AquaPredicto – Freshwater Quality Management System for Lakes

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Abstract:** Lakes are important part of urban ecosystem. Though relatively small in size, lakes perform significant environmental, social and economic functions, ranging from being a source of drinking water, recharging groundwater, acting as sponges to control flooding, supporting biodiversity and providing livelihoods. Water in lakes is an easily available source of water for the needs of many sectors of economy such as agriculture, domestic and industrial. These water bodies, whether man-made or natural, fresh water or brackish play a very vital role in maintaining environmental sustainability particularly in urban environments especially in today's context when the cities are facing the challenges of unplanned rapid urbanization. At present, in India, lakes and wetlands are in extremely bad shape and are in varying degrees of environmental degradation. Despite knowing their environmental, social and economic significance, city planners have wilfully neglected and destroyed these water bodies. Today these water bodies are encroached, full of sewage and garbage. Due to unplanned urbanization, much of the landscape around the lakes has been covered by impervious surfaces. As a result, instead of rainwater, it is the sewage and effluents that are filling up urban water bodies. Once the sponges of urban area, today urban lakes have turned into hazards that get choked even with low rainfall and overflow into the blocked canals during high rainfall causing floods in the city. It is the disappearance of these sponges of the city that has exacerbated floods and sharpened the pain of droughts (Churning Still Water, 2012). Our system consists of sensors including temperature, Total Dissolved Solids (TDS) and pH sensor to calculate the water quality index and create the mathematical model to predict the variation of the parameters in the future. The system will help stakeholders and public to be aware of the condition of the lakes and take corrective actions to prevent further degradation.

Keywords: *Sensors, Data Acquisition, Regression Analysis, Neural Networks, Signal Processing*

I. INTRODUCTION

Water quality management is a critical component of overall integrated water resources management. Most users of water depend on adequate levels of water quality. When these levels are not met, these water users must either pay an additional cost for water treatment or incur at least increased risks of damage or loss. As populations and economies grow, more pollutants are generated. Many of these are waterborne, and hence can end up in surface and groundwater bodies. Increasingly, the major efforts and costs involved in water management are devoted to water quality protection and management. Conflicts among various users of water are increasingly over issues involving water quality as well as water quantity. Water resources management involves the monitoring and management of water quality as much as the monitoring and management of water quantity. Various models have been developed to assist in predicting the water quality impacts of alternative land and water management policies and practices. Regrettably, in most parts of the developed world it is no longer safe to drink natural surface or ground waters; they usually need to be treated before they become fit for human consumption. [1]

II. LITERATURE SURVEY

The increasing demand by citizens and other involved parties for cleaner waters in rivers, lakes, ground waters etc., was one of the main reasons why the European Union (EU) Commission in 1995 started formally the process towards a new and more holistic approach to European water policy, accepting so also requests from European Parliament's Environment Committee and from the Council of Environment Ministers (European Commission,2002). [2]

There are many good reasons why models are used in providing advice, information and even predictions for the management of our lakes, rivers and other water bodies, which are complex systems and consist of numerous interconnected subsystems. As Dale (2003) phrases it, models help to organize, synthesize, and track information and scientific knowledge and hypothesis in a way that would not be possible otherwise. Appropriate models represent the essential features of a system, and they can be valuable tools e.g. for environmental managers to enhance understanding of both the complexities and the uniqueness of a given situation and its response to environmental management decisions or other changes. Although many consider that models' main function is to give predictions about the future, often a much more useful and appropriate way to use models is to improve one's understanding and insight about the system's relationships and management implications (Dale, 2003). [3]

The economic activity of society brings negative changes in aquatic systems e.g. changing the chemical composition of water and disrupting aquatic systems. Most human activities are carried out using water from rivers, which is lately steadily declining. Water must meet quality standards in order to be used.

The term "water quality" is defined in several ways:
- Depending on the intended use of the water – is a set of chemical, physical and biological characteristics, concerning its capacity for a particular case application [4].
- From the point of view of environmentalists – the state of an aquatic system referred to the physicochemical conditions of this system, which could support a healthy community to the aquatic biota in balance in local conditions.
- According to sanitary engineering – water quality refers to a specific location in terms of human health, including diseases transmitted through water. From the point of view of specialists in water management – water quality is defined by human uses, such as drinking water, irrigation, industrial or transportation use and power generation [5].

