Application of Wireless Sensor Network for River Pollution Management

Muniyan Sundararajan[1], Anand Mohan[2], Gaurav Chakrabarty[3], Vijeta Jha[4]
[1]CSIR - Central Institute of Mining and Fuel Research, Dhanbad (Jharkhand) India.
[2] NHSM– Dept. of Computer Science & Management Studies, Business School, Durgapur (West Bengal) India.
[3]Research Scientist, Trinity, Loharkulli, Saraidhela, Dhanbad (Jharkhand) India.
[4]Techno-IPR Mentor, IIM Udaipur Incubation Centre, Udaipur (Rajasthan) India.

ABSTRACT

This paper presents an Extended Wireless Sensor Network with three-fold tasks for assessing water quality along any river system blended with multi-industrial effluent outfalls. First, it assesses river water quality at all confluence points of industrial effluents with river using sensors and transmits to control room using the Wireless System with inbuilt Wi-Fi. Secondly, it predicts water quality along each stretch between two consecutive outfalls using a computer algorithm developed with river quality dispersion model. Thirdly, it the predicted data transmitted to controller in the cloud to be accessible by the industries for necessary action to control pollution in the river.

Keywords-Wireless sensor network, river quality, pollution management, data visualization, sustainable industrialization

I INTRODUCTION

Although industrial development of a country influences its economic growth, on another hand it causes serious impact on the environment. Each industry must contribute towards green environment in order to balance industrial impact on the environment and ensure the sustainable industrial development. Pollution management is one of the factors of sustainable industrial development to bring the concentrations of toxic elements within the permissible limits [1]. Continuous discharges of industrial effluents pollutes the river water and it spreads diseases among the people and animals in the residential colonies situated along the sides of the river course as the water is being used for domestic use [2-4]. Thermal power plants are drawing water from river for cooling its units and discharges. The raised temperature lowers the level of dissolved oxygen and disturbs aquatic life in the water [5]. Study reveals that a coke plant generates minimum of 175 m^3 effluents and the concentration of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Phenol and Cyanide exceeds the limits with high concentration of Ammonia, TDS, and Oil & Grease [6]. It is obvious to say that Dissolved Solids (DO) decreases when BOD increases in industrial effluent. Assessing the impact of industries on river water quality requires planning sampling stations, regular sampling, laboratory analysis, reporting and action of pollution control. Manually and frequently collecting samples at different points of the river stretches in the downstream involves huge project fund towards deputation of manpower and laboratory analysis. Further there will be a significant delay in obtaining the report of the collected samples from the internal or external investigating agencies. Therefore there is a need for quick analysis and earlier action of pollution control to maintain the river water quality within permissible limits for intended use in the downstream. Thus, ideas emerged to design and develop a wireless sensor network for appropriate pollution management of the river stretch through quick assessment of water quality, which is one of the responsibilities of the industries to march together contributing towards the sustainable development. Water quality monitoring at each monitoring station must regularly be assessed at uniform interval of time for providing data creditable to be analyzed as time series to define present conditions and also to establish forecasting models to control pollution [7-9].

In the recent years, Internet of Things (IoT) has become very popular and is being used for integration of cloud computing. The IoT can effectively be used for promoting smart homes and smart cities in urban development [10–12].Many researchers developed wireless sensor network for online monitoring of water quality [13,14]. Attempts have been made to apply online monitoring systems in urban development activities such as water distribution, water resource management and quality assessment. Sometime municipal supply water and sewage are merging together in the crossing points due to rusting of buried pipelines in water supply network and contamination can be detected in water distribution systems using a modeling approach [15-19]. Wireless sensor network has effectively been applied for online water resource management and distribution. Jianhua et al [8] made a survey on existing research on smart water quality monitoring system (SWQMS) and found the application of wireless sensor network effectively [20-24]. Xiuna et al [25] have applied a remote wireless system to assess and ensure quality of water for fish culture through online monitoring.

Focusing on software system for water quality prediction, a dynamic water quality prediction method may be useful wherever SWQMS is applied. There are several methods available to predict water quality [26-36]. Most of the water quality prediction studies use Neural Network (NN) [37]. NN is a vital as a high non-linear system for finding optimized solution of complex problem [38-42].

Gentic Algorithm (GA) optimizes calibration of water quality models and their monitoring networks [27-29]. Further, GA combined with Back Propagation Neural Network (BPNN) improves prediction accuracy and speed [43-46]. A study reports that a method combining both BPNN and GA predicts water quality assessment with real time early warning systems [37]. Since all these online SWQMS deal with only assessment of water quality at discrete points of a river system or an isolated water sample [9,16,18,19, 50-54], there a need to develop SWQMS to predict water quality of a dynamic river system.

Therefore, initially an algorithm, namely River Quality Management (RQM) to predict water quality parameters has been developed taking into accounts the ratio and velocity of setteable bio-flocculated particulate matters, velocity variation and the changes in river dimension [47-49]. Later an improved version of RQM information system, which is also called as Advanced River Quality Management (ARQM) information systemis developed as an online SWQMS. The proposed system provides real time analysis of data at the set monitoring stations where sensors are installed and the prediction of water quality along the stretches is carried out using ARQM taking sensor data as input data. The present work aims to present cost effective and simpler solution for river pollution management through SWQMS using controller inbuilt with Wi-Fi module to send SMS alert when the water quality exceeds threshold and also to monitor parameters such as TSS, TDS, BOD, COD and DO.

II PROPOSED SYSTEM

This section is divided into two different sub-sections to explain the proposed system in detail. The first one is hardware design, which presents schematic diagram of the entire function of the present system and explains the water quality parameters and employed sensors. The second one is software design and flow chart that updates sensor data at the set time interval in the cloud, the language and the server used for developing the system.

(a) Hardware design

The proposed system measures the parameters pH value, conductivity, turbidity and river depth using different sensors. Though the parameters BOD, COD, TSS and Conductivity are independent, BOD and TSS may be calculated while COD and Conductivity can be deduced from the values of BOD and COD using regression analysis of the data if database is created for a certain period of time and for a certain source of water [55-57].

A correlation study is carried out among seventeen parameters of groundwater water quality and have found that eight parameters possesses adequate correlation with EC, that is, EC with TH is 88%, with Mg 97%, TA 84%, TDS 99%, chloride 98%, sulfate 94%, SAR 90%, sodium 95% [58]. The conductivity and turbidity are used to predict the water quality parameters such as TSS, TDS, BOD, COD and DO. The parameters such as TH, Mg, TA, Chloride, sulfate and SAR also can be estimated using statistical formulae derived for particular river water at the outfall points where the sensors are installed and used to predict the same for point-to-point prediction along the river stretch with the help of the ARQM information system.

The schematic diagram that explains function of the present system is presented in **Fig. 1.1**. The functions of water quality monitoring system were made active by the central unit of the IoT as a controller. Researchers have used a verities of controllers in smart water quality monitoring system, namely AtMega [59, 60], PIC [9, 51, 61], Raspberry pi with IOT [52,53,62], ARM LPC [44,63], Arduino [64-67], Controller 8051 [20] and MSP430 [68]. The IoT based solution normally is neither economic nor power effective as it uses controller additionally supported with externally attached Wi-Fi Further its circuitry design is very complex. Geetha and Gouthami (2014) use a single chip microcontroller TI CCS3200 with in-built Wi-Fi module and ARM Cortex M4 core, which searches nearest Wi-Fi hot spot for internet connectivity [54].

