range	20 to 40°C
Body Type	**Shell material:** ABS thermoplastic polymer
Calibration and Testing	Calibration at the time of installation & periodic maintenance.
Applications	• Domestic tank water quality monitoring and control. • Water Fluoridation Monitoring is used to manage dosages and prevent tooth decay. • Fluoride monitoring to avoid overdose to prevent fluorosis. • Environmental Monitoring. • Compliance Monitoring.

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Component 5: Nitrate Sensor

Lead Lab - CSIO

Nitrate monitoring in potable water is essential to protect public health. Elevated nitrate levels can lead to methemoglobinemia, or "blue baby syndrome," especially in infants, and may also indicate contamination from agricultural runoff or wastewater, which can contain harmful pathogens and pollutants. Regular monitoring ensures that water quality standards are met and helps prevent potential health risks associated with nitrate exposure.

CSIR-CSIO, Chandigarh, developed a Nitrate Sensing System to detect nitrate concentration in potable water rapidly. The nitrate sensing system measures the photocurrent generated by the light emitted by the nitrate-containing sample upon absorbing UV. The photocurrent is linearly proportional to the nitrate concentration. To control the complete functioning of the nitrate sensing system, it uses a power-efficient, affordable, high-speed microcontroller (MCU) chip that processes the output light intensity into a corresponding concentration of nitrate in the water sample. The sensing system is operated with a small sample requirement of 3.5mL in an absorbance cuvette. Due to fast response time, the sensing system could be used for large-scale field applications.

	Specifications (Nitrate Sensor)
Feature	**Principle:** Optical – UV Absorbance **Light Source:** UV Lamp; **Detector:** Photodiode with filter; **Sample Cell:** Quartz cuvette 10 mm path length **Sample Volume Required:** 3.5 ml **Measurement Mode:** Offline
Power Supply	12 VDC
Measuring Range	1 to 100 mg/L
Resolution	1 mg/L

Accuracy	±2% FS;
Response Time	< 5 Sec
Operating temperature range	20 to 40°C
Body Type	**Shell material:** Aluminium
Calibration and Testing	Calibration at the time of installation & periodic maintenance.
Applications	• Domestic tank water quality monitoring and control. • Aquaculture monitoring to maintain optimum level of nitrate to maintain aquatic health. • Drinking water safety. • Agriculture monitoring to optimise nutrient levels. • Wastewater treatment in effluent streams.

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Component 6: Multiparameter Sensor (TDS, pH Turbidity)

Lead Lab - CEERI

A single sensor provides TDS, pH and Turbidity readings in a single setup. While the overall setup provides output in RS-485 MODBUS RTU format, the measurement paradigms use electrochemical and optical methods. The sensor is capable of fast response time in providing a measurement after a request. It is suitable for field applications.

Specifications (Multiparameter Sensor-TDS, pH, Turbidity)	
Feature	**Principle:** **TDS:** Voltammetry; **pH:** Ion Selective Electrode; **Turbidity**: IR Nephelometry
Power Supply	5 VDC
Measuring Range	**pH:** 0 to 14; **TDS:** 0 to 10000 ppm; **Turbidity:** 0 to 1000 NTU;
Resolution	**pH:** 0.1 pH; **TDS:** 1 ppm; **Turbidity:** 0.01 NTU;
Accuracy	**pH:** ±0.2 pH; **TDS:** ±5% FS; **Turbidity:** ±0.5 NTU;
Response Time	90% in 5 sec
Operating temperature range	0 to 50°C
Output/Interface	**Digital output:** RS-485
Body Type	**Shell material:** ABS thermoplastic polymer
Calibration and Testing	Calibration and certification required at the time of supply.
Applications	• Surface Water Monitoring for rivers, lakes, ponds. • Groundwater Monitoring by sampling wells, boreholes and springs. • Drinking Water Source Protection to protect against contamination. • Wastewater Discharge Monitoring for effluent discharge monitoring.