According to the Water Framework Directive 2000/60/EC (Amended by Directive 2008/32/EC) approved by the European Commission, till 2015 it is required to be insured status "very good" for all Water Bodies. The main objective of the Directive is to protect and improve the ecological status of aquatic ecosystems. This can be achieved through appropriate management of water systems and environmental quality standards on pollution management processes of water systems. Currently, water quality assessment in accordance with the requirements of the Water Framework Directive for several rivers in Europe showed a satisfactory or unsatisfactory environmental condition. In this connection, it is necessary to fulfil the "river-type" water systems to rehabilitate and maintain them in a state "very good" [6, 7].

Problems of environmental pollution requires swift action to prevent lowering water quality. Choosing pollution control methods and determining quality is an important step in improving water quality. An effective method of controlling and predicting water pollution is the use of information systems consisting of two main components: mathematical models and software, which are generated by numerical models [8].

Knowing the importance of water for sustenance of life, the need for conservation of water bodies especially the fresh water bodies is being realized everywhere in the world. This need has added significance, especially in the water stressed region such as Rajasthan. Srivastava et al., (2003) [9] reported that the Jal Mahal Lake water was most polluted due to high pH, hardness, alkalinity, free Carbon Dioxide and Zinc content and a low level of dissolved oxygen. Study of other physiochemical properties of the Jamwa Ramgarh Lake in Jaipur revealed that the water quality is not fit for drinking without treatment. Changes in water quality were due to use of land for agriculture after water recedes in the dried up area of the wetland, waste disposal and polluting practices around the lake (Moundiotiya et al., 2004). The present study, deals with assessing the quality of main water bodies of Jaipur, viz. Amber Lake, Jal Mahal Lake and Galta Lake.

That study assessed the physio-chemical parameters of three lakes of Jaipur. The results revealed that the various parameters like temperature, pH, alkanity, hardness and dissolved oxygen, were found to be on the higher side at Jalmahal Lake as compared to Amer and Galta Lake.

Upper Lake is one of the important urban lakes of India, located in Bhopal which is a state capital of Madhya Pradesh. This lake is being used as a prime source of drinking water supply for Bhopal city. Present investigation was an attempt to assess the Upper Lake water quality by using palmer and trophic state index for better understanding of limnetic chemistry. Results revealed that concentration of important parameters which mainly govern the lake chemistry were found beyond the permissible limits and above to the threshold level of eutrophication. By perusing the results of Palmer Index, out of 20 Genus, 12 Genus were found with total index value of 27 that indicate organic pollution in lake while results of trophic state index indicate that Upper Lake is in higher stage of eutrophy due to high nutrients loading [10]. The next study was conducted in Bramhasarovar Lake to determine the levels of water quality indicators and to study statistical interrelationships amongst them. An attempt has also been made to establish regression equations to provide a prediction of water quality prior to detailed investigation. The studies were conducted at the "Brahmsarovar" an important religious water tank at Kurukshetra in India, where mass bathing (about 3-4 lakh pilgrims) on new moon day is an important activity.

III. METHODOLOGY

To solve the pertaining problem, we thought of providing an engineering solution to it which will assess the physical and chemical parameters of the lake and then project a general overview about the current viable condition of the lake. With techniques such as mathematical modelling we intend to make a product which can collect a data and present the trend of values the lake ecosystem can project in coming months and years. This will not only help in generating awareness among the public but also take necessary preventive steps and measures to counter the negative trend. This project has a huge scope in protecting the deteriorating state of lakes and maintain a balance in the ecosystem.

The aim of the project is to develop a device [Fig.1] for the above mentioned problem using sensors and build a physical model which can do the following actions:

1. Assessing of physical and chemical parameters of the lake.
2. Derive a water quality of the index and study the behavioural relations of the parameters over a span of time.

