An Integrated IoT-GIS Framework for Water Quality Monitoring in Arid Regions of Western Rajasthan

Article *in* Applied Ecology and Environmental Sciences · July 2022

DOI: 10.12691/aees-10-7-3

Naveen Kumar Suniya
MBM UNIVERSITY, JODHPUR

Umesh Kumar
MBM University

Kapil Parihar
Jai Narain Vyas University

Applied Ecology and Environmental Sciences, 2022, Vol. 10, No. 7, 444-452
Available online at http://pubs.sciepub.com/aees/10/7/3
Published by Science and Education Publishing
DOI:10.12691/aees-10-7-3

An Integrated IoT-GIS Framework for Water Quality Monitoring in Arid Regions of Western Rajasthan

Abhisek Gour[1,*], Naveen Kumar Suniya[2], Umesh Kumar[3], Kapil Parihar[4], Khamma Kanwar[5], Santosh Kumari Meena[5]

[1]Department of Computer Science & Engineering, MBM University, Jodhpur, India
[2]Department of Production & Industrial Engineering, MBM University, Jodhpur, India
[3]Department of Civil Engineering, MBM University, Jodhpur, India
[4]Department of Electronics & Communication Engineering, MBM University, Jodhpur, India
[5]Department of Electrical Engineering, MBM University, Jodhpur, India
*Corresponding author: abhisek.gour@gmail.com

Received June 02, 2022; Revised July 05, 2022; Accepted July 13, 2022

Abstract Water acts as a critical resource in sustaining the life of human beings and all other life forms on this earth. Despite the increased awareness and better management techniques in recent times, water scarcity has been a significant concern for most governments worldwide. Especially in arid regions, such as the western areas of Rajasthan, which are heavily dependent upon a few rivers, their tributaries and underground water sources. It becomes crucial to optimize water consumption and maintain water quality in such water bodies. In this work, an Internet of Things (IoT) based framework has been developed to monitor the water quality parameters of the Jojari River, a tributary of the Luni River. Data collected from the IoT endpoints is passed to a GIS-based system designed to support continuous data monitoring and alerts for abnormal changes in the monitored parameters. Analysis of the collected data for some time denotes that the current state of water quality in the Jojari River is not appropriate for drinking or the surrounding ecosystem. Over time, the system can enable forecasting of water quality parameters and locate significant sources of pollution.

Keywords: *water quality monitoring, internet of things, sensors, geographical information systems*

Cite This Article: Abhisek Gour, Naveen Kumar Suniya, Umesh Kumar, Kapil Parihar, Khamma Kanwar, and Santosh Kumari Meena, "An Integrated IoT-GIS Framework for Water Quality Monitoring in Arid Regions of Western Rajasthan." *Applied Ecology and Environmental Sciences*, vol. 10, no. 7 (2022): 444-452. doi: 10.12691/aees-10-7-3.

1. Introduction

Several regions in India are facing an acute shortage of water due to the decreasing annual rainfall and lack of conservation methods. Specifically, farmers and cattle in the desert areas of Rajasthan and Gujarat are heavily affected by the low availability of potable water.

Surface water bodies act as the primary water source for the municipal water supply in these areas. However, water available from rivers and lakes is highly dependent upon the sporadical rains in these arid regions. Although reservoirs are used to hold the rainwater from seasonal rivers, there is not enough rainfall to ensure year-long availability. Further, due to local geology and environmental conditions, only a small quantity of available water can be used for domestic purposes. As a result, surface water pollution has become a significant concern worldwide [4]. Therefore, it is imperative to enforce a proper quality monitoring mechanism to avoid pollution, ensure water quality and prevent loss of the surrounding ecosystem in these circumstances.

In the western districts of Rajasthan state, ten rivers, namely Bandi (Pali), Dhogri, Lathi and Kakney (Jaisalmer), Sagi (Jalore), Gunaimata and Jojri (Jodhpur), Jawai and Sukri (Pali, Sirohi, and Jalore), Luni (Ajmer, Nagaur, Jodhpur, Pali, Barmer, and Jalore) are majorly identified [1]. Among these, the Luni River is the longest river that originates from the Aravali Ranges in Pushkar, Ajmer and leads to the Rann of Kutch in Gujarat while crossing six districts of western Rajasthan. Moreover, Jawai, Sukri, Bandi, Guhiya, and Jojari are tributaries of the Luni River.

Since the Luni river is a seasonal river (generally flows during the monsoon season) that highly depends upon the rainfall in the Aravali ranges, three dams have been constructed on this river, namely, the Dantiwada dam, Sipu dam, and Jaswant Sagar Dam. Apart from these dams, two major irrigation projects, i.e. Sardar Samand Project and Jawai Sagar Project, are also based on the Luni River. Effectively, the Luni river acts as a major source of municipal water supply, irrigation, transportation, energy generation, and wastewater conveyance in the western districts of Rajasthan State.

Recent growth in population, residential settlements and industries have increased the load on these watersheds in terms of consumption as well as pollution. As noted by Masere et al., such expansion usually results in a decline in the surface water quality. [2] Moreover, the decrease in water quality does not only prove to be expensive when it comes to treatment and possible reclamation, but it is also detrimental to human health [3].

Therefore, it is crucial to proactively monitor and manage the water quality in the Luni river. For this purpose, many researchers have proposed developing IoT-based solutions to gather water quality data in real-time. For e.g., Moparthi et al. developed a system based on IoT to determine the variation in pH level of the water to ensure a safe supply of drinking water [5]. Vijaykumar et al. designed a Raspberry Pi B+ based cost-effective IoT system to measure and monitor the physical and chemical parameters, including temperature, turbidity, conductivity, pH, and dissolved oxygen of the surface water [6]. Madhavireddy et al. developed a water quality monitoring system to ensure the safe distribution of drinking water using various sensors like pH sensor, water level sensor, and CO_2 sensor. The data collected from the model was available for access and analysis from anywhere. In addition, a buzzer was integrated to notify in case of abnormal or interrupting situations, e.g. when sensors are not working correctly etc [7].