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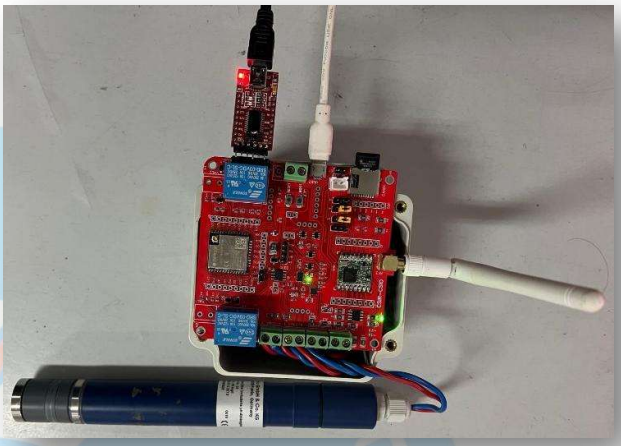
Component 7: JAL-IoT- Remote Terminal Unit (RTU)

Lead Lab - CSIO

The JAL-IoT communication module is capable to work with either a battery supply, or an external power supply capable to charge a battery while microcontroller performs operations to record data with the help of peripheral sensors. The module is capable to transmit data with the help of wireless channel using encryption, while storing the acquired data locally. It is also having an IP67 casing, providing protection from corrosion due to environment, making it portable and capable of field applications.



Specifications (JAL-IoT: RTU)	
Power Mechanism	Battery-based or power supply based
Networking	Cellular (GSM/GPRS, 4G/LTE) or LoRa or Wi-Fi
Communication Protocol	Secured transmission of telemetry via MQTT.
Data Transmission	15 min data transmission for power-supply based RTU / 2-times a day for battery powered RTUs
Data Backup	Memory card for storing data for a minimum of 30 days in case of power failures / loss of connectivity
Body Type	IP67
Applications	• Surface Water Monitoring for rivers, lakes, ponds. • Groundwater Monitoring by sampling wells, boreholes and springs. • Drinking Water Source Protection to protect against contamination. • Wastewater Discharge Monitoring for effluent discharge monitoring. • Aquatic Ecosystem Monitoring for aquatic health.

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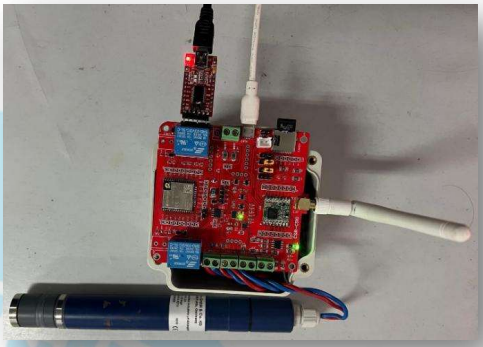
Component 8: JAL-IoT- Gateway Device

Lead Lab - CSIO



The gateway module can work with either a battery or an external power supply capable of charging a battery. At the same time, the microcontroller performs operations to record data with the help of peripheral sensors to a cloud dashboard. The module can transmit data with the help of a wireless channel using encryption while storing the acquired data locally. It can be networked with other remote terminal units to receive data and pass it to a cloud dashboard. It also has an IP67 casing, providing protection from corrosion due to the environment, making it portable and capable of field applications.

Specifications (JAL-IoT: Gateway)	
Features	Output: Wi-Fi, GSM/GPRS Hardware support for precise timestamping Protective Casing: IP67
Power Mechanism	Power supply/battery
Networking	RF (e.g., LoRa) / Wi-Fi / for Connecting with nodes; Cellular (GSM/GPRS, 4G/LTE) or Wi-Fi for connecting to Cloud/server
Communication Protocol	Secured transmission of telemetry via MQTT.
Data Transmission	15-minute data transmission for power-supply based RTU / 2 to 4-hour data transmission on battery.
Data Backup	Memory card for storing data for a minimum of 2 months in case of power failures
Applications	• Surface Water Monitoring for rivers, lakes, and ponds. • Groundwater Monitoring by sampling wells, boreholes, and springs. • Drinking Water Source Protection to protect against contamination. • Wastewater Discharge Monitoring for effluent discharge monitoring. • Aquatic Ecosystem Monitoring for aquatic health. • Datalogging locally and on Cloud.

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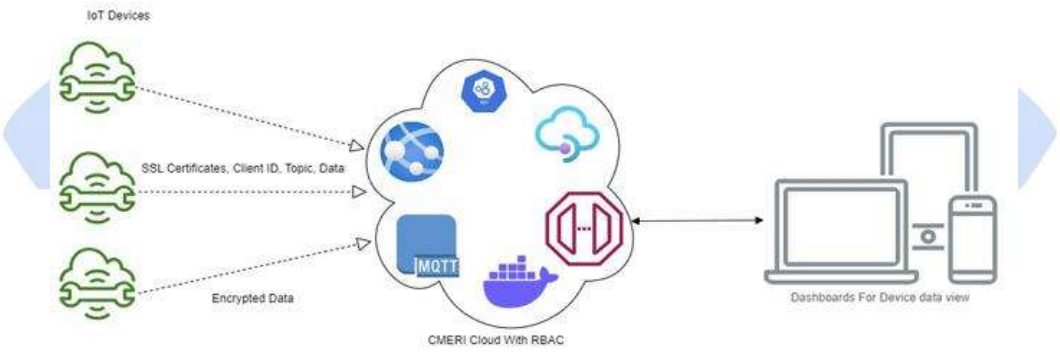
Component 9: CSIR-Megha NJJM Cloud and Data Analytics Module

Lead Lab - CMERI

The IoT cloud platform has been developed per the specification of National Jal Jeevan Mission (Har Ghar Jal) released by NJJM, Department of Drinking Water and Sanitation, Ministry of Jal Shakti, Govt. of India. The Cloud is meant to be deployed in any district/state/private data centre that would capture the IoT data on the quality, quantity, and regularity of water supply in rural/ urban areas. To achieve interoperability between the IoT nodes, Gateway, and Dashboard of different OEMs, industry-standard IoT protocols have been adopted and deployed after augmenting them with different security and validation modules. The CSIR-Megha NJJM cloud has IoT-specific dedicated features, allowing it to validate and accept real-time data from different IoT nodes and Gateways only in an encrypted format. All the communications between nodes are signed with 256-bits SSL certificate for proper data encryption. Our cloud software module also provides features to handle highly scalable data storage systems. The Cloud also provides fully authenticated APIs features for securely feeding live and historical raw data and statistically analysed data to any rule engine and third-party dashboard for visualisation and automation.



	Minimum Specifications
Features	Open-source design; Device authentication and access control; API security for dashboard; Role-based access control; secure storage and encryption; Logging and auditing; Tested in rural environment.

Data encryption	256-bit SSL Certificate; unique client ID
Device Authentication and Access Control	IoT devices with SSL encryption, unique client IDs, and proper authorisation credentials can only publish their data to the Cloud. Secured communication protocols, such as SSL/TLS, X509 Certificates, 256-bit encrypted key to protect data transmission between IoT nodes/ Gateway and the Cloud.
Role-Based Access Control (RBAC)	RBAC (Publisher/Subscriber) implementation to ensure that IoT devices have appropriate access rights based on their roles and responsibilities.
Data Backup	System events (IoT data communication and API accesses) are being logged in the industry standard syslog format for future debugging and tracking.
Applications	• Capture the IoT data on water supply quality, quantity, and regularity in rural/ urban areas. • Water Quality Monitoring in Real-Time. • Data storage for historical observations over a long-term period.

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Component 10: Dashboard and Visualisation — Lead Lab - NEERI

CSIR-NEERI has developed a dashboard for the live display of water sensors data is a step forward and aims to provide cutting-edge research & innovations with an interdisciplinary/transdisciplinary approach (Fig 1). The GIS-based dashboard is a one-stop web portal that will depict them in interactive mode using meta-data, sensor data, and geo-data. Besides, the data captured via non-sensor means/manual data using field testing kits (FTKs) by the ground staff and water quality testing at subdistrict/district laboratories will also be punched through in situ/POC devices and integrated into the online web portal. The dashboard is customised for each stakeholder/administrative hierarchical level, such as Centre, State, District, Taluka and End-User/households.

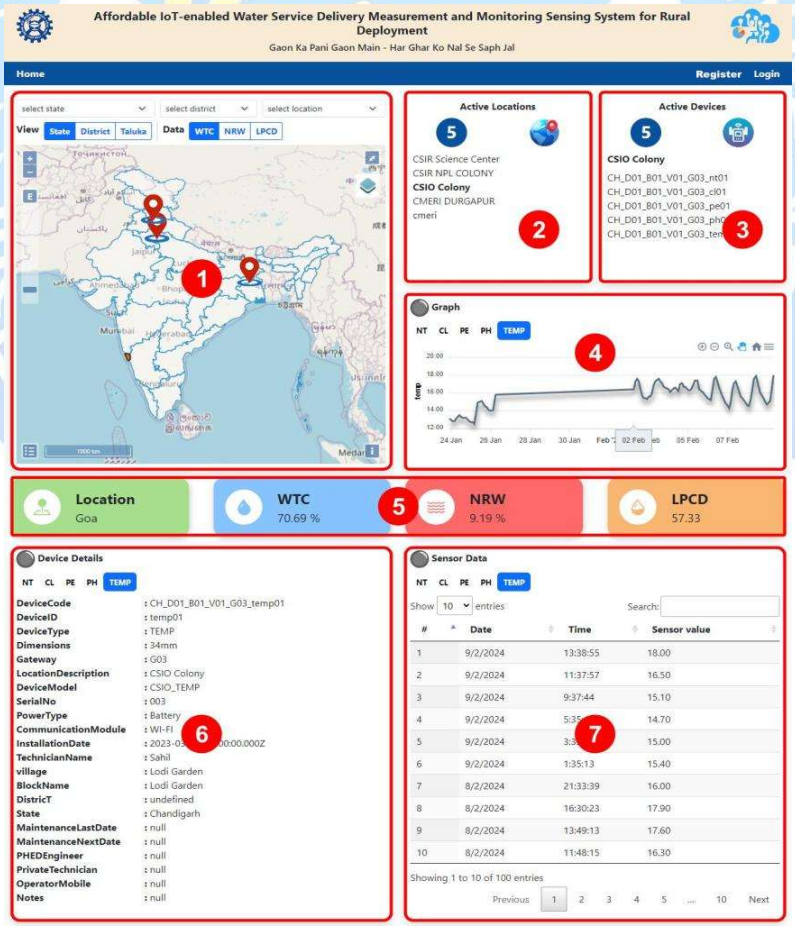


Fig 1. Dashboard UI

1. **Map :**

- In the top left corner (marked as 1), there's a map of India.
- Three locations are marked on the map, representing where the water service devices are deployed.
- The UI includes dropdown menus for selecting the state, district and location.
- Buttons allow users to switch views (e.g., NRW, LPCD).

2. **Active Location :**

- Displays the names of active locations (e.g., "CSIR Science Center," "CSIR COLONY," "CSIR DOLPHIN CMTI").

3. **Active Devices :**

- Lists specific devices (e.g., "CH_DOL_001_V01_003_temp01," "CH_DOL_001_V01_005_temp01") associated with those locations.

4. **Plot:**

- Below the active devices, there's a graph (marked as 4) showing sensor data trends over time.

5. **Secondary Data:**

- Show the amount of WTC, NRW & LPCD of the selected region in the map.

6. **Detailed Device Information :**

- At the bottom left (marked as 6), detailed information about a specific device is provided:

  Device/Code: Unique identifier for the device.

  Type: Type of the device (e.g., temperature sensor).

  Dimension: Physical dimensions or specifications.

  Location/Description: Describes where the device is installed.

  Device Model: Specific model of the device.

  Other relevant details like installation date, maintenance date, and operator information.

7. Sensor Data :

- At the bottom right (marked as 7), there's a section displaying sensor data:

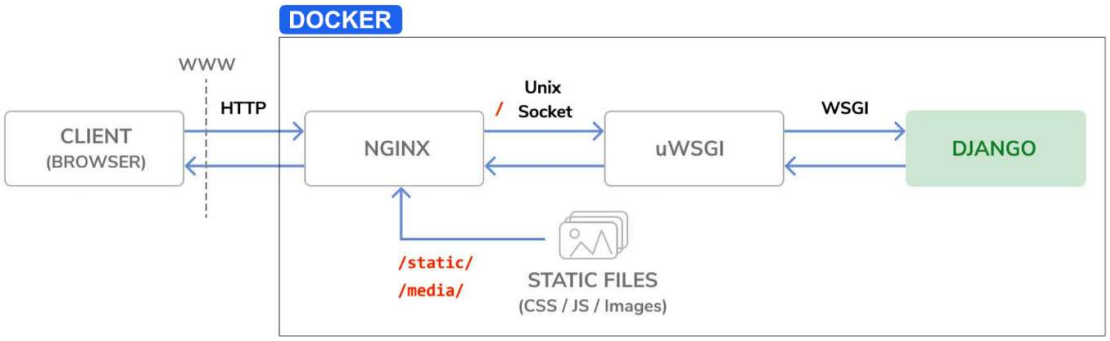
  NT: Nitrate levels.

  CL: Chlorine levels.

  PE: Pressure.

  TEMP: Temperature.

  The data is associated with specific date and time stamps.



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Component 11: Sensor Calibration & Validation

Lead Lab - NEERI

CSIR-NEERI has developed a protocol for performance validation of the sensors. Validation is a critical aspect of monitoring the reliability of a sensor and ensuring that it consistently produces data that meets predetermined specifications and quality attributes. Successful validation is essential for producing high-quality sensors. If the sensor's measurements fall outside of acceptable limits, calibrations are necessary to ensure its reliability and minimize measurement errors. Calibration and validation measurements can be carried out periodically to ensure that the sensors continue to perform accurately over time, typically every sixth month to ensure high performance. However, the actual validation frequency will depend on factors like water quality, biofilm generation, atmospheric conditions, scaling, and other relevant variables.

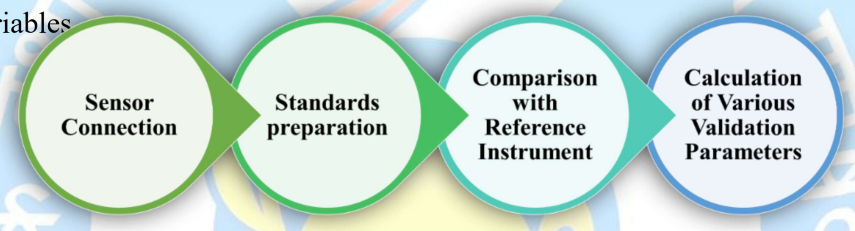

Fig: Validation Methodology

Methodology:	1. Proper sensor connections 2. Preparation of a series of standard solutions covering the predetermined range of the sensor 3. Comparison of sensors' output with a reference instrument. 4. Calculation of various validation parameters.
Validation Parameters	Accuracy, Precision, Linearity, Limit of Detection (LOD), Limits of quantifications (LOQ), Acceptable Range, Sensitivity, Resolution, Offset error, Response Time
Reference Instruments	pH meter, Conductivity meter, UV-Vis Spectrophotometer, Fluoride meter, Colorimeter, Turbidity meter, ICP-OES
Validation Frequency	Recommended every six months to ensure high performance
Recommended Acceptable limits	95% Accuracy, 5% Error, High precision (low standard deviations), Fast response, High Linerity (R^2 close to 1), Zero offset error
Application	The protocol will facilitate on-site calibration and validation procedures.

Component 12: Power Systems

Lead Lab - CEERI

The input to the system is through a Solar PV Array, which may be in the form of a solar tree/solar rooftop array. The energy from the solar PV array is stored in an auxiliary battery using a solar battery charger. The EV charger is connected to the auxiliary battery and charges the EV battery.

Specification of Solar Battery Charger

3 kW Charging System				
S. No	**Parameters**	**Minimum**	**Typical**	**Maximum**
1	Input Voltage	160 V	185 V	231
2	Output Voltage	120 V		
3	Input Current	17.26 A		
4	Input Power	3.2 kW		
5	Output Current	25 A		
6	Efficiency	97%		

750 W Charging System						
S. No	**Parameters**	**Minimum**	**Typical**			**Maximum**
1	Input Voltage	105 V	120 V			135V
2	Output Voltage	45 V	48 V	60 V	72 V	90V
3	Allowed O/P Transient	0.5 V				
4	Output Power	750W / 1500W				
5	Efficiency	96%				

Unique Selling Proposition (USP):

The system will work independently of the grid and can be charged through a solar PV array.

Significance/Relevance for Applications:

It is handy for highways, forest regions, and hilly areas.

Readiness: The laboratory model is tested with in-house solar

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