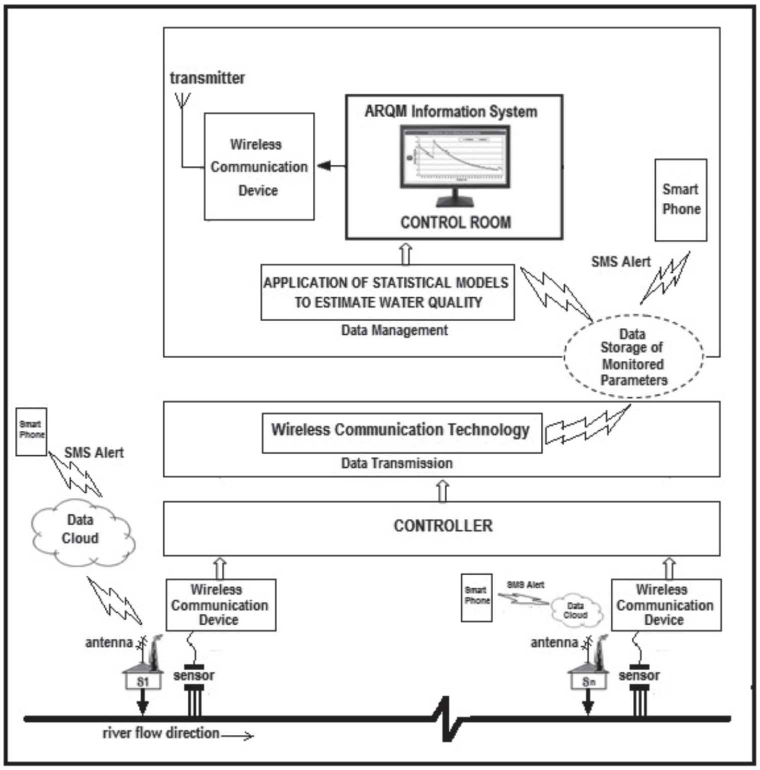


Fig. 1.1. **Schematic diagram of the ARQM system**

In the proposed ARQM Information System, four different sensors for measuring different parameters, namely conductivity, turbidity, pH value and river depth are installed at the reference and confluence points of industrial effluents just before mixing with the river and directly interfaced to wireless communication device (WCD). Sensor for measuring multiple parameters can also be used. An arrangement of Liquid Crystal Display (LCD) is made to display the measured water quality. The sensor data are transmitted to controller in the cloud using WCD. The threshold limit is set in the cloud based on the standards provided by Central Pollution Control Board (CPCB) for each parameter of surface water. Automatically SMS is sent from cloud to alert the environment manager of the respective industries whenever the river quality exceeds the permissible limit. Extending the circuit diagram reported by Geetha and Gouthami [54] for assessing drinking water samples, a mobile application is developed for assessing water quality of different locations along a river stretch and further to carry out point-to-point prediction of the same in a dynamic river system. The data obtained by each sensor in the cloud is viewable and the parameters TSS, TDS, DO, BOD and COD are estimated using statistical models with an assistance of a computer system. The ARQM information system is applied to predict river water quality using the input parameters from the database and the graphic of the same is plotted to display in LCD. The predicted data is again transmitted in the cloud with SMS alert so that the officer of each industry concern with environment management might take necessary action to control pollution along the river stretch adjusting the effluent discharging rates. Now the arrangements for measuring sensor data are explained in details as follows:

(i) Turbidity is measured as a degree to which the transparency or quality of water goes down due to the presence of suspended particulates. The more total suspended solids in the water, it seems gloomy and the higher the turbidity. Thus, the parameter turbidity is considered as a good measure of the quality of water. Light Dependent Resistor (LDR) and Light Emitting Diode (LED) are useful optoelectronic tools for measuring turbidity by allowing light transmitted through the water samples. When the LED emits light upon suspended particulate matters of river water sample and LDR receives the reflected light and the semiconductor engrosses the photons that represents the quantum of light and gives adequate energy to the bound electrons for soaring into the conduction band while the light falls on the device of high frequency. In between the tools LDR and LED, a fixed gap of 90 mm is kept. The resistance decreases when free electrons conduct electricity.

(ii) A mechanical system is fabricated and made to float on the surface water flexible to move up or down as the water level increase or decrease in the river with the help of two fixed rods on river bed and the water level is sensed to determine the depth of the river using IP68 Ultrasonic depth sensor.

(iii) The parameter pH is the amount of acid in the water. A pH meter of 3 in 1 which boosts the voltage from mV to V with inverting operating amplifier is installed to measure pH value. The pH sensor consists of two kinds of electrodes. The first is known as reference electrode and another is measuring kind. The first kind develops a potential which is proportional to pH while these electrodes are immersed in river water and the second kind measures. The pH value varies from 0 to 14 and the threshold limit is set in the range from 6 to 8.8.

(iv) Electrical conductivity of water is nothing but its ability to carry or pass current and it is used to assess the concentration of salt in the water. A sensor YL-69 consisting of two electrodes is used in the design to measure the conductivity of the river water while an electric potential is generated. This potential increases with the measure of conductivity. The conductivity is measured in seimens per cm. The acceptable limit of conductivity varies from 150 to 500 µ seimens per cm. SMS alert is sent to the concerned industrial units for necessary action to control pollution level when these parameters exceed the limit. Necessary arrangement is made for uninterruptible power supply at the monitoring sites to support the smooth function of the sensors.

(b) Software design

A software system is developed for sensor data updation in the cloud and the process of the system is explained through the flowchart as shown in **Fig. 1.2**. Readings from the different sensors are constantly updated in the cloud for the set interval and also displayed in the LCD. Energia IDE which is an open source and community-driven integrated development environment and software framework is used for programming the proposed system and the data sent to controller are stored in “Ubidots” cloud. “Ubidots” provides a podium for developers for capturing sensor data and make them serviceable so that other water quality parameters can be estimated using statistical models [69].

The data pertaining to river flow attributes such as river width distance between outfalls points, dispersion coefficients, settling velocity of settle able parameters, average rate of water pumped out for industrial use, average rate of effluent discharge are time to time updated in the database to be used as input parameters for the proposed ARQM information system. The water quality data that statistically generated from sensor data including the current water level in river are also input parameters to the system. The system consists of a real-time control panel to control the devices, to analyze the data and share them through public links.

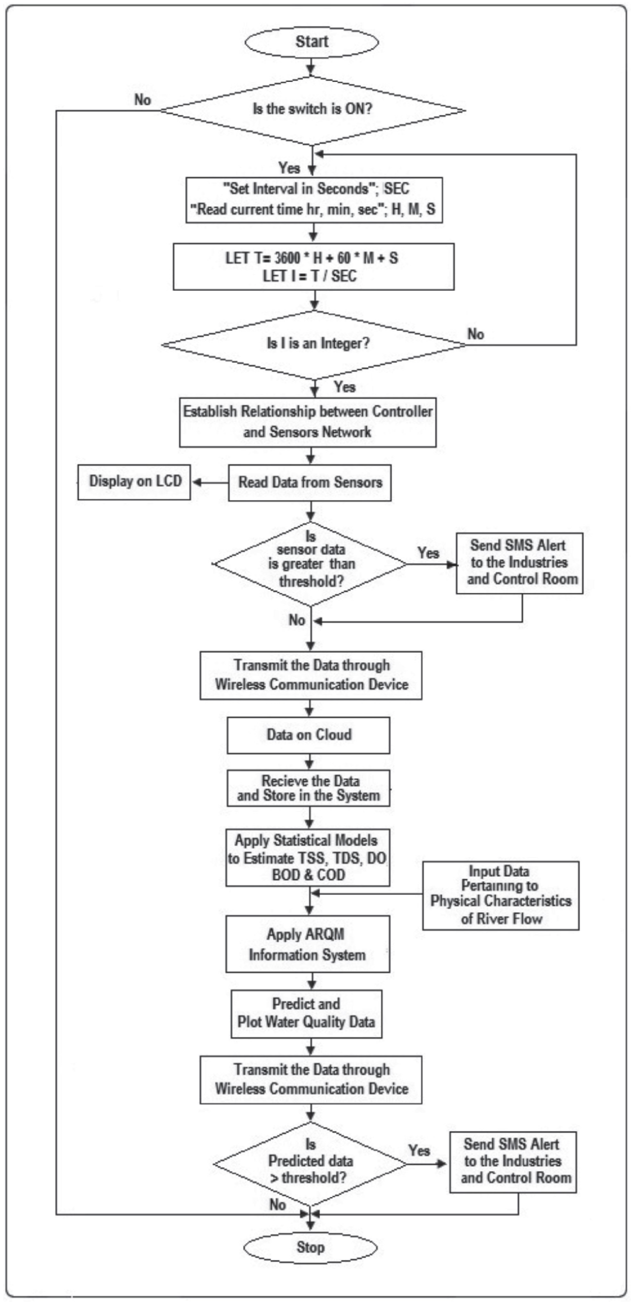


Fig. 1.2. Flow chart for updating sensor data in the cloud

Data transmitted in the cloud is retrieved for statistical analysis and arrangement for sending SMS alert is also programmed as and when the data exceeds the permissible limit. The following steps may help the users to connect the system with the Ubidots cloud:

- (i) Switch on to connect the access point with the help of SSID and password through mobile or computer
- (ii) Turn on Wi-Fi to connect the controller
- (iii) Login to cloud platform, where a user ID is generated
- (iv) Use the user ID in the program
- (v) Load the data from the controller into the cloud
- (vi) View data on the cloud platform

The ARQM information system is typically constructed with 3 layers of architectural design consisting of the provisions for presentation, business logic and data access based on the concepts, methodologies, tools involved in New Generation Wireless Sensor Network [73]. The presentation layer contains the component that implements and display the user interface and manage user interaction along with arrangement to control and display the outputs. The business layer represents the business rules that are enforced via programming logic regarding how those rules are applied. The data access layer consists of the definitions of database tables and columns and the computer logic that is needed to navigate the database [49]. An excellent user friendly interface and secured database management are the most important features of the system and also the need of the hours. The ARQM was developed with a database and process design in Visual Basic.NET using Visual Studio 2010 with MS SQL Server 2008.

III WATER QUALITY DISPERSION MODELLING

A river quality dispersion model is developed incorporating the variation in velocity and flow rate, average depth and width along the entire river stretch considered for study. The model computes flow rate at the reference point of the river system for the stream velocity fed to the system by the use and then simulates the velocity as well as the flow rates for each stretch according to the variation in depth and width of the stretch duly taking the intake water for industrial or domestic use and the water from the tributaries or effluents from the industries discharged into river system into consideration [48]. The dispersion model is supported with velocity distributive functions and flow rate computing model to incorporate the changes in stream velocity as well as flow rates while computation [49]. The reader may refer these articles for detailed information. However, only the model is recited here for the ready reference as follows:

Let us consider a analytical river system in 3D space wherein its XY-plane represents cross section of the river and Z-axis the length of the river stretch in the downstream where the point of origin assigned to the point on the top most layer of water flow corresponding to its maximum depth level. According to principle of fluid dynamics, the river flow rate will be greater the flow rates at all other points of the cross section normal to the flow direction. The dispersion model for predicting water quality parameters at P(x, y, z) when initial concentration and stream velocity at reference point P(0,0,0) just after critical mixing distance are c_o and v_o respectively, is as follows:

$$C(x,y,z) = \underbrace{p\left(\frac{c_o v(x,y,z)}{v_o}\right)\left[1-\frac{v_s' e^{-k' v(x,y,z)}}{\frac{D}{a_o^2}(a_o^2-x^2)}\left(\frac{z}{v(x,y,z)}\right)\right]}_{\text{Prediction of Settleable Component}} + \underbrace{(1-p)\left(\frac{c_o v(x,y,z)}{v_o}\right)e^{-\frac{kz}{v(x,y,z)}}}_{\text{Prediction of Non-Settleable Component}} \qquad (1.1)$$

IV APPLICATION OF ARQM

The industrial developments always take place at the river banks as it is convenient for the industries to dispose the effluents. The various industries situated at the bank of a river stretch identified as highly polluted segment are responsible to maintain the quality of river water and protect the aquatics following the norms for environmental pollution control. The database consisting of both sensed and measured from the reference as well as outfall points of the industrial sources S_1, S_2, S_3, …, S_n is communicated to control room through the network of schematic block diagram as shown in **Fig. 1.1**.

The ARQM information system is executed as explained through a flowchart presented in **Fig. 1.2** for point-to-point prediction of river water quality along the river stretch as output of the system and communicated to all the monitoring units of all industries connected in the network so that the necessary action such as controlling either the effluent flow or operation of industrial units to minimize impact of effluent on river quality. For an illustration of application of the system, a river, namely Damodar is chosen and a stretch of 38 km length starting from the effluent discharging point of Mahudah Coal Washery to the point of confluence a tributary, namely Gobai with the river. Research studies have revealed that the stretch is highly polluted [2, 6, 47-49]. The stretch is blended with effluent from seven coal washeries, one domestic sewage discharging point from Sindri Township and four tributaries called Katri river, Jitpur stream, Patherdih stream and Gobai river.

The data pertaining to reference point of Damodar river stretch and different industries situated at the bank of river such as velocity and flow rate of river water, concentration of water and effluent quality, average river depth, distance of industries from reference point are used as input parameters. Different sources of water pollution that pollutes associated with the selected Damodar river stretch along with their intake flow, effluent discharge during summer and winter are presented in **Table 1.1**. The concentration of different water quality parameters which are established to have adequate correlation with sensor data, are estimated from the same for a summer season and presented in **Table 1.2. T**he dispersion coefficients for the four conservative water quality parameters are estimated using the standard methods [70-72] and listed in **Table 1.3**.

There two categories of input data. The first one consists of input data that is assumed to be constant with season and time, which includes dispersion coefficients of different water quality constituents, distance between the outfall points, ratio of settleable bio-flocculated particulate matters, its settling velocity and dispersion coefficient, intake flow rates and discharging rates of effluents. The second one consists of the water quality constituents that vary frequently with season and time. The database consists of both categories of input data in the required data structure to be read by the computer program. The system primarily receives the required input data from the database and predicts the river water quality using ARQM information system.

The system is user friendly with Graphical User Interface (GUI) to receive information such as names of monitoring stations, intake quantity of water and effluent discharging rate from various industrial sources along with concentrations of different water quality parameters, which are correlated and deduced from sensor data using regression equations for reference point as well as industrial out-fall points from the database. Now the system simulates the flow rates and calculates the cross-sectional area of river along different sections of reference point as well as outfall points. Using the varying cross sectional area and simulated flow rates, the system calculates stream velocity at each outfall point and predicts the water quality along each stretch. Further, the system also provides options for editing of raw input data. Some snapshots of the system are provided in **Figs. 1.3** to **1.5.**

Table 1.1.
Different sources of water pollution that pollutes the selected Damodar river stretch and its flow rate

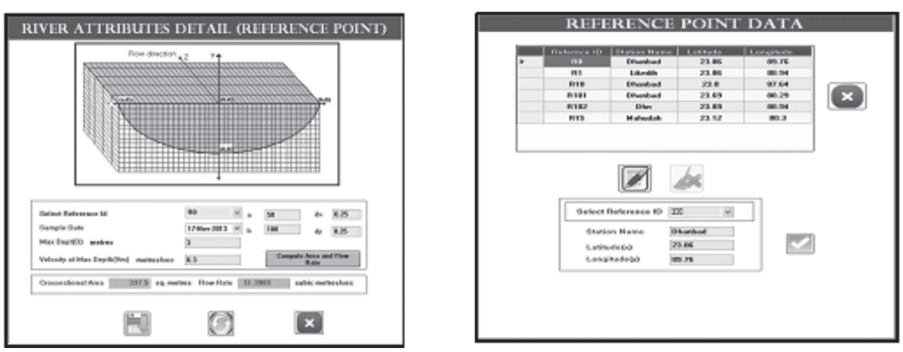
Source	Sources of Water Pollution	Intake (m^3/s)		Discharge (m^3/s)	
		Intake	Total	Sumer	Winter
S0	Mahuda Washery	0.005	0.005	0.004	0.004
S1	Loyabad Coke Oven Plant Loyabad Power House	0.046 0.038	0.080	0.040	0.044
S2	Moonidih Washery	0.016	0.016	0.014	0.014
S3	Jamodoba Washery Jamadoba Power House-1 Jamadoba Power House-3	0.011 0.045 0.048	0.104	0.099	0.101
S4	Patherdih Coal Washery	0.013	0.013	0.012	0.124
S5	Sudamudih Coal Washery	0.015	0.015	0.013	0.013
S6	Chasnallah Coal Washery	0.016	0.016	0.014	0.015
S7	FCI (Outfall - 1) & P&D Sindri Township	0.429	0.429	0.226	0.220
S8	FCI (Outfall - 2) Sindri	0.000	0.000	0.164	0.184
S9	Bhojudih Washery Santaldih TPS	0.014 0.011	0.025	0.022	0.025

Table 1.2.
Concentration of estimated water quality parameters

Sourse Code	Sources	Discharged through:	Water Quality Concentration (mg/l)				
			TSS	TDS	DO	BOD	COD
R	Damodar River (Upstream source)	Damodar	112	260	5.45	10.85	180
S0	Mahuda Washery	Directly	1270	300	3.35	7.25	3595
S1	Loyabad Coke Plant Loyabad PH Loyabad Township	Katri river	235	258	5.66	19.90	308
S2	Moonidih Washery	Directly	1203	335	3.72	4.46	3675
S3	Jamodoba Washery Jamadoba, Pump House – 1 & 3 and Jamadoba Township	Jitpur stream	370	283	5.72	6.25	125
S4	Patherdih Washery Patherdih Township	Patherdih stream	640	390	4.59	6.60	1930
S5	Sudamudih Washery	Directly	1780	560	3.25	7.20	3965
S6	Chasnalla Washery	Directly	1455	360	3.84	4.42	3673
S7	FCI (Outfall -1) P&D Sindri Township	Directly	890	421	6.31	3.83	1870
S8	FCI (outfall - 2) Sindri	Damohani river	589	352	4.52	5.52	75
S9	Bhojudih Washery Santaldih TPS Bhojudih Township	Govai river	555	425	6.54	4.85	552

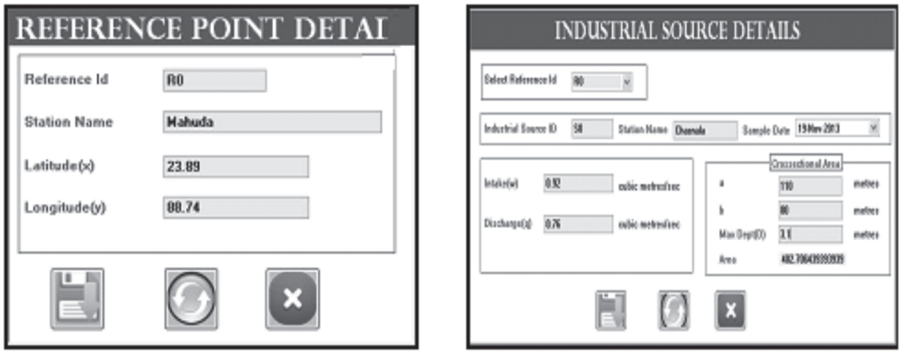
Table 1.3.
Dispersion coefficients of water quality parameters

Parameter	Dispersion Coefficient
BOD	0.2×10^{-3}
DO	-0.14×10^{-4}
TSS	0.2×10^{-4}
TDS	-0.2×10^{-4}



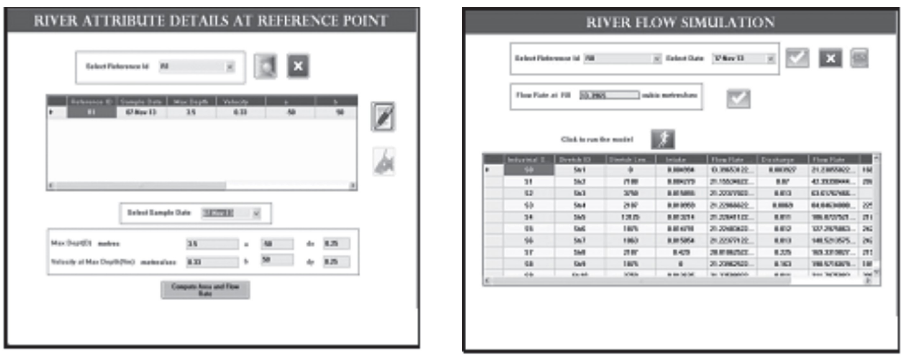
(a) (b)

Fig. 1.3. River attributes: (b) Cross section details and (b) Reference point data



(a) (b)

Fig. 1.4. Industrial source data: (a) Reference point and (b) Industrial source



(a) (b)

Fig. 1.5. River flow data: (a) Reference point and (b) River stretch

V RESULTS

The ARQM information system reads the required input data from the database after the set interval of time and predicts the water quality parameters. The point-to-point prediction of water quality data IS graphically visualized for each parameter and the same is transmitted in the cloud again to the terminals of the industries to receive and take necessary action to control the river pollution by controlling either the industrial operation or effluent discharging rate. The graphics generated by the system are presented for different parameters considered for the present study in **Figs. 1.6** to **1.10**.

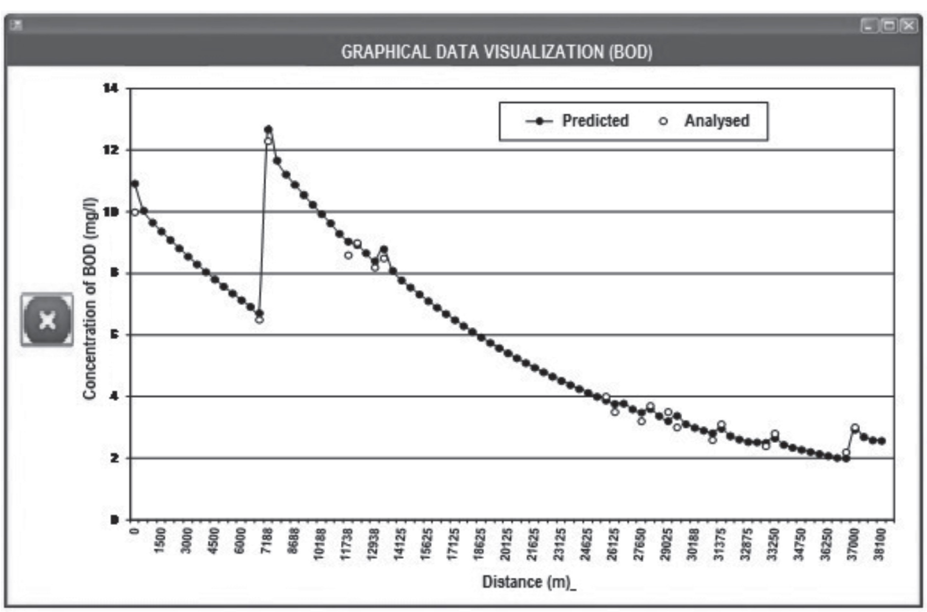


Fig. 1.6. Prediction of BOD along river stretch

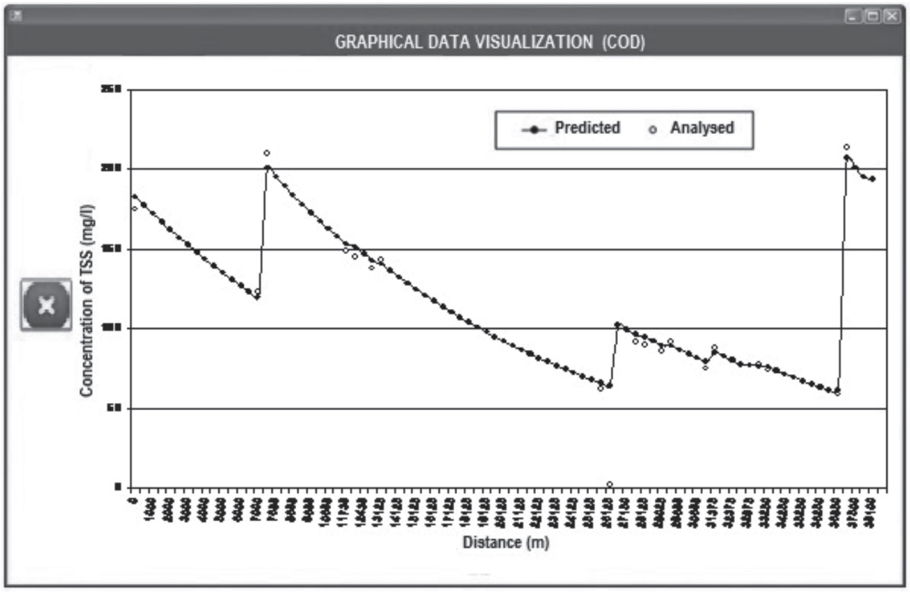


Fig. 1.7. Prediction of COD along river stretch

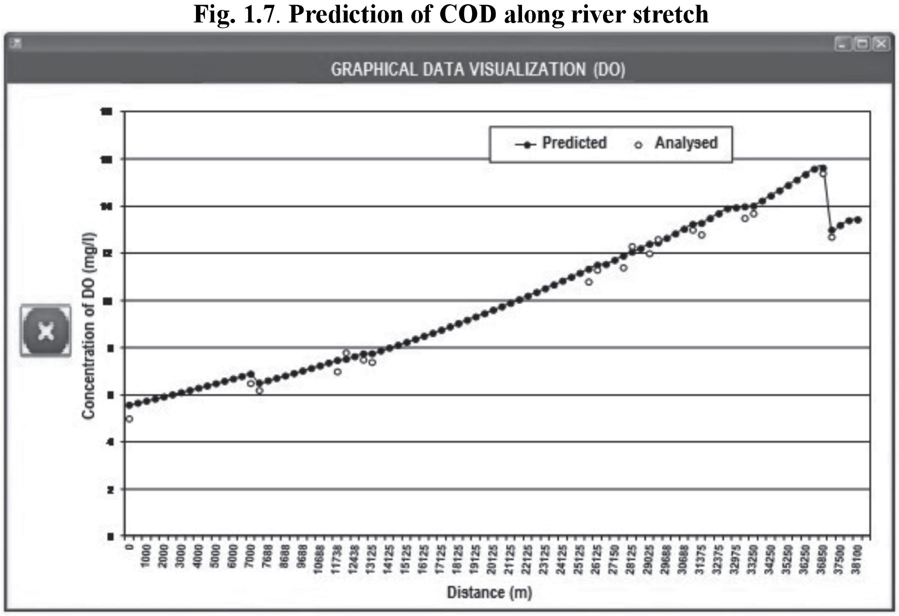


Fig. 1.8. Prediction of DO along river stretch

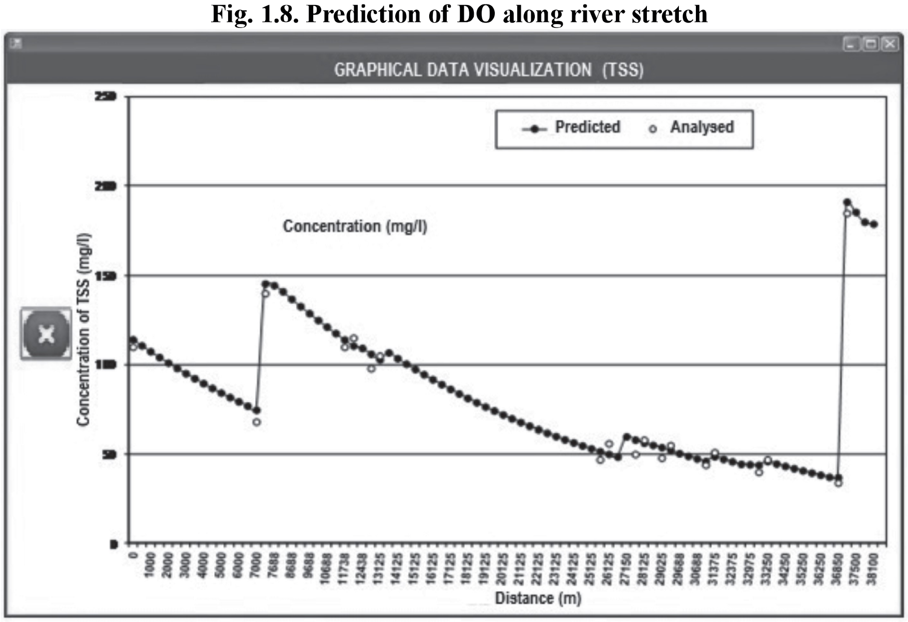


Fig. 1.9. Prediction of TSS along river stretch

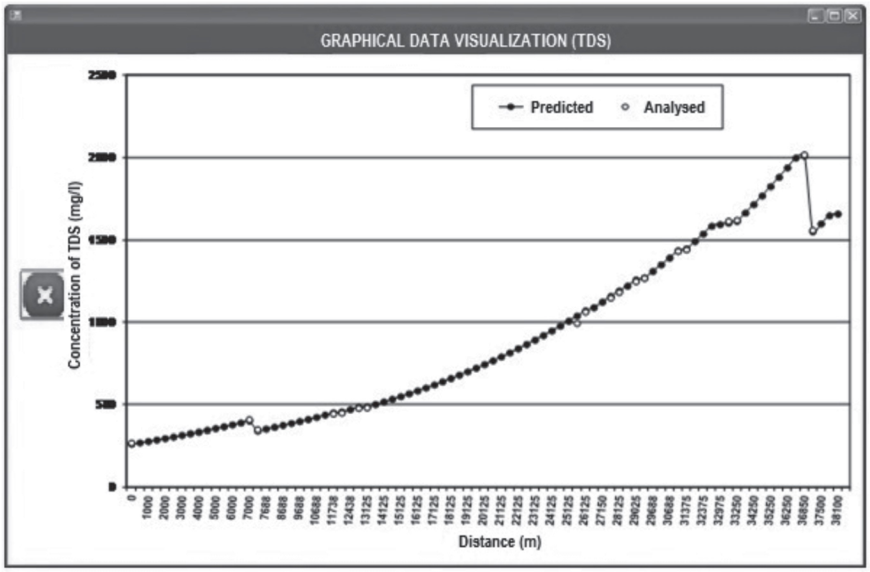


Fig. 1.10. Prediction of TDS along river stretch

VI DISCUSSION

Function of the present system has three-fold stages. At first stage, the analog signals of the sensor are converted into digital signals by an inbuilt analog-to-digital converter (ADC) into digital signals at the receiving end so that the computer can process the data in its digital format. The data is transmitted in the cloud to the Control Unit/Room and also SMS alert is sent to the officer of the respective industry concerned with the environment for necessary action as and when the parameter exceeds the threshold limit. At the second stage, the Control Unit/Room receives the data from the cloud and the river quality parameters BOD, DO, COD, TSS and TDS are estimated using the regression models and stored in the database along with the other required input parameters which are not variable with season for each outfall points which are discharging their effluents to the river stretch starting from the reference to the end of the river stretch selected for the prediction study. Finally at the third stage, the ARQM information reads the data from the input file and predicts the water quality along the river stretch and the predicted data are stored in output file. The system was validated and it was found that the predicted data reveals 3-7% variation from the actual data, which may be acceptable for environmental studies. Further it is observed that there is a reduction in the impact of effluent when the outfalls meet with the river as dilution takes place after the effluent mixing well in huge quantity of water. However, the parameters TDS and DO increase with time or distance in the downstream whereas TSS, BOD and COD decrease.

VII CONCLUSION

In the progress of ICT, development of online river quality monitoring system for river pollution management is gradually gaining the importance as it is more effective and economic. Finding solutions save huge investment of fund towards assessment of river water quality in conventional method. The present study addresses an online pollution management tool, namely ARQM information system which is an effective in power consumption and simple IoT technology for smart water quality monitoring. The present wireless sensor network is used for estimating conductivity, turbidity, water level and pH and further used for estimating BOD, COD, DO, TSS and TDS using regression models.

These parameters are used as input parameters as a part of the required input parameters for predicting water quality. The system also warns remote users through SMS alerts whenever the water quality exceeds the thresholds. The proposed system was developed user friendly with appropriate GUI so that any non-programmer can easily handle the system. The system is unique from other existing algorithms as it assesses the water quality and carries out point-to-point prediction along the river stretch. The system is applied for the prediction of water quality along the stretch of Damodar in Jharkhand State, India, blending with multi-industrial outfalls and the effluents from township areas as environmental monitoring system [74]. It is necessary to check the energy competency to apply solar panel to meet the required energy for smooth function of the system so that it may be installed in remote area where electricity is not possible [75]. The statistical analysis of the predicted data and the analyzed one reveals that 3-7% error may occur in the predicted water quality data, which may be admissible. Employing the technique of data visualization in the frame work of .NET provides vivid choice of graphs to visualize the different water quality parameters to the end users with adequate clarity and accuracy. The present system would be a great help to the industrialists concern with the department of environment management control to minimize the pollution load along the river stretch by either optimizing the discharge rates of the effluents or controlling operational units.

(a) Notations Used

a_o= half of the river width measured as length of topmost layer normal to flow direction

C(x,y,z) = concentration of the water quality constituent of volumetric element whose centre is at ***P(x,y,z)***

D = maximum depth of the river

k = dispersion coefficient of the water quality constituent

k′ = dispersion coefficient of the bio-flocculate particulate matter able settle down in the water

p = fraction of the settleable bio-flocculated particulate matters

P(x,y,z) = a point on the cross section of the river normal to flow direction whose coordinates are x, y, z from the origin of the 3D analytical river system in the directions of X, Y, Z – axes respectively

v(x,y,z) = velocity of the stream flow at the point ***P(x,y,z)***

v′ = settling velocity of the bio-flocculate particulate matter able to settle down in static condition

REFERENCES

[1] Nath A, Kumar R, Behura AK, Sundararajan M (2019) Corporate Social Responsibility for Sustainable Development, Indian Journal of Environmental Protection, Vol 36, No. 6, pp. 545-550

[2] Singh G (2005) Regional Environmental and Social Challenges facing the Coal Industry. The Coal Summit, Organised the India Energy Forum, Indian Coal Forum and MGMI, 19-20 October

[3] Ugya AY, Ajibade FO, Ajibade TF (2018) Water Pollution Resulting from Mining Activity: an Overview, Proceedings of the 2018 Annual Conference of the School of Engineering & Engineering Technology (SEET), The Federal University of Technology, Akure, Nigeria, 17-19 July

[4] Water Resource Information System of India (2017) http://www.india-wris.nrsc.gov.in/wrpinfo/index.php?title=River_Water_Quality_Monitoring. Accessed 2 May 2017

[5] Central Ground Water Board (2017) Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. http://cgwb.gov.in/. Accessed 24 July 2017

[6] Ghose MK, Roy S (1994) Impact on surface water quality due to coke oven effluents. India: N. pp. 201-205 https://www.osti.gov/etdeweb/biblio/97484

[7] Muinul H, Syed I, Alex F, Homayoun N, Rehan S, Manuel R, Mina H (2014) Online Drinking Water Quality Monitoring: Review on Available and Emerging Technologies. Crit Rev Env Sci Tech 44(12):1370–1421

[8] Jianhua D, Guoyin W, Huyong Y, Ji X, Xuerui Z (2015) A survey of smart water quality monitoring system. Environ Sci Pollut Res 22(7):4893–4906

[9] Niel AC, Reza M, Lakshmi N (2016) Design of Smart Sensors for Real-Time Water Quality Monitoring. J IEEE Access 4: 3975–3990

[10] Alessio B, Walter D, Valerio P, Antonio P (2016) Integration of Cloud computing and Internet of Things: A survey. Futur. Gener Comput Syst 56:684–700

[11] Bushra R, Mubashir HR (2016) Applications of wireless sensor networks for urban areas: A survey. J Netw Comput Appl 60:192–219

[12] Biljana L, Risteska S, Kire VT (2017) A review of Internet of Things for smart home: Challenges and solutions. J Clean Prod 140(3):1454–1464

[13] Andrea Z, Nicola B, Angelo C, Lorenzo V, Michele Z (2014) Internet of Things for Smart Cities. IEEE Internet Things J 1(1):22–32

[14] Al-Fuqaha A et al (2015) Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. IEEE Commun Surv Tutorials 17(4):2347–2376

[15] Eliades D, Lambrou T, Panayiotou C, Polycarpou M (2014) Contamination Event Detection in Water Distribution Systems using a Model-Based Approach. In: 16th Conference on Water Distribution System Analysis. 14–17 July 2014

[16] Offiong N, Abdullahi S, Chile B, Raji H, Nweze N (2014) Real Time Monitoring Of Urban Water Systems for Developing Countries. IOSR J Comput Eng 16(3):11–14

[17] Gye WC et al, (2016) SWMI: new paradigm of water resources management for SDGs, Smart Water International Journal for @qua – Smart ICT for Water 2016, 1:3

[18] Xin W, Longquan M, Huizhong Y (2011) Online Water Monitoring System Based on ZigBee and GPRS. Adv Control Eng Inform Sci:2680–2684

[19] Xiuli M, Xo H, Shuiyuan X, Qiong L, Qiong L, Chunhua T (2011) Continuous, online monitoring and analysis in large water distribution networks. In: International Conference on Data Engineering, 11-16. April 2011

[20] Li Z, Wang K, Liu B (2013) Sensor-Network based Intelligent Water Quality Monitoring and Control. Int J Adv Res Comput Engg Tech 2(4):1659–1662

[21] Ruan Y, Tang Y (2011) A water quality monitoring system based on wireless sensor network & solar power supply. In: 2011 IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent System, 20–23, Mar 2011

[22] Tomoaki K, Masashi M, Akihiro M, Akihiro M, Sang L (2016) A wireless sensor network platform for water quality monitoring. In: IEEE Sensors, Oct. 30-Nov. 3 2016

[23] Azedine C, Antoine G, Patrick B, Michel M (2000) Water quality monitoring using a smart sensing system. Measurement:219–224

[24] Goib W, Yudi Y, Dewa P, Iqbal S, Dadin M (2015) Integrated online water quality monitoring. In: International conference on smart sensors and application, 26–28 May 2015

[25] Xiuna Z, Daoliang L , Dongxian H, Jianqin W, Daokun M, Feifei L (2010) A remote wireless system for water quality online monitoring in intensive fish culture. Computers Electronics Agriculture :S3-S9

[26] Brydon DA, Frodsham DA. (2001) A model-based approach to predicting BOD5 in settled sewage, Water Science and Technology, vol. 44, no. 2-3, pp. 9-15

[27] Cho JH. et al (2004) A river water quality management model for optimising regional wastewater treatment using a genetic algorithm, Journal of Environmental Management, vol. 73, no. 3, pp. 229-242

[28] Zou R, Lung WS (2004) Robust water quality model calibration using an alternating fitness genetic algorithm, Journal of Water Resources Planning and Management, vol. 130, no. 6, pp. 471-479

[29] Icaga Y (2005) Genetic algorithm usage in water quality monitoring networks optimization in Gediz (Turkey) river basin, Environmental Monitoring and Assessment, vol. 108, no. 1-3, pp. 261-277

[30] Chandramouli V. et al (2007) Backfilling missing microbial concentrations in a riverine database using artificial neural networks," Water Research, vol. 41, no. 1, pp. 217-227

[31] Han HG et al (2011) An efficient self-organizing RBF neural network for water quality prediction, Neural Network, vol. 24, no. 7, pp. 717-725

[32] Liu Y et al. (2008) Water quality modeling for load reduction under uncertainty: a Bayesian approach, Water Research, vol. 42, no. 13, pp. 3305-3314

[33] Ip WC et al (2009) Applications of grey relational method to river environment quality evaluation in China, Journal of Hydrology, vol. 379, no. 3-4, pp. 284-290

[34] Smeti EM et al (2009) Treated water quality assurance and description of distribution networks by multivariate chemometrics, Water Research, vol. 43, no. 18, pp. 4676-4684

[35] O'Connor E et al (2012) A neural network approach to smarter sensor networks for water quality monitoring, Sensors (Basel), vol. 12, no. 4, pp. 4605-4632.

[36] Senkal O et al (2012) Precipitable water modelling using artificial neural network in Cukurova region, Environmental Monitoring and Assessment, vol. 184, No. 1, pp. 141-147

[37] Ding YR, Cai YJ, Sun PD, Chen B (2014) The Use of Combined Neural Networks and Genetic Algorithms for Prediction of River Water Quality, Journal of Applied Research and Technology, Vol. 12, P.493-499

[38] Rogers LL et al (1995) Optimal field-scale groundwater remediation using neural networks and the genetic algorithm, Environmental Science & Technology, vol. 29, no. 5, pp. 1145-1155

[39] Ledesma-Orozco S et al (2011) Hurst Parameter Estimation Using Artificial Neural Networks, Journal of Applied Research and Technology, vol. 9, no. 2, pp.227-240

[40] Baharodimehr A. et al (2009) Capacitive MEMS accelerometer wide range modeling using artificial neural network, Journal of Applied Research and Technology, vol.7 no. 2, pp. 185-192

[41] Arab MR, et al. (2010) Electroencephalogram Signals Processing for the Diagnosis of Petit mal and Grand mal Epilepsies Using an Artificial Neural Network, Journal of Applied Research and Technology, vol. 8 no.1, pp. 120-129

[42] Rivera-Mejía J. et al (2012) PID based on a single artificial neural network algorithm for intelligent sensors, Journal of Applied Research and Technology, vol.10, no.2, pp. 262-282.

[43] Petridis, V, et al (1998) A hybrid neural-genetic multimodel parameter estimation algorithm," IEEE Transactions on Neural Networks, vol. 9, no. 5, pp. 862-876

[44] Kuo JT et al (2006) A hybrid neural-genetic algorithm for reservoir water quality management, Water Research, vol. 40, no. 7, pp. 1367-1376

[45] Dalal SG. et al (2010) Evaluation of significant sources influencing the variation of water quality of Kandla creek, Gulf of Katchchh, using PCA, Environmental Monitoring and Assessment, vol. 163, no. 1-4, pp. 49-56

[46] Olsen RL et al. (2012) Water quality sample collection, data treatment and results presentation for principal components analysis--literature review and Illinois River Watershed case study," Water Research, vol. 46, no. 9, pp. 3110-3122

[47] Mohan A. & Sundararajan M (2010) Algorithm Development for Water Quality Prediction System along Industrial Outfall River Stretch Using Modeling and Computer Simulation. International Journal of Engineering Science and Technology, 2(11), 6204-08

[48] Sundararajan M, Tiwary RK, Singh AK (2013) A Strategic Study on Assimilative Capacity of Damodar River Stretch Blended with Multi-Outfalls of Industrial Effluents through flow analysis and Dispersion Modeling, Proceedings of the National Conferences on Recent Advances in Mathematics and its Applications, ISM, 365-367, Dhanbad.

[49] Sundararajan M, Mohan A, Chakrabarty G (2014) Development of River Quality Management (RQM) Information System for River Stretches Blending with Multi-Industrial Effluents, Environmental Science, vol.3, no.12, p.769-773

[50] Xin W, Longquan M, Huizhong Y (2011) Online Water Monitoring System Based on ZigBee and GPRS. Adv Control Eng Inform Sci:2680–2684

[51] Theofanis PL, Christos CA, Christos GP, Marios MP (2014) A Low-Cost Sensor Network for Real-Time Monitoring and Contamination Detection in Drinking Water Distribution Systems. IEEE Ssensors J 14(8):2014

[52] Vijayakumar N, Ramya R (2015) The real time monitoring of water quality in IoT environment. In: international conference on circuits, power and computing technologies, 19–20 March 2015

[53] Jayti B, Patoliya J (2016) IoT based water quality monitoring system, In: Proc of 49th IRF Int Conf, 21 Feb 2016

[54] Geetha S, Gouthami S (2016) Internet of things enabled real time water quality monitoring system. Smart Water 2, 1 https://doi.org/10.1186/s40713-017-0005-y

[55] Dasharath D, Reddy EN (2018) Relation between turbidity and total dissolved solids based on flow rate of the godavari water, Journal of Ultra Chemistry, Vol. 2, No. 2, P. 45-48

[56] Fondriest Environmental, Inc. (2014) Turbidity, Total Suspended Solids and Water Clarity, Fundamentals of Environmental Measurements. 13 Jun. 2014.

[57] Bakhtiar Jemily NH., Ahmad Sa'ad FN., Mat Amin AR., Othman MF., Mohd Yusoff MZ. (2019) Relationship Between Electrical Conductivity and Total Dissolved Solids as Water Quality Parameter in Teluk Lipat by Using Regression Analysis. In: Abu Bakar M., Mohamad Sidik M., Öchsner A. (eds) Progress in Engineering Technology. Advanced Structured Materials, vol 119. Springer, Cham

[58] Shroff P, Vashi RT, Champaneri VA, Patel KK (2015) Correlation study among water quality parameters of groundwater of Valsad District of South Gujarat (India), Jl. Fundamental & Applied Sciences, Vol. 7, No. 3, 340-349, ISSN: 1112 9867.

[59] Thinagaran P, Nasir S, Leong CY (2015) Internet of Things (IoT) enabled water monitoring system. In: 4th IEEE global conference on consumer electronics, 27–30 Oct. 2015

[60] Mitar S, Goran M, Libu M, Krzystof Z (2016) Multi-sensor system for remote environmental (air and water) quality monitoring. In: 24th telecommunications forum, 22–23 Nov. 2016

[61] Vinod R, Sushama S (2016) Wireless acquisition system for water quality monitoring. In: Conference on advances in signal processing, 9–11 June 2016

[62] Sathish K, Sarojini M, Pandu R (2016) IoT based real time monitoring of water quality. Int J Prof Eng Stud VII(5):174–179

[63] Francesco A, Filippo A, Carlo GC, Anna ML (2015) A Smart Sensor Network for Sea Water Quality Monitoring. IEEE Sensors J 15(5):2514–2522

[64] Anthony F, Aloys N, Hector J, Maria C, Albino J, Samuel B (2014) Wireless Sensor Networks for Water Quality Monitoring and Control within Lake Victoria Basin: Prototype Development. Wirel Sens Netw 6:281–290

[65] Christie R, Mallory C, Jared L, Alan M (2014) Remote Delay Tolerant Water Quality Monitoring. In: IEEE global humanitarian technology conference, 10–13 Oct 2014

[66] Pandian DR, Mala K (2015) Smart Device to monitor water quality to avoid pollution in IoT environment. Int J Emerging Tech Comput Sci Electron 12(2):120–125

[67] Gerson G, Christopher B, Stephen M, Richard O (2012) Real-time Detection of Water Pollution using Biosensors and Live Animal Behavior Models, In: 6th e Research Australasia Conference, 28 Oct −1 Nov 2012

[68] Peng J, Hongbo X, Zhiye H, Zheming W (2009) Design of a Water Environment Monitoring System Based on Wireless Sensor Networks. J Sensors 9:6411–6434

[69] Ubidots (2017) IoT platform | Internet of Things. https://ubidots.com/. Accessed 22 June 2017

[70] Glover, RE. (1964) Dispersion of dissolved or suspended Materials in Flowing Streams, U.S. Geological Survey Professional Paper 433-K, U.S. Government Printing Office, Washington, D.C

[71] Fischer HB. (1967) The mechanics of dispersion in natural streams, J. Hydraulic Div., American Society of Civil Engineers, 93(HY6), 187

[72] Fischer HB. (1967) Dispersions predictions in natural streams, J. Sanit. Eng. Div., American Society of Civil Engineers, 94(SA5), 927

[73] Yang W, Wang X, Song X, Yang Y, Patnaik S (2018) Chapter 28: Design of Intelligent Transportation System Supported by New Generation Wireless Communication Technology, Intelligent Systems: Concepts, Methodologies, Tools, and Applications (4 Volumes), Edited by Information Resources Management Association (USA), pp.715-732

[74] De D, Mukherjee A, Das SK, Dey N (2020) Chapter 1: Wireless Sensor Network: Application, Challenges and Algorithms, Nature Inspired Computing for Wireless Sensor Networks, Edited by De D, Mukherjee A, Das SK, pp. 1-20, Springer

[75] Das SK, Tripathi S, Burnwal AP (2015)Intelligent energy competency multipath routing in WANET. In Information systems design and intelligent applications, pp. 535-543). Springer, New Delhi