3. Use mathematical modelling techniques for prediction of parameters helping in conservation of lakes.

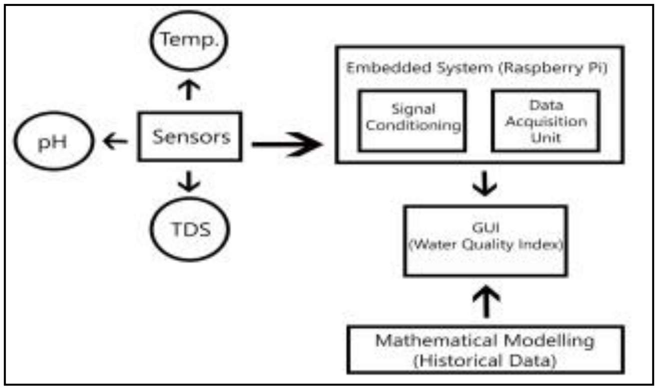


Fig.1: Block Diagram of the device

As it can be seen three sensors have been interfaced with Raspberry Pi using after the signal conditioning circuit helps in removing the unwanted noise and necessary amplification is provided. These three sensors are temperature, pH, and total dissolved solids (TDS). Tkinter[12] is used for the programming of the Graphical User Interface (GUI) which is a python based IDE. The water quality index is shown on the screen using the algorithm discussed in the later parts of the report on Q Values of each factor and how weighing factors affect the value of the final Q factor. Also, mathematical modelling techniques using MATLAB and Mathematica are taken up to best-fit a curve for each 'parameter vs time' dataset over 10 years. The model was trained to predict values over the time and generate high correlation between the surveyed value and the calculated one

Lakes, as we know is a complex ecological system consisting of various physical, chemical and biological parameters. As prescribed before, sensors will be used for acquiring data. A sensor is a device that responds to a certain parameter by producing a repeatable signal that can be read and interpreted by an observer or electronic equipment. Sensors are used in the context of lake science to measure many environmental characteristics that may assist in drawing conclusions about water quality and ecologically important parameters.

Using a combination of physical, chemical, biological, and meteorological sensors it is possible to develop a more complete understanding of lakes and how they function.

Residence time [11] (also known as removal time) is the average amount of time that a particle spends in a particular system. This measurement varies directly with the amount of substance that is present in the system. The residence time of a lake is highly dependent on internal physical processes in the water mass conditioning its hydrodynamics; early attempts to evaluate this physical parameter emphasize the complexity of the problem, which depends on very different natural phenomena with widespread synergies. The evaluation of the mean residence time of water in a lake is a problem of fundamental importance for theoretical and applied limnology. Only such an evaluation in real terms can lead to a knowledge of, for example, the proportions and dynamics of the chemical substances dissolved in the water, or the rate at which the processes of concentration, dilution and permanence of substances within the lake occur, with resulting implications for the water quality.

We calculated the residence time of three lakes in Bangalore (INDIA) viz. Lalbagh, Ulsoor, Agara and found that Ulsoor has the highest among them.

Fig.2: Total area covered by Lalbagh lake, Bangalore

Residence Time = $\Gamma = V / Q_o$

Qo = Mean discharge out of the lake

The inverse is water renewal rate or hydraulic throughput $h = Q_i / V$

Qi = mean discharge from watershed into the lake

Qo = Qi + (P – E) A

Lalbagh lake area = 105330.76 m^2

Mean depth = 3 m

Hence, lake volume (V) = 3.15992×10^5 m^3.

Primary inflow into the lake (Qi) = 105330.76 x 859 mm

Total amount of rain in Bangalore per year = 0.904×10^5 m^3/yr

Now, to find the annual precipitation minus evaporation curve of Bangalore, we find that the average value per day amounts to 0.2 mm from the Surface Climatologies graph [Fig.3] provided by European Centre for Medium-Range Weather Forecasts (ECMWF).

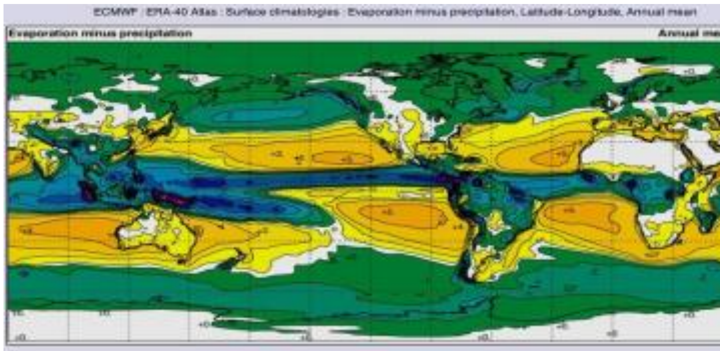


Fig.3: Difference curve between annual precipitation and evaporation

Then, annual P-E = 0.2 x 365 = 73 mm
Qo = Qi + (P-E) x A
= $0.904 \times 10^5 + 0.768 \times 10^4 = 0.98 \times 10^5$ m^3/year

Γ = V/Qo = $3.15992 \times 10^5 / 0.98 \times 10^5 = 3.22$ years.

The same process was followed for Ulsoor and Agara and it was found that the residence time were 6.24 and 4.30 years respectively.

IV.I SYSTEM DESIGN

The implementation phase of our project deals with the step by step modules starting from the simulation phase followed by testing phase and finally the prototyping of the entire model. We initially used Arduino Uno for testing of our sensors and finally built our prototype using Raspberry Pi. The details and architecture of the hardware and software used will be discussed in the following stages of implementation phase.

We have used BNC type pH electrode to determine the pH of samples from different lakes. This type of pH electrodes comes with a BNC connector to produce an output in the range of millivolts. The resultant voltage can be tapped into the signal conditioning circuit [Fig.4] designed to produce a suitable gain and offset in the form of Y = aX + b to get an output in the range of 0-5V. This output can be scaled linearly in the range of 0-14pH to get the desired pH value.
The above signal conditioning circuit of the pH electrode sensor is simulated using National Instrument's Multisim. As we can see the input pH voltage varies between -0.0014V - 0.0014V. Hence, we get a pH of 7 for Vin as 0V and so on. Various buffer solutions were taken of pre-known pH values. Buffer tablets of pH values 4, 7, 9.2 were taken to make the solutions. Repeated iterations were performed on various data and data points were obtained. Curve fitting methods were used to extrapolate the curve and find the values of the voltage obtained for other pH values. Later, offset was used to use these values in the WQI equation.

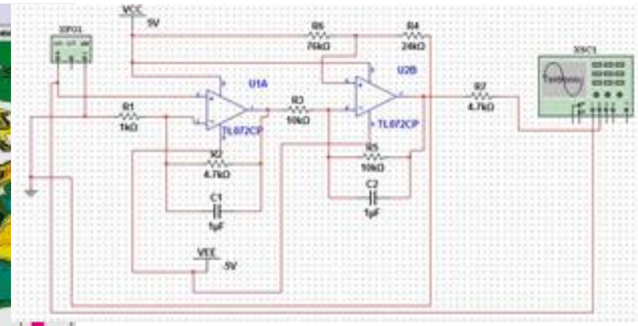


Fig.4: Signal conditioning circuit for measuring pH

The Raspberry Pi [12] is a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. It is a capable little device that enables people of all ages to explore computing, and to learn how to program in languages like Scratch and Python. In this proposed solution, Raspberry Pi is being used as the core with the sensors and display connected to it. [Fig.5]

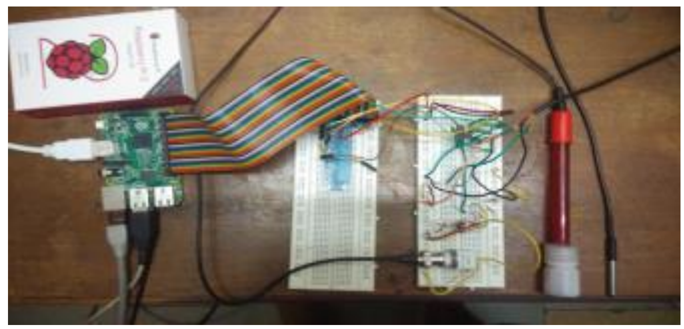


Fig.5: Raspberry Pi connected to pH and temperature sensors

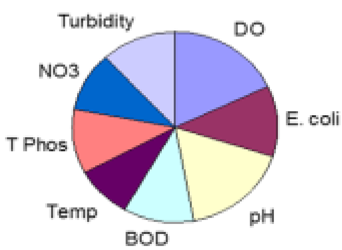
Additionally, Tkinter library is used to develop the GUI [Fig.6] for the system. We have used threading to run parallel processes of acquisition and make the GUI more user-oriented. Finally, we have also used Plotly to plot the waveform for the generated data and carry out the subsequent analysis and host our data in the cloud platform.

Fig.6: GUI screen of the proposed device

The integrity of an ecosystem is typically assessed through its ability to provide goods and services on a continuous basis. Together with the air we breathe, the provision of clean water is arguably the most fundamental service provided by ecosystems. Yet, human activities have fundamentally altered inland water ecosystems and their catchments. As a consequence, species dependant on inland waters are more likely to go extinct, and future extinction rates of freshwater animals could be up to 5 times higher than for terrestrial animals.

In an effort to develop a system to compare water quality in various parts of the country, over 100 water quality experts were called upon to help create a standard Water Quality Index (WQI). The index is basically a mathematical means of calculating a single value from multiple test results (8 parameters) [13]. The index result represents the level of water quality in a given water basin, such as a lake, river, or stream. Now, all these eight parameters are not equally important. Hence, we assign a Weighting Factor (F_i) to each of these parameters [Fig.7].

Weighting Factors



DO	0.18
pH	0.12
E. coli	0.17
Temp	0.11
Turbidity	0.09
T Phos	0.11
NO_3	0.10
BOD	0.12
Total	1.00

Fig.7: Weights assigned to various parameters

Additionally, all these 8 parameters exhibit different scales and relating them directly is absurd. To overcome this problem, we assign another factor to the parameters i.e. Q-Value. It’s a linear scale (1-100) and any value of any of the 8 parameters can be mapped directly to it [14]. This way, we have mapped all the 8 parameters to a common scale which can then be co-related. The formula for WQI (based on Fi and Q-Value i.e. Q_i) and a sample calculation for WQI are shown in Fig.8 and Fig.9 respectively.

$$W_Q = \frac{\sum_{i=0}^{n} Q_i F_i}{\sum_{i=0}^{n} F_i}$$

Fig.8: Expression for WQI in terms of Weighting Factor (Fi) and Q-Value (Qi)

Parameter	Units	Result	Q-Value	Weight Factor	Parameter Index
DO % Sat	%	-	-	-	-
pH	pH units	8	88	0.11	9.68
E. coli	CFU/100 mL	-	-	-	-
Temp	Δ deg C	0	100	0.11	11.00
Turbidity	NTU	10	79	0.09	7.11
T Phos	mg/L P	-	-	-	-
NO3	mg/L N	-	-	-	-
BOD	mg/L	-	-	-	-
			Total Weight Factor	0.31	**27.79**
				WQI =	**89.64**
				Quality Rating =	**GOOD**

Fig.9: A calculation of WQI from sample vales

IV.II REGRESSION ANALYSIS

In statistical modelling, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modelling and analysing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors'). More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables – that is, the average value of the dependent variable when the independent variables are fixed. Less commonly, the focus is on a quantile, or other location parameter of the conditional distribution of the dependent variable given the independent variables. In all cases, the estimation target is a function of the independent variables called the regression function. In regression analysis, it is also of interest to characterize the variation of the dependent variable around the regression function which can be described by a probability distribution.

Regression analysis is widely used for prediction and forecasting, where its use has substantial overlap with the field of machine learning. Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships. In restricted circumstances, regression analysis can be used to infer causal relationships between the independent and dependent variables.

V. RESULTS AND DISCUSSIONS

In this scenario, we have taken the three parameters i.e. pH, TDS and temperature. The dataset is from Ulsoor lake for a period of 2005-15, courtesy of Lake Development Authority of India (LDAI). From this repository, we have monthly values of pH, TDS and temperature from 1/1/2005 to 31/12/2015 i.e. 120 values for each parameter. Based on these dataset, we extrapolate values of 2016 (WQI in particular) and compare it against the present values taken onsite.

We first scatter plot the datasets for each of the three parameters and try to fit a curve through it. [Fig. 10.1]

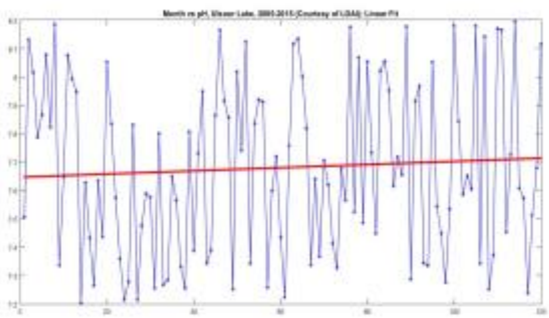


Fig. 10.1: Fitting a straight line to the pH dataset

In the above case, we have plotted the pH data of Ulsoor lake from 2005 to 2015 monthly, i.e. 120 data points. When we find the correlation coefficient matrix, it comes out to be:

1.0000	0.0636
0.0636	1.0000

Here, the non-principal-diagonal elements are closer to zero, thus the relationship between time and pH is highly non-linear. Now, we first find the period of the dataset and fit a sine curve through Fourier Series and then try fitting a sine curve through it. [Fig 10.2]

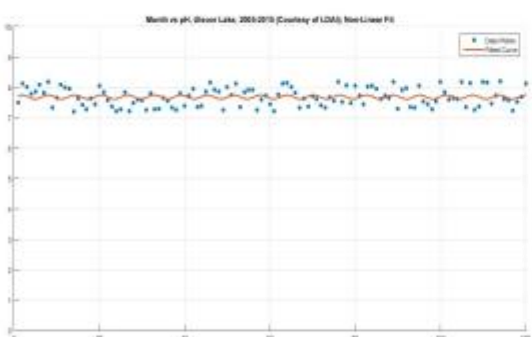


Fig. 10.2: Fitting a sine curve to the pH dataset

As visible from the above graph, the curve is a better fit compared to the linear fits. Also, the R-Squared value has shown an increase depicting better fit. The R-Square value has increased from 0.0044 in the linear fit to 0.029 in the non-linear fit.

The sine curve thus found can be represented as:

y = (b1 + b2*sin (b3*x + b4))

where b1, b2, b3 and b4 are coefficients found mathematically.

Similarly, we plot a linear fit for the TDS dataset. [Fig.11]

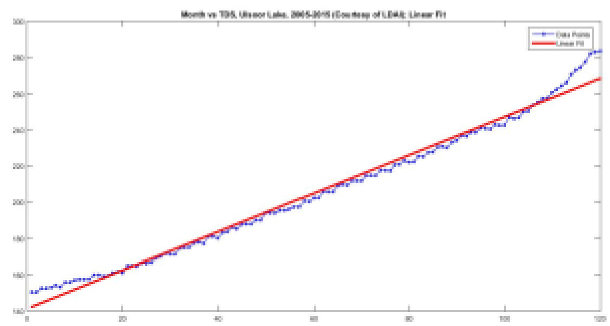


Fig. 11: Linear fit for TDS data

Also, we get the correlation coefficient matrix as

1.0000	0.9832
0.9832	1.0000

Here, the non-principal-diagonal elements are closer to +1, thus the relationship between time and TDS is highly linear. Thus we go for a linear fit. Since we now have pH, temperature and TDS datasets and the curves, we plot the WQI dataset and try to fit a curve through it. [Fig.12]

Fig.12: Time vs WQI; linear plot

When we find the correlation coefficient matrix, it comes out to be:

$$\begin{matrix} 1.0000 & -0.9581 \\ -0.9581 & 1.0000 \end{matrix}$$

From above, we infer that the relationship is non-linear and the curve exhibits exponential nature. Thus, we fit an exponential function to the given dataset. [Fig.13]

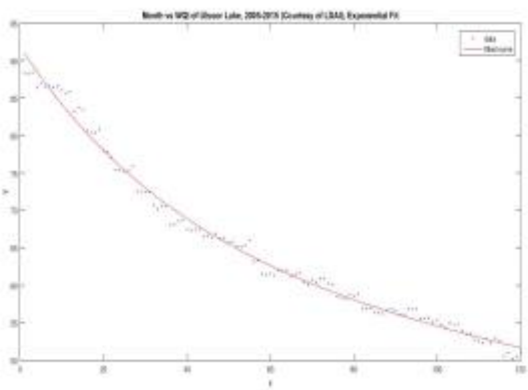


Fig. 13: Fitting an exponential curve to the WQI dataset

The above curve corresponds to the following equation, obtained through MATLAB:

y = 27.4*exp(-0.02657*x) + 64.47*exp(-0.002028*x)

Here, x represents to the month's number where,

x = 1 corresponds to January 2005
x = 120 corresponds to December 2015

Fresh samples were taken in the month of April (x = 124) from Ulsoor lake and WQI was obtained empirically which came out to be 53.23. On the contrary, using the above equation with x = 124 plugged in gave a value of 51.15, giving an error of 2.08%.

A sample survey was conducted on the three lakes (Agara [Fig.14], Lalbagh [Fig.15] and Ulsoor) on 18th and 19th of April, 2016 (Table 1). Standard procedures were followed to collect the samples and TDS and temperature was checked at various GPS locations around the lake.

There are standard ways of taking water samples from inland water bodies. Some of them are mentioned below:

1. The sample collected should be small in volume, enough to accurately represent the whole water body.

2. The water sample tends to modify itself to the new environment. It is necessary to ensure that no significant changes occur in the sample and preserve its integrity till analysed (by retaining the same concentration of all the components as in the water body).

The essential objectives of water quality assessment are to:

1. Define the status and trends in water quality of a given water body.
2. Analyse the causes for the observed conditions and trends.
3. Identify the area specific problems of water quality and provide assessments in the form of management to evaluate alternatives that help in decision-making.

Fig.14: Sample collection from Agara Lake

Fig.15: Sample collection from Lalbagh lake

Name of the lake	**pH Range**	**Temperature (in Celsius)**	**TDS Range (in ppm)**
Lalbagh	8.12-8.63	37	308-325
Ulsoor	7.59-7.85	35	289-294
Agara	6.81-7.21	30	795-822

Table 1: Results from the sample survey

Contour and surface plots for pH and TDS characteristics of Agara and Lalbagh lakes were also implemented. First, we have stored the longitude and latitude wise distribution of pH and TDS values in separate text files. After importing each text file in MATLAB, we have converted the discrete data in the form of matrix. For any type of contour or surface plot, we need a continuous set of data for interpolating in the 3D contour or surface grid. Therefore, we used the 'linspace' command of MATLAB to generate linear vectors in X and Y axis with 30 equally spaced points between the minimum and maximum value of the data set. Then we created a 'meshgrid' using those vectors and interpolated the Z axis of the meshgrid in accordance to our TDS or pH values. We plotted a contour fill plot using 'contourf' function and a Surface plot using the 'surf' function. A 'colour-bar' is added for reference.

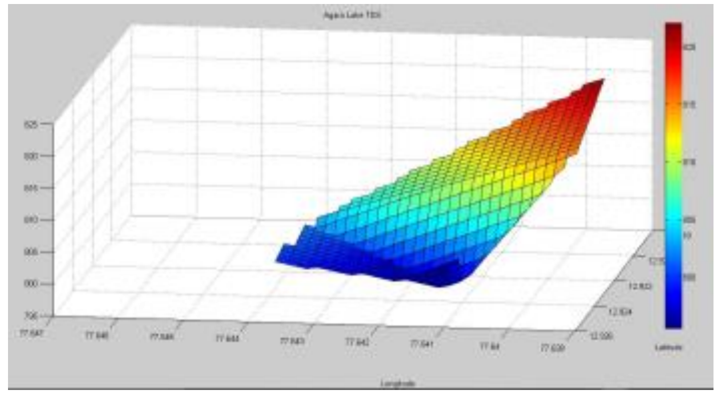


Figure 3: 3D Surface plot of TDS in Agara Lake

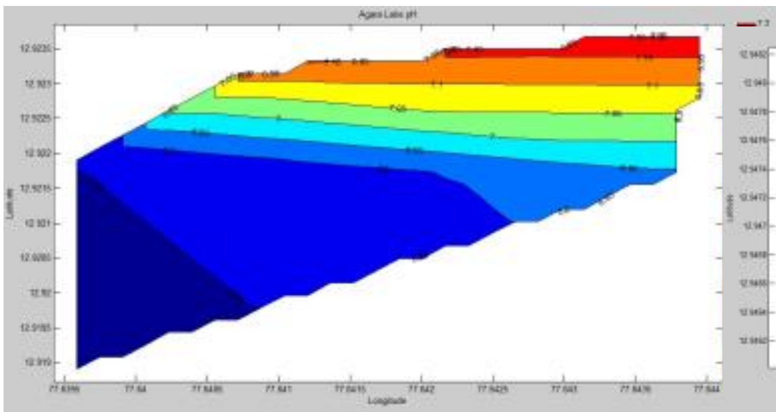


Figure 1: 2D Contour Plot of pH in Agara Lake

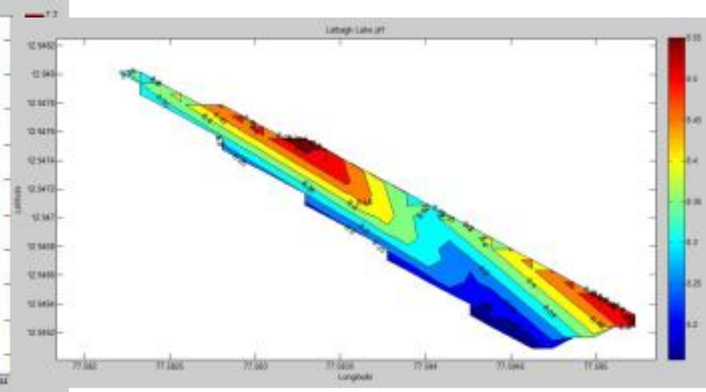


Figure 4:2D Contour Plot of pH in Lalbagh lake

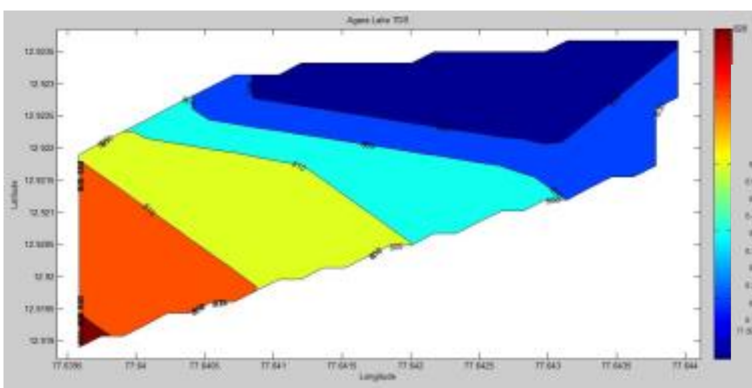


Figure 2: 2D Contour plot of TDS in Agara Lake

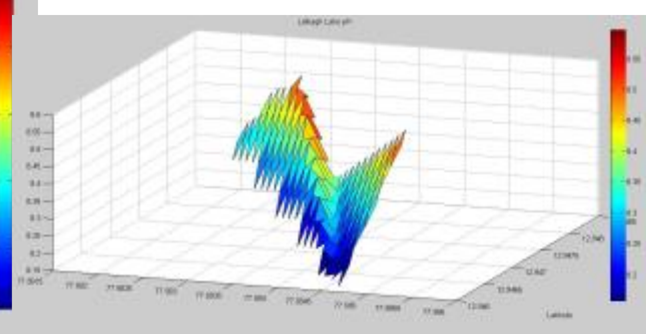


Figure 5: 3D surface plot of pH in Lalbagh Lake

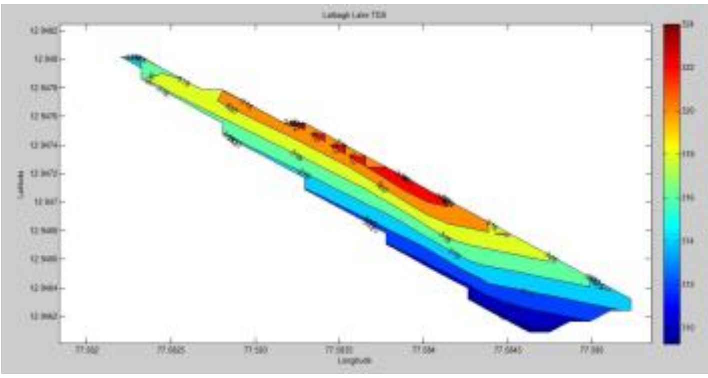


Figure 6: 2D Contour plot of TDS in Lalbagh

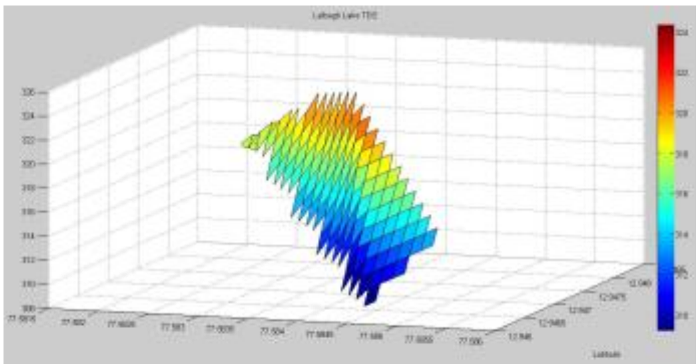


Figure 7: 3D surface plot of TDS in Llabagh Lake

VI. CONCLUSION

This project received a positive social feedback from the concerned people of Bangalore. In fact, various NGOs and organizations are taking measures to conserve the lakes around here. As we know, for or any successful conservation comes identification of problem and trend of the values over time. Our system with a graphical user interface and training of historical data could predict the deviation in the near future.

The water quality index which was taken from the curve fitting data for Ulsoor Lake was found to be 51.15 and the actual measured WQI of our system was 53.23 which gives an error percentage of 2.08. Efforts are driven to reduce the error and introduce neural network to reduce the error even more and portray an accurate state of the system. A successful prototype was built for acquisition of data using Raspberry Pi and portrayed on GUI using Tkinter platform. Further development of product into a module is currently going on.

The Geographical based Information Systems based analysis concluded that Ulsoor Lake is the best maintained comparatively out of the three lakes ie. Lalbagh and Agara with the water Quality Index higher as well. The residence time of Ulsoor was 6.24 years which was considerably higher than the other two lakes.

Comparatively Agara was found to be the most polluted with extremely high TDS levels and its high time the water is treated to make it potable and used for other purposes.
The future scope is outlined below for this project.

1. Inclusion of more number of sensor for calculation of WQI e.g. Dissolved Oxygen (DO).

2. More number of sampling points to be monitored over a longer period of time for more accurate training of the model.

3. Development of a 3D printed model to make a successful instantaneous online prototype [Fig.x]. The head in this case consists of the Raspberry Pi and supporting peripherals whereas the tail is comprised of all the sensors which can be directly inserted in the water.

Fig.x: Proposed design for a 3D printed model

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