Research Article

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Modelling and simulation of economical water quality monitoring device

Abstract

In this novel system design a statistical regression analysis approach is used for development of new device incorporating various physicochemical parameters. Various water quality parameters from different sites were estimated following standard methods and procedures. Comparison of estimated values with W.H.O. standards revealed that there is a need of some economical device for water quality management. Regression analysis of data from different sites suggests that conductivity of drinking water is an important parameter and it is significantly correlated with ten parameters out of twelve water quality parameters studied. It may be suggested that drinking water quality can be checked effectively by the conductivity of water. The new device is quite stable and can predict all the major fifteen parameters used to determine the quality of water. The device consists of few components including one PIC microcontroller, resistors and conductivity sensor. The device is tested for the different samples of water and it found to be fairly accurate. The advantages of this device is it robust, consumes very low power, and economical within the range of a common man.

Keywords: Conductivity sensor, Regression equations, Microcontroller, Correlation, Water quality management

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Introduction

Emerging as the mainstream of VLSI design, ASIC (Application-Specific Integrated Circuit) technology is revolutionizing the design, manufacturing, and marketing practices in electronics-related industries.[1] Ground water is one of the important resource of water. In our country most of the people are depend upon it to fulfil their daily needs.[2] Since we have limited fresh water resources thus ground water can be used along with fresh water.[3-5] A sensor has been developed to measure the conductivity of a solution and is interfaced to the analog port of the microcontroller.[6] The microcontroller used here has many channel inbuilt A/D Converter which converts analog voltage signal to digital one. The sensor gives the value of the measured parameter and then the other subsequent values are calculated using equations shown in later in this paper and the results are displayed on LCD.

According to Central Pollution Control Board, 90% of the water supplied in India to the town and cities are polluted, out of which only 1.6% gets treated.[6-8] Therefore, water quality management is fundamental for the human welfare.[10-11] It is important to set up advanced real-time online monitoring systems for water source development and utilization.[6] Usually water pollution monitoring needs a sample from the targeted area, then that sample is analysed in the lab, which is high cost and low efficiency. Water samples change and if pollution is not detected in a timely fashion, the transmission may affect the analysed results. Therefore, we developed a real-time online remote water quality monitoring system based on the Wireless Sensor Networks (WSNs).[11-13] WSNs have been growing rapidly in the past few years. Lots of research has been done on WSN communications, power conservation, routing algorithms, etc. However, most research mainly focuses on terrestrial sensor networks. Research on sensor networks facing territorial waters is limited.[6] It's very important to conduct research on sensor networks facing territorial waters because they can benefit many areas of science and industry, such as water quality monitoring, ocean graphic data collection, disaster detection and prevention, oil field monitoring etc.

Water quality

Water quality is a term used to describe the chemical, physical, and biological characteristics of water, generally in terms of suitability for a particular use. Water-quality monitoring is the process of sampling and analyzing water conditions and characteristics. Various water characteristics that have an effect on the designated uses of water bodies are used to measure these characteristics. Water characteristics, such as dissolved oxygen, pH, nutrients, and temperature are known as parameters. Parameters can be physical, chemical or biological in nature.

Water Quality Parameters

Some important water quality parameters are described in the following sections:

pH: pH is defined as the measure of acidity or basicity of the water. It can be calculated in terms of hydrogen ion concentration. This is an important water quality parameter on the basis of which acidity or basicity of water can be determined.

Turbidity: Turbidity can be measured in terms of suspended particles inside the water. This parameter can be measure by optical phenomenon. Turbidity can be calculated by the amount of scattered light by the suspended particles. It is measured in Nephelometric Turbidity Units (NTUs).

Total Dissolved Solids: Total Dissolved Solids (TDS) is measured in milligrams per liter (mg/L). Mineral ions such as potassium, sodium, chloride, carbonate, calcium, sulphate, and magnesium all contribute to the dissolved solids in the water. TDS is very important factor as far as drinking water is concern.

Electrical Conductivity: Conductivity is the ability of a substance to pass an electrical current. It is measured in micro Siemens per centimeter (µS/cm). Mineral ions inside the water like sodium, potassium, and chloride give water its ability to conduct electricity.