Mukta et al. developed an IoT-based water quality monitoring system to measure various parameters such as pH, temperature, conductivity and turbidity using multiple sensors associated with Arduino-Uno [8]. The data collected from the sensors were compared with the standard values of the parameters measured, and a fast-forest binary classifier was implemented to classify the water samples based on their quality. Konde and Deosarkar designed an IoT environment to measure various parameters, including pH, surrounding humidity, water level, turbidity, water temperature, and CO_2 on the water surface with the help of a field-programmable interface device and integrated sensors. The system was proposed to be relatively more cost-effective than traditional IoT systems [9].

Inspired by these works, an integrated IoT-GIS framework is designed and proposed in this study to enable continuous data collection and assessment of water quality at multiple test locations with minimal manual intervention. The data collected from IoT architecture can be pushed into GIS-enabled software that helps with continuous monitoring and analysis of the water quality. The proposed system was deployed at five locations on the banks of the Jojari tributary of the Luni River. Four parameters, namely, pH, TDS, turbidity and dissolved oxygen, are collected over the IoT framework.

A detailed discussion about the selected test environment and design of the proposed system is presented in sections 2 and 3, respectively, followed by an analytical discussion in section 4.

2. The Jojari River

Among the five tributaries of the Luni River, Jamai, Sukri and Jojari are considered more significant because of their geological and ecological impact on the surrounding population. Specifically, the Jojari River, which spans 128 km in length, originates from Pandlu Village and crosses through Nagaur, Barmer and Jodhpur districts of the Rajasthan state. The river is the only tributary of the Luni river which does not originate from the Aravali Ranges and joins the Luni River on its right bank. The total watershed area of the Jojari River is 1453 km^2, of which 917 km^2 is in the Jodhpur region. The primary water source for the river is seasonal rains in the surrounding regions. Due to this, the river usually carries little water during the dry seasons (Meena and Meghwal, 2019) [10]. However, occasionally, due to the heavy monsoon rains and the low water absorption capability of the soil in these desert regions, the river has also been the cause of flash floods in some areas of the Barmer and Jodhpur districts.

A route map of the Jojari River basin through the Jodhpur district is presented in Figure 1.

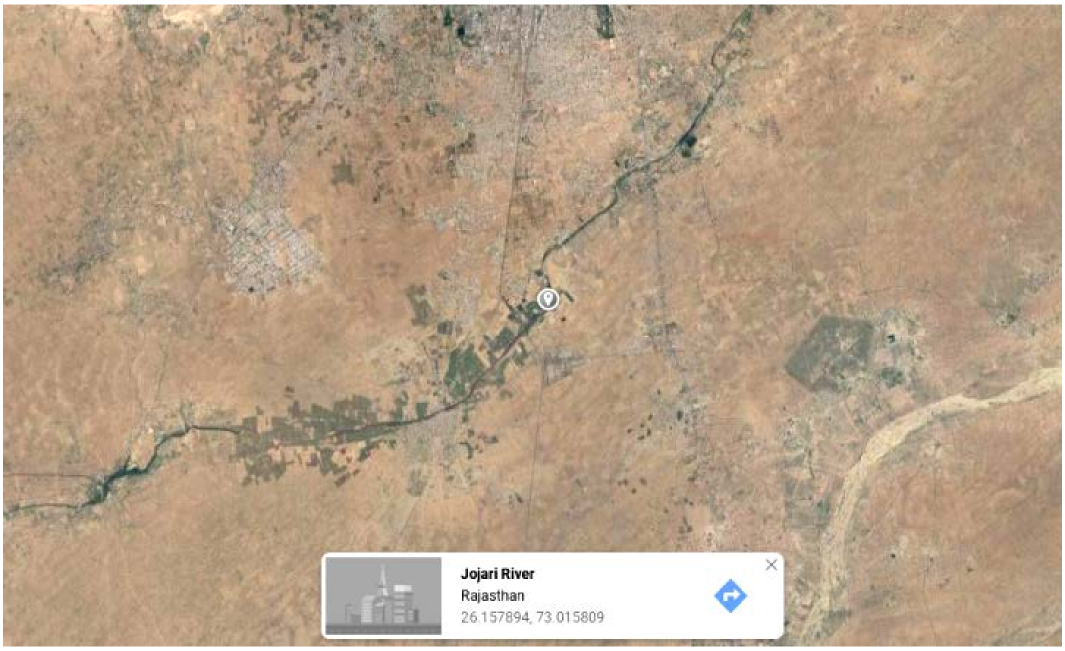

Figure 1. Jojari River Basin in Jodhpur district (Google Maps) [15]

2.1. Water Contamination in Jojari River

In the districts of Jodhpur and Barmer, several textile dyeing, handicraft, polishing, printing, and steel-rolling industries have been established around the banks of the Jojari River. Without proper monitoring and water treatment facilities, these industries heavily target the river for authorized and unauthorized wastewater disposal. As a result, the river water is found to have heavy concentrations of carbonates, bicarbonates, nitrates, phosphates, and various hazardous metals.

Apart from the industrial affluents, a heavy amount of sewerage disposal from the Jodhpur city is also a significant concern. While the supply from Rajiv Gandhi Lift Canal has been extended up to the Jodhpur city and nearby regions, a few arrangements have been made to manage the resulting increase in groundwater penetration and urban sewerage by the local administration. As per the local news reports, only 75-80 MLD of the sewage collection reaches the STP. Unfortunately, most of this polluted sewerage is released untreated into the Jojari river through identified and unidentified city drains.

Due to such high levels of pollution and extremely low levels of dissolved oxygen, the river has reached a eutrophic condition resulting in the rapid growth of the phytoplankton & zooplankton population. Consequently, it has adversely affected the quality of soil, flora-fauna, and human life in regions surrounding the river basins [14]. Moreover, during the summer season, the high levels of surface temperature in these areas (primarily due to the environmental conditions and the geographical location) also lead to higher evaporation rates. Under such conditions, the concentration of these pollutants increases significantly and renders the river water inappropriate for drinking or domestic use when it is needed the most.

2.2. Identification of Test Locations

From the above discussion, it is evident that, despite being an important source of water, the rivers in the arid regions have to bear a lot of contamination from urban and industrial entities. It is crucial that regular quality monitoring is carried out at different places across the river to increase the accountability and efforts of the local administration, citizens and law enforcement bodies toward the prevention and decontamination of these water sources [13]. Practically, it is challenging to perform such quality surveys manually due to strategic, logistic and financial limitations. Moreover, such manual surveys are prone to external influences.

Considering the above facts, the Jojari River was chosen as the suitable candidate for the initial deployment of the proposed IoT-based water quality monitoring system. However, the exact locations for deployment of the endpoints had to be chosen carefully because of the following reasons –

a. Safety of the IoT endpoints,
b. Defer human interference during the testing phase,
c. Proximity to the pollution sources,
d. Availability of network connectivity,
e. Permission from local authorities.

Eventually, five locations were identified for the initial deployment of the endpoints, as listed in Table 1.

Table 1. Identified locations for deployment of IoT endpoints

Location Code	Area/Village	Latitude	Longitude
WQMS01	Shikargarh	26°16’ 14” N	73°06’ 28” E
WQMS02	Kudi	26°11’ 46” N	73°03’ 09” E
WQMS03	Salawas	26°08’ 30” N	73°00’ 09” E
WQMS04	Bhandu Kallan	26°06’ 33” N	72°53’ 25” E
WQMS05	Lunawas	26°05’ 15” N	72°48’ 27” E

Based on the initial samples from these locations, the WRASTIC index [12] for the Jojari river was calculated to be 52. As per the New Mexico Environment Department’s WRASTIC rating system, it indicates that the Jojari River falls under low impact risk, high probability of occurrence and moderate vulnerability category.

3. Water Quality Monitoring using IoT

Generally, a water quality monitoring system is composed of the following components –

a. Sensor components (pH sensor, conductivity sensor, temperature sensor etc.),
b. Microcontroller (for processing sensor input and generating desired response),
c. Display / Notification lights,
d. Batteries and/or Power Supply,
e. Solar charging plates (optional),
f. Actuator/Alarm devices (optional).

Sensors are sophisticated transducer circuits carefully designed and calibrated to measure a physical phenomenon and generate an electrical response accordingly. Usually, the electrical signals generated by these sensors are analog in nature and have low amplitude levels. A supporting electronic circuit is used to convert the generated analog signal into digital or amplify the contrast between different levels of measurement on a discrete scale.

These sensor outputs are then fed as input to a microcontroller designed for low power consumption and continuous operation for extended periods. The microcontroller is responsible for processing, logging, and generating desired responses based on the input values. Often the output response is displayed as text/symbols on an attached display or by turning the corresponding notification lights on/off. In some cases, an actuator and/or alarm unit is deployed along with the sensing unit to generate a desired physical response or notify the concerned authorities about any events of interest.

The major drawback of such monitoring systems is their lack of connectivity to a broader network. Due to this, the data logged at such endpoints must be manually collected and compiled at a centralized location for further analysis and strategic planning. To overcome these limitations, many researchers have used an IoT-based architecture.

3.1. Proposed System Architecture

A schematic diagram of the water quality monitoring system proposed in this study is presented in Figure 2.

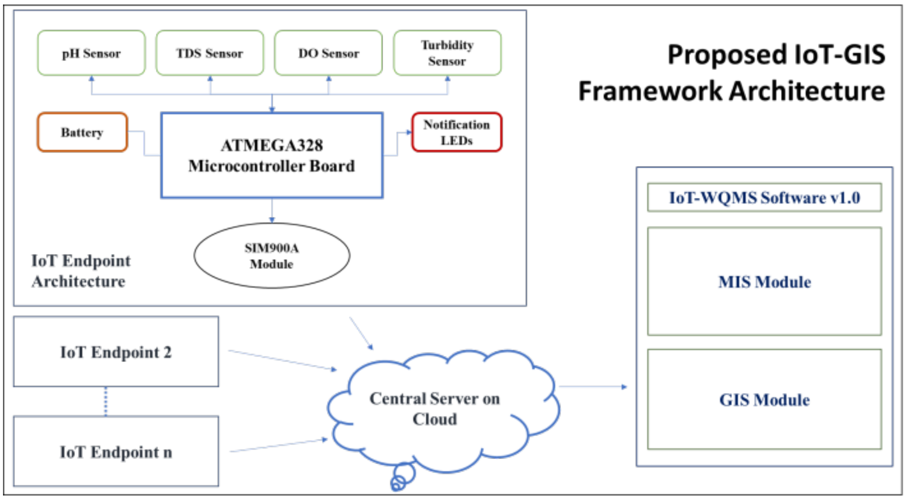

Figure 2. Proposed system architecture for water quality monitoring

Table 2. Water Quality Sensor Specifications

S. No.	Sensor	Specification	Value
1.	Analog pH Sensor	Range	0-14 pH
		Measurement Temperature	0 - 60°C
		Accuracy	±0.1 pH (at room temperature)
		Interface	PH2.0 Interface with BNC Connector
2.	Analog Dissolved Oxygen Sensor	Detection Range	0~20 mg/L
		Type	Galvanic Probe
		Pressure Range	0-50 PSI
		Temperature Range	0-40°
		Interface	BNC Connector
3.	Dual-mode Turbidity Sensor	Detection method	Optical
		Operting Temperature	5-90°C
		Insulation Resistance	100 M
		Interface	PH2.0 with BNC Connector
		Filling Solution	0.5mol/L NaOH Solution
4.	TDS Sensor	TDS Range	0 ~ 3000ppm
		TDS Accuracy	± 2% F.S. (at room temperature)
		Interface	Plug ¼” PE Probe
		Output Range	0 - 2.3V

To look after computational requirement at the endpoints, the Arduino-based ATMEGA328 micro-controller was used because of its lower cost and easy prototyping capabilities. For recording various water quality parameters, the four sensor components (specifications given in Table 2) were interfaced within each endpoint node.

Most villages in these areas of the Rajasthan State do not have good 3G/4G/WiMax Connectivity. Further, since the payload size is small and the delivery assurance is not required to be very high, a GSM/GPRS-based module was interfaced with the MCU for data transfer. SIM900A module supports dual-band (900/1800 MHz) GSM connectivity, multi-slot Class 8/10 GPRS connectivity (download: 85.6KBps and upload: 42.8KBps), on-chip UART interface, and an internal TCP/IP stack for internet communication. Moreover, the SIM900A module was selected due to its low cost, low power consumption, and compatibility with the Arduino framework. In addition, a SIM from BSNL was installed within each node because of their broader coverage and reliable service in rural areas.

The MCU was programmed to read the data from all connected sensors, prepare a data packet in the desired format and send the packet over GPRS to a custom-designed IoT server application. The server application was developed using Fast API, a python framework for rapid development of REST APIs, and was installed on a free-tier public cloud for demonstration purposes.

The endpoints were configured to send the sensor packet to the server application over HTTP at an interval of every one minute after clicking a “Start/Stop” button (a push button). The endpoints keep sending the data until the button is pressed again, network connectivity is disturbed, or the battery level is below the set threshold value (in which case, an SMS is also sent to a predefined number to notify the administrator).

3.2. GIS-Based Application for Water Quality Analysis

Most works related to water quality analysis conclude with the collection of water quality data followed by manual modelling and analysis of the collected data. Various computational tools, such as MATLAB, R, Weka, ArcGIS etc., have been used in the literature for exploratory, inferential, and geographical analysis of the collected data. However, in the context of continuous water quality monitoring, since the data will keep on accumulating over time, it is very cumbersome to extract the data from the server and perform offline assessments at regular intervals. Moreover, although these tools offer several API packages and GUI tools for detailed data analysis, these tools lack geographical modelling of information. Alternatively, by using GIS platforms, it is possible to present the information in thematic layers for underlying political boundaries, satellite imagery, data points, and analytical information separately.

In the proposed system, a software program was designed to offer two data analysis methods through two major modules - an MIS for statistical analysis of the raw data and a GIS for performing visual and geographical operations. Additionally, features have been designed to bind the map data with processed outputs from the MIS module. The GIS Module was designed using ArcEngine SDK Runtime v10.7.1 on the JavaSE platform. An authentication module has been integrated to enable restricted access to the collected data. In the MIS module, the following submodules have been developed –

1. View/Filter Water Quality Data

The module allows users to filter and view the water quality parameters received over the IoT network. Module implicitly fetches the data from the central server and stores it in local storage for offline access at every invocation. In addition, the module allows sorting and filtering of the data packets using date range and location.

2. Plot Data

This module allows the user to plot any selected Water Quality Data (through filters) on the GIS Module. In addition, the users can also edit details like layer name, enable/disable annotations etc., while plotting.

3. Calculate Overall Index of Population

Sargaonkar and Deshpande proposed the Overall Index of Population as a measure to indicate the level of pollution in water based on various quality parameters [11]. It is calculated as –

$$OIP = \frac{\sum Pi}{n}$$

Where P_i is the pollution index of the i^{th} quality parameter and n is the total number of parameters. Although the initially proposed method includes index values for 11 water quality parameters, the four index values corresponding to the sensors integrated with the system are presented in Table 3.

Table 3. Pollution index values for selected water quality parameters as per the Overall Index of Pollution

Parameters	Range	Equation
pH (0 to 14)	7	P = 10
	>7	P= exp(y-7)/1.082
	<7	P= exp(7-y)/1.082
DO (mg/l)	<50	P= exp(-(y-98.33)/36.067)
	50-100	P=(y-107.58)/14.667
	>100	P=(y-79.543)/19.054
TDS (mg/l)	≤ 500	P=1
	500-1500	P= exp((y-500)/721.5)
	1500-3000	P=(y-1000)/125
	3000-6000	P=y/375
Turbidity (NTU)	≤ 5	P=1
	5-10	P= (y/5)
	10-500	P=(y+43.9)/34.5

This module allows users to perform bulk calculations of OIP for each data packet received over the IoT network. Based on the calculated OIP value, a water sample from any location can be classified into five classes as per Table 4. The same is displayed next to each data entry upon completion of the calculation process.

Table 4. Water Quality Classes as per QIP

OIP Value	Class	Water Quality
0-1	C_1	Excellent
1-2	C_2	Acceptable
2-4	C_3	Slightly polluted
4-8	C_4	Polluted
>8	C_5	Highly polluted

4. Add/Update Event Triggers

This module allows users to create (and later update) triggers for certain threshold values of different sensors and OIP for different locations. When the threshold value for any selected parameters is crossed, the trigger is invoked, and the system initiates the corresponding action (specified in trigger settings). Apart from water quality parameters, a trigger can also be created for battery levels of various endpoints.

5. Trigger Settings

In response to a trigger, there are three options that can be selected by the user – create a software notification, send an email, or switch to low power mode depending upon the type of trigger. In the case of software notification, a persistent tooltip is displayed on the GIS module. In the second case, an email is sent to the specified email address containing the message specified in the settings. In the last case, the corresponding endpoint node is switched to a low power mode in which the endpoint sends new packets every 15 minutes and remains in sleep mode in between.

In the GIS Module, the primary objective was to allow the stacking of information from different sources on a georeferenced map screen in the form of layers to allow for easier access and analysis. Following sub-modules have been developed for the same –

1. Map View

This module offers an interactive GUI component where users can see the GIS layers added to the map and perform various operations on them. Available functions are select a feature, more information, zoom in/out, zoom to globe/document, pan, select, view coordinates etc. Most of these operations are implemented using the classes from ArcEngine SDK Runtime.

2. Table of Contents

This module allows users to view, enable/disable, add, remove, rearrange, and repaint different GIS layers added to the map.

3. Display settings

This module allows users to choose the colour, symbols and opacity of data points displayed on the map based on their values. For e.g. the user can choose to display a red circle for a data point if the current TDS value for that location is more than 3000. Four symbols (circle, triangle, square and star), five colours (red, blue, green, orange, black), and four opacity levels (100%, 80%, 60%, 40%) are available to choose from for each threshold condition created with this module.

4. Notification Settings

Through this dialog, users can change the display properties of software notifications. As discussed earlier, whenever a threshold trigger is invoked, users may choose to display a software notification. These notifications are displayed as a tooltip near the respective data point on the map (in a separate layer). Users can choose the background colour, text size, duration of persistence, and date/time format for these notifications using this sub-module.

5. Import/Export Data

The application is designed to allow the users to export the information currently displayed on the map in one of the supported GIS file formats (.gdb, .kml etc.) to view the information on other GIS applications (such as Google Earth, ArcGIS etc.) Similarly, data stored in a previously exported file can be imported for viewing on the map as a separate layer group.

Some screenshots of the developed GUI components are displayed in Figure 3 & Figure 4.

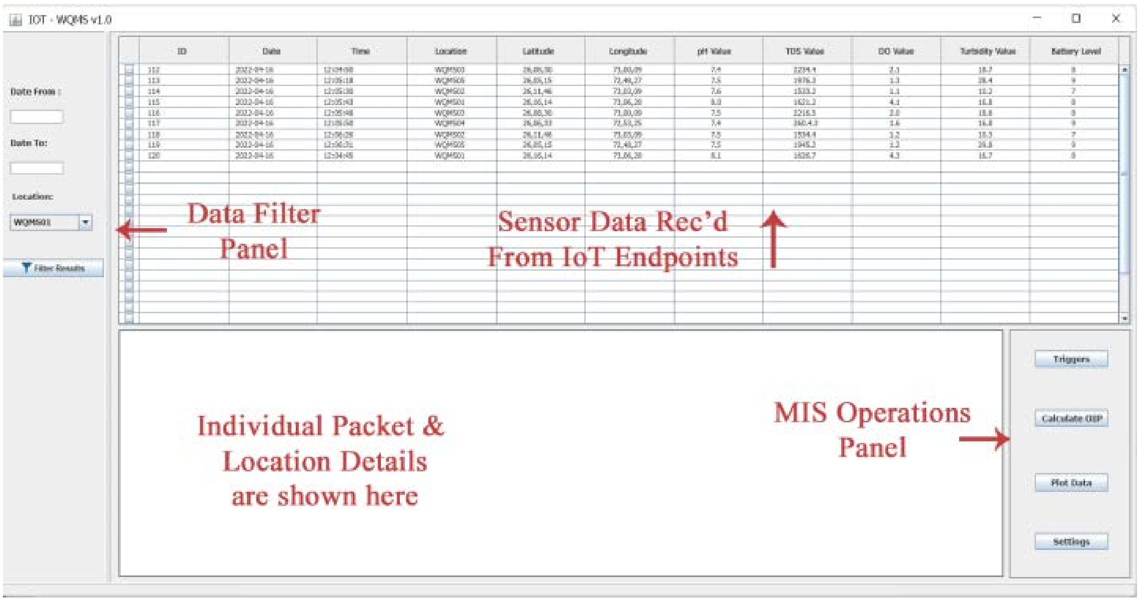

Figure 3. Screenshot of the MIS Module

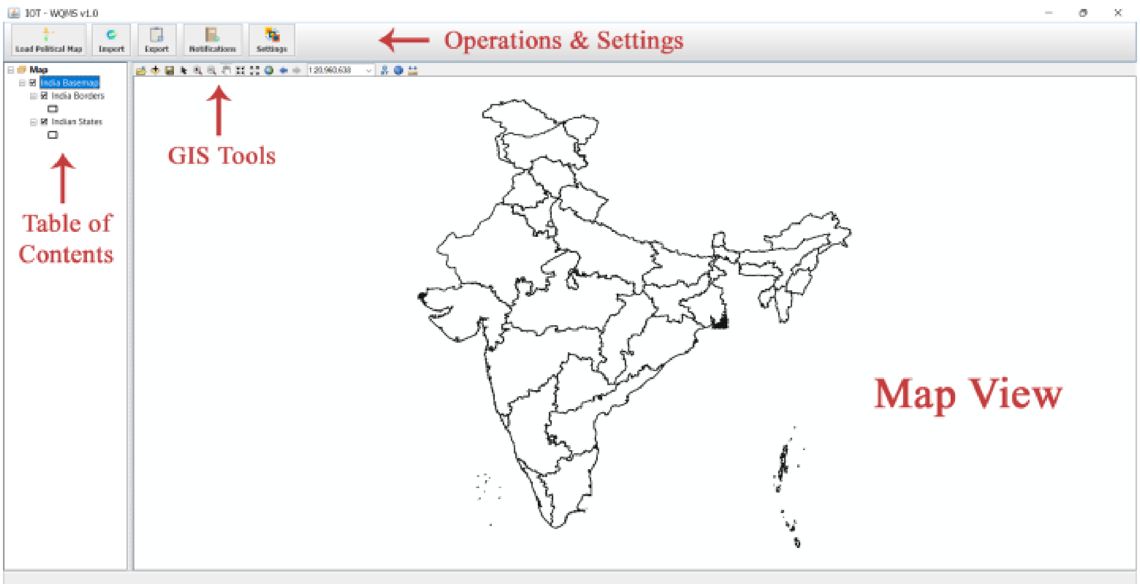

Figure 4. Screenshot of the GIS Module

4. Results & Discussion

The proposed system was strategically deployed at five locations on the banks of the Jojari River to study the impact of nearby industries and CET plants on water quality. Initially, the sampling frequency was selected as 1 minute, i.e. one data packet containing sensor readings is sent by endpoints to the server every minute. Line plots of the pH, dissolved oxygen, TDS and turbidity values collected for all the five locations over a period of two hours are presented in Figure 5, Figure 6, Figure 7, and Figure 8, respectively.

It can be observed from these values that since the location WQMS01 is situated after Nandri Sewerage Treatment Plant, the corresponding TDS and Turbidity levels are relatively low; however, pH values are significantly higher because of the chemicals involved in the treatment process. The location WQMS02 is also near the Kudi water treatment plant; therefore, similar readings can be noted for this location. However, the other three locations are situated at places where contaminants are introduced into the river water. For e.g., the location WQMS03 is situated just after the Salawas Railway Bridge, where the STP & CETP wastewater is discharged; the location WQMS04 is situated near Bhandu Kallan road bridge, where a lot of industrial waste is disposed of in the river; and the location WQMS05 is located near Lunawas village after the nearby industrial area (but relatively farther as compared to WQMS03 and WQMS04). As per the sensor values received from these locations, it can be observed that the introduction of wastewater and other industrial waste increases the TDS and turbidity levels of the water. However, in contrast to the WQMS03 and WQMS04, these levels fall significantly at the location WQMS05, possibly, due to the self-purification of the river).

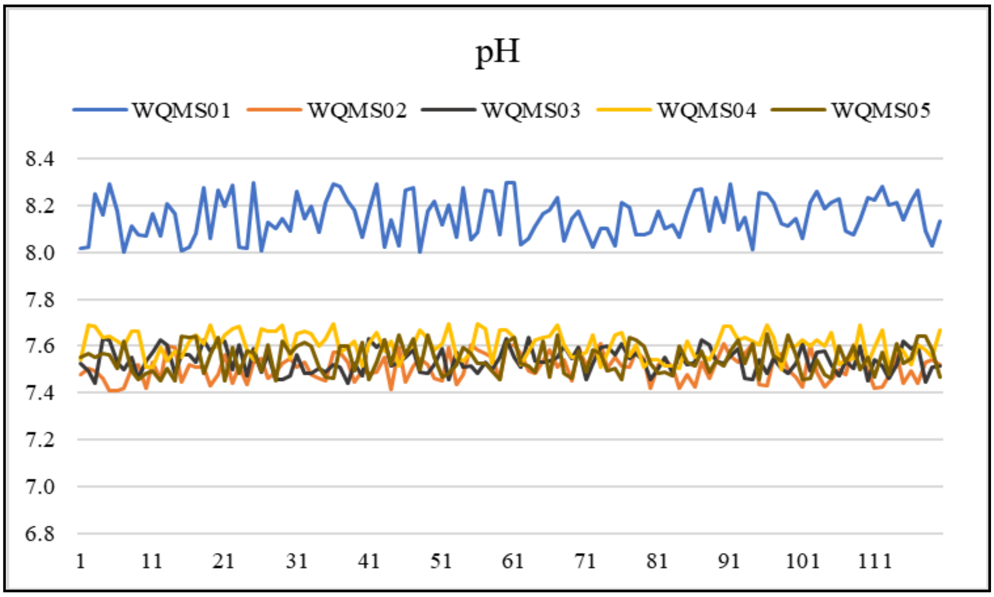

Figure 5. pH readings for all five locations

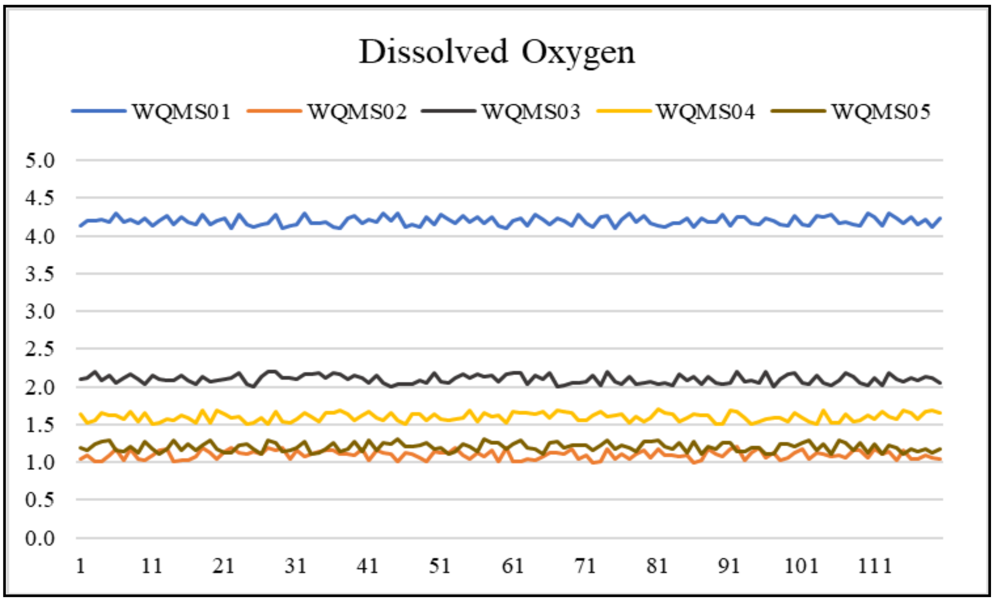

Figure 6. Dissolved Oxygen readings for all five locations

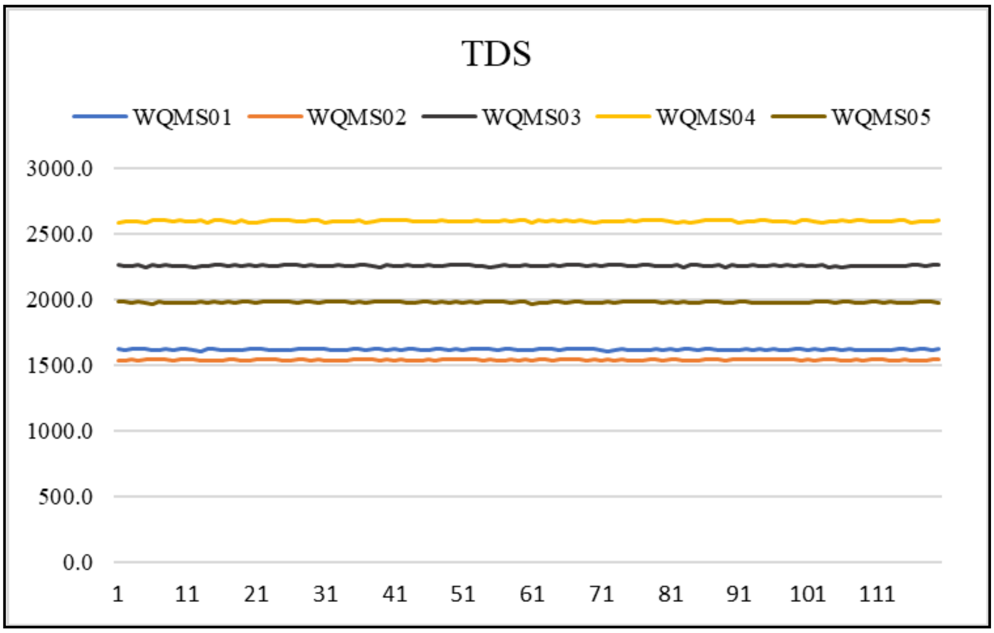

Figure 7. TDS readings for all five locations

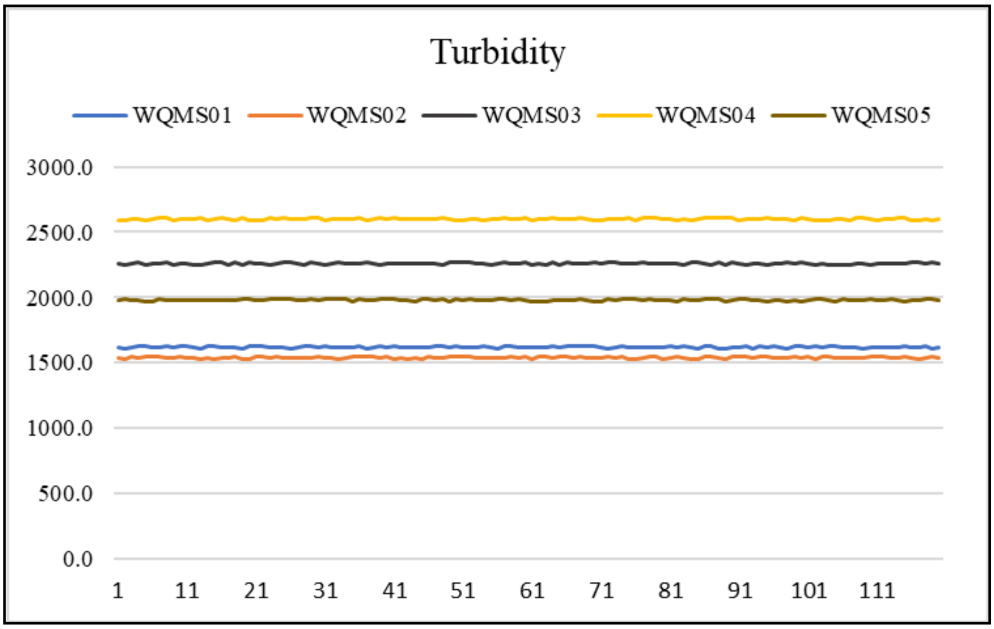

Figure 8. Turbidity readings for all five locations

5. Conclusion

Several initiatives and inspection strategies have been conceptualized and deployed by local governments to prevent uncontrolled contamination of water bodies. Still, due to the limitations of the manual sample collection process and the loopholes in the monitoring and enforcement procedures, it is difficult to prevent unauthorized disposal of wastewater and contaminating agents in the rivers spanning hundreds of kilometres. Specifically, in arid regions where the surface water availability is significantly low, it is crucial to build solutions that can be reliably used for water quality monitoring and assurance. In this study, an integrated framework based on newer technologies like the Internet of Things and Geographical Information Systems has been developed and deployed at five locations on the banks of the Jojari River in the Jodhpur District of the Rajasthan State. Based on early readings and corresponding OIP values, it can be reported that the water in the Jojari river is polluted and harmful to the environment and the neighbourhood.

Apart from the water quality assessment at the Jojari river, it can be concluded from the collected data and subsequent manual validation that the proposed system successfully gathers important water quality parameters at regular intervals without needing manual sample collection or analysis.

Further, it can be observed that the proposed system is also effective in studying the effects of wastewater and contamination discharge on the water quality in river bodies. Specifically, with the help of the integrated GIS capabilities, it becomes effortless to correlate the collected Data with the geographical information such as vicinity to urban/industrial areas, treatment plants, etc. Based on this study, it is proposed to increase the type of sensors, improve battery management and add remote configuration and calibration capabilities to the endpoint nodes. Also, some software features have been identified, such as performing cross-validation of the collected data based on values from nearby nodes, increasing the type of triggers and corresponding responses, etc., which shall be developed and integrated with the existing system. As a future possibility, mechanisms can be designed to share the analytics derived from the system with the general public and responsible authorities for effectively monitoring and assuring water quality in highly affected river bodies.

References

[1] Rajasthan Rivers by District - RajRAS. [online] RajRAS. Available at: <https://www.rajras.in/rajasthan-rivers-district/> [Accessed 8 June 2022].

[2] Luni River - Wikipedia. [online] Available at: <https://en.wikipedia.org/wiki/Luni_River> [Accessed 8 June 2022].

[3] Meybeck, M. and Helmer, R., 1996. An Introduction to Water Quality. In: D. Chapman, ed., Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring, 2nd ed.

[4] Ali, M., Ali, M., Islam, M. and Rahman, M., 2016. Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring & Management*, 5, pp.27-35.

[5] Moparthi, N. R., Mukesh, C., & Sagar, P. V. (2018, February). Water quality monitoring system using IoT. In 2018 Fourth International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB) (pp. 1-5). IEEE.

[6] Vijayakumar, N., & Ramya, A. R. (2015, March). The real time monitoring of water quality in IoT environment. In 2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS) (pp. 1-5). IEEE.

[7] Madhavireddy, V., & Koteswarrao, B. (2018). Smart water quality monitoring system using IoT technology. Int. J. Eng. Technol, 7(4.36), 636.

[8] Mukta, M., Islam, S., Barman, S. D., Reza, A. W., & Khan, M. S. H. (2019, February). IoT based smart water quality monitoring system. In 2019 IEEE 4th International Conference on Computer and Communication Systems (ICCCS) (pp. 669-673). IEEE.

[9] Konde, S., & Deosarkar, D. (2020, June). IOT based water quality monitoring system. In 2nd International Conference on Communication & Information Processing (ICCIP).

[10] Meena, A. and Meghwal, B., 2019. Jojari River Water: Pollution And Its Impact On The Human Health. International Journal of Research in Engineering, IT and Social Sciences, 09(05), pp.352-357.

[11] Sargaonkar, A. and Deshpande, V., 2003. Development of an Overall Index of Pollution for Surface Water Based on a General Classification Scheme in Indian Context. *Environmental Monitoring and Assessment*, 89(1), pp.43-67.

[12] Maleki, P., Rahman, P., Jafariyan, H., Salmanmahiny, A., Ghorbani, R., Gholizadeh, M. and Harsij, M., 2020. The risk assessment of water pollution in the Gorgan Bay catchment using the WRASTIC index. *Environmental Nanotechnology, Monitoring & Management*, 14, p.100393.

[13] Singh, K., Goswami, A., Kalamdhad, A. and Kumar, B., 2020. Surface water quality and health risk assessment of Kameng river (Assam, India). *Water Practice and Technology*, 15(4), pp.1190-1201.

[14] Abbasi, T. and Abbasi, S., 2011. Water quality indices based on bioassessment: The biotic indices. *Journal of Water and Health*, 9(2), pp.330-348.

[15] Google Maps, 2022. Jojari River [online] Available at: <https://www.google.com/maps/@26.1623627, 73.0168385,22032m/data=!3m1!1e3!5m1!1e4> [Accessed 15 April 2022].

[16] Genda Singh, P.R. Nagora, Parul Haksar et al. Water Quality, Soil Characteristics and Vegetation Diversity Along Effluent-dominated Rivers in Western Rajasthan, India, 03 June 2021, PREPRINT (Version 1) available at Research Square.

[17] Pathak, A.K., Kantharajan, G., Saini, V.P. *et al.* Fish community and habitat diversity profiling of Luni, an ephemeral saline river from Thar Desert of India for conservation and management. *COMMUNITY ECOLOGY.* 21, 303-316 (2020).

[18] Singh, N., Sharma, B.K. & Bohra, P.C. Impact assessment of industrial effluent of arid soils by using satellite imageries. *J Indian Soc Remote Sens.* 28, 79 (2000).