Conductivity most commonly used to estimate the amount of total dissolved solids (TDS) rather than ensuring each dissolved constituent separately.

Dissolved Oxygen: Dissolved Oxygen (DO) is very important parameter and very important for aquatic life. In normal streams, dissolved oxygen levels usually determine its ability to support aquatic life which is dissolved oxygen dependent. As plant and animal material decays will consumes dissolved oxygen.

Biochemical Oxygen Demand: Biochemical oxygen demand (BOD) is a very important term used for measuring water quality. While there are many factors that influence dissolved oxygen but the amount of organic matter decomposing in the water is very important. Oxygen in the surrounding water is taken by microorganisms decompose this organic matter.

Hardness: The Hardness of water is due to excess of mineral dissolved inside water. It can be further classify into two permanent and temporary. As water moves through ground soil or rock. It dissolves very tiny amounts of these natural minerals and carries them into the ground water supply. Since the solubility of water is a great it dissolve calcium and magnesium ions.

Chemical Oxygen Demand: The COD (Chemical Oxygen Demand) is again very important parameter that represents the amount of chemically digestible organics in other words food. COD measures all organics that were biochemically digestible. It can also measure the organics that can be digested by heat and sulfuric acid. It is used in the same applications where BOD used.

Sulphates and phosphate: Sulphates and Phosphorous are the important minerals present in the water. Sulphate mainly found in the lake water and occurs as a principal ion in it. Under the absence of oxygen means anaerobic conditions the biological oxidation produces hydrogen sulphide. When aerobic means presence of oxygen biological oxidation produces hydrogen sulphide. Sulphate have a unique odour which often popularly identified with the "death" of a lake.

Phosphorus: Phosphorus is usually found in natural water as phosphates or in composition form as orthophosphates, polyphosphates, and organically bound phosphates. It deteriorates the quality of water and makes it unfit for drinking and other household purposes.

Chlorides: Chlorides are present in both fresh and salt water. Its presence in water is very essential. Chlorides can also enter a watershed through water softener. It is responsible for hardness of water Water softeners remove magnesium and calcium ions from hard water by performing an ionic exchange reaction with sodium chloride in ion exchange chamber.

Iron: Iron and manganese are minerals found in drinking water supplies. These minerals will not harm you, but they may cause reddish-brown or black stains on clothes or household fixtures. Under guidelines for public water supplies set by the Environmental Protection Agency (EPA), iron and manganese are considered secondary contaminants. Secondary standards apply to substances in water that cause offensive taste, odor, color, corrosion, foaming, or staining but have no direct affect on health.

Circuit diagram

The water quality monitoring system has been modeled to measure the above parameters which determine the quality of water using a microcontroller, a sensor and an LCD display.

The water quality monitoring system is shown in Figure 1. The novelty in the design of device is that it measures all the parameters simultaneously giving fairly accurate results. A conductivity sensor is used for determining the value of various water quality parameters. Conductivity of water is a main parameter to determine the other parameters. Regression analysis of electrical conductivity with other parameters has been done to find the relation between them and plots between various parameters have been created and device standards are set.

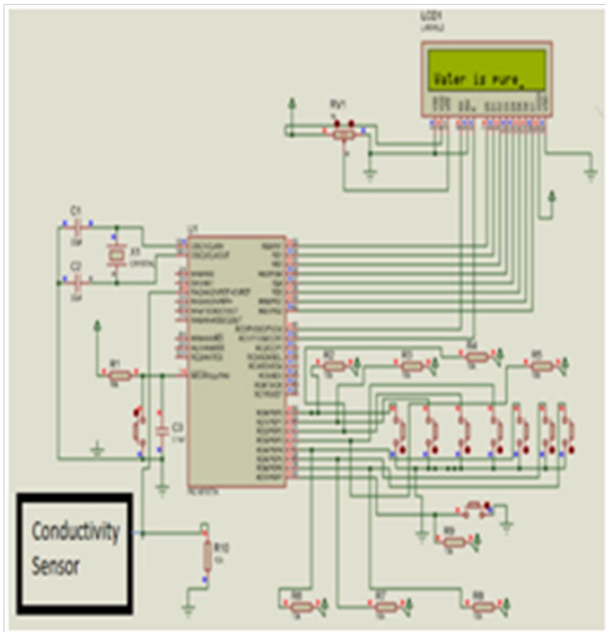

Figure 1 Circuit Diagram of Water Quality Monitoring System.

Device simulation

The hardware implementation for water quality monitoring system is shown in figure 2. The simulation of the device has been done and the results are found to be within range.

Regression Analysis of electrical conductivity with respect to other parameters

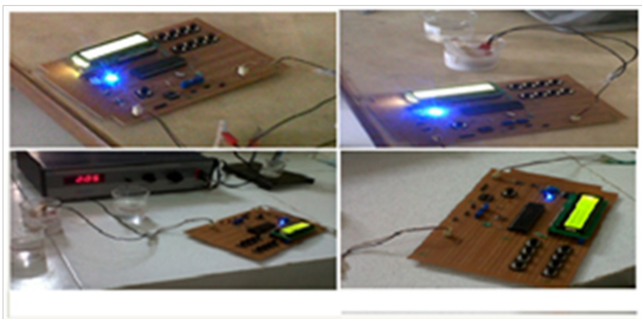

Figure 2 Hardware Implementation of Water Quality Monitoring System.

The regression analysis is a powerful tool and can be used for finding the relationship or dependencies of one parameter of certain data above other. It is measure in terms of degree of similarities of different data (independent and dependent data). The value of coefficient of correlation shows the degree of relation among the data. If the coefficient of correlation is nearer to +1 or -1, the value shows perfectly positive or negative correlation among the data. In this

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way analysis efforts to lift-off the trend between the independent or dependent variables and thereby provides a mechanism for prediction or forecasting for the future value.

Various graphs have been plotted between the water quality parameters to show the dependence of one parameter on the others. On observing these graphs, the same variation occurs in figures 3-7&10 that show Conductivity increases with increase in TDS, TS, BOD, Conductivity and Hardness. Whereas same variation occurs in figures 5,8,9&11 that show that Conductivity decreases with increase in turbidity, COD, Phosphate and Iron. Figure 12 shows the variation of Output voltage with respect to conductivity.

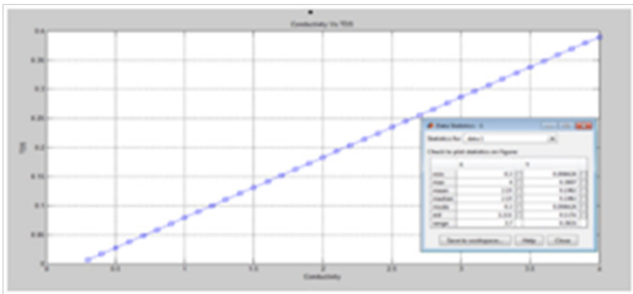

Figure 3 Relationship between Conductivity V/s TDS.

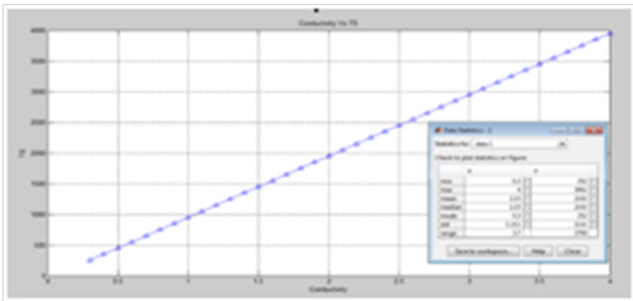

Figure 4 Relationship between Conductivity V/s TS.

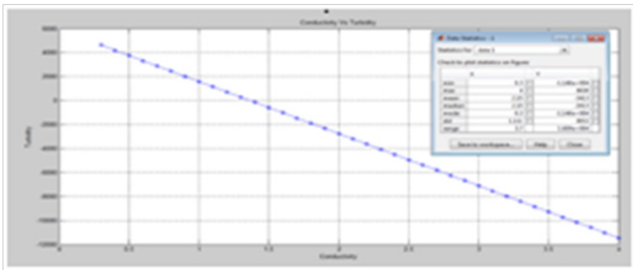

Figure 5 Relationship between Conductivity V/s Turbidity.

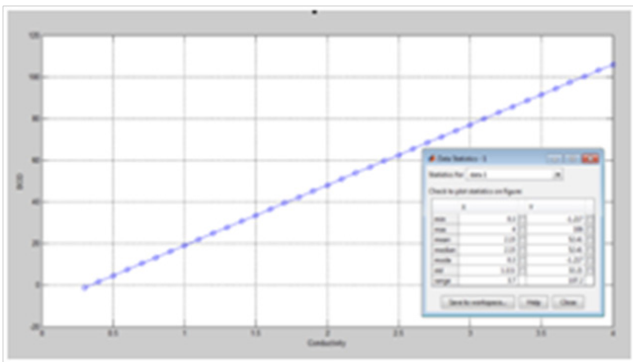

Figure 6 Relationship between Conductivity V/s BOD.

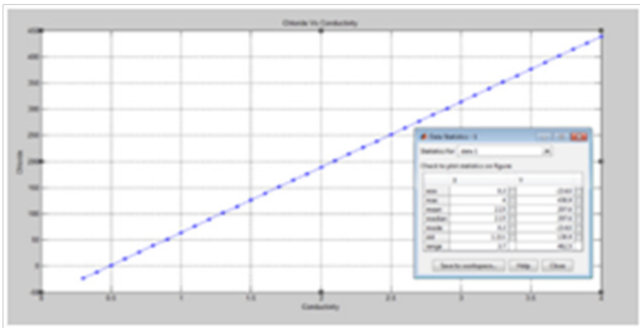

Figure 7 Relationship between Chloride V/s Conductivity.

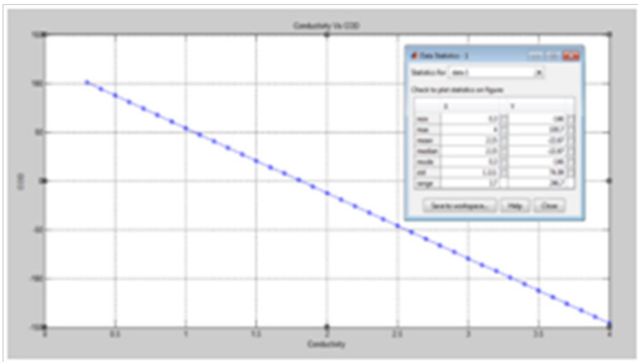

Figure 8 Relationship between Conductivity V/s COD.

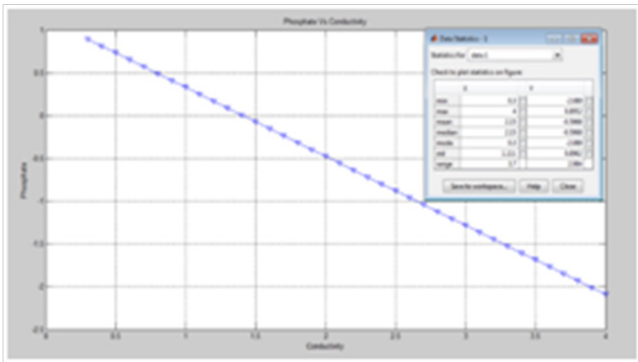

Figure 9 Relationship between Phosphate V/s Conductivity.

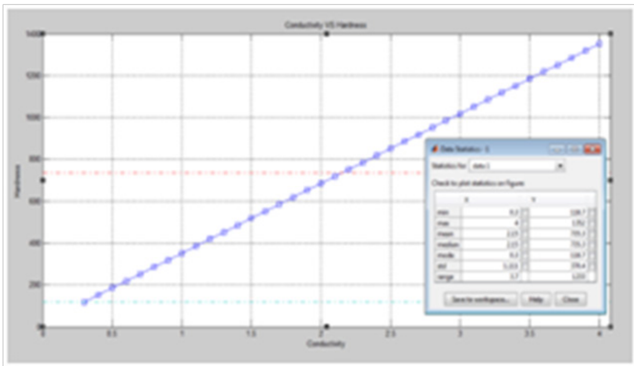

Figure 10 Relationship between Conductivity V/s hardness.

Mathematical Regression Analysis

In the regression statistics of a device has been done and shown in Table1. The table includes different values of multiple □, □square, and adjusted □square, the standard error as obtained from the experiment.

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Inferences from Table 1.

Table 1 Regression Statistics

Regression Statistics	
Multiple R	0.998
R square	0.997
Adjusted R square	0.997
Standard error	0.081
Observations	18

The value of R Square shows the linear relationship of one parameter with respect to other. The Value of R Square is very close to unity shows that the proportion of the variance (fluctuation) of one variable that is predictable from the other variable.

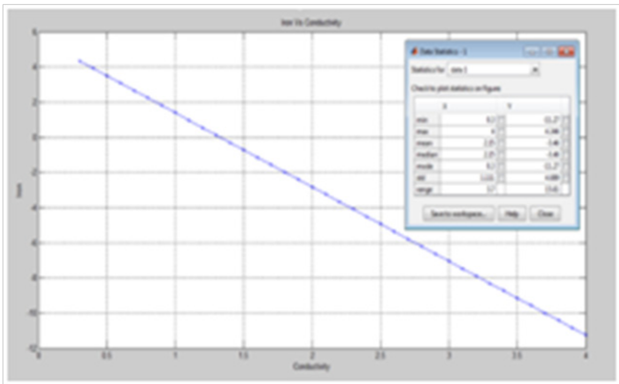

Figure 11 Relationship between Iron V/s Conductivity.

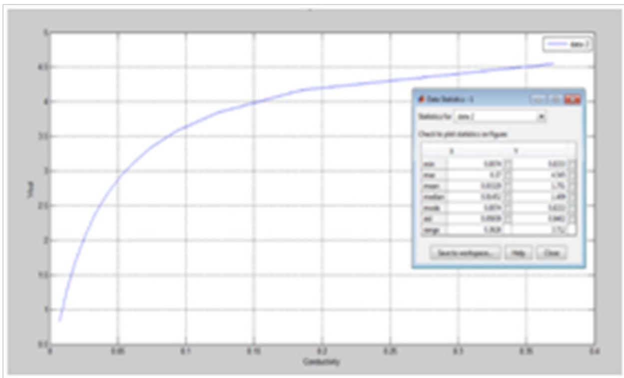

Figure 12 Relationship between V_{out} V/s Conductivity.

Standard error is the difference in the value of actual and estimated variable. The least the value of standard error shows how close the actual and predicted value or in other words, sensitivity of the device. The value of standard error is small which shows the better accuracy of the device.

The ANOVA analysis for the device is presented in Table 2. ANOVA analysis is a simple analysis of variance on data for two or more variables. The ANOVA table gives the following information:

Table 2 ANOVA Analysis

	Df	SS	MS	F	Significance F
Regression	1	33.49	33.492	5077.88	$1.86E-21$
Residual	16	0.10	0.0065		
Total	17	33.59			

Degrees of freedom (df),The Sum of the Squares (SS), The Mean Square (MS), The □ ratio (□), The Significance □.

ANOVA analysis is very important to test the hypothesis for every sample value with same probability distribution. A high □ value represents there is very little deviation between the means. The value of means is same which leads to least value of standard error and the device is fairly accurate.

Residual Plot

Residual plot is a tool which determines whether the derived regression model is fit for experimental data. If in a regression model is random in nature means there should be no recognizable pattern then the experimental data is fit Otherwise, unfit. Good regression models give uncorrelated residuals.

The standard residuals result for the device is shown in Table 3.

Table 3 The Standard Residuals Results for the Conductivity Sensor

Observation	Predicted Y	Residuals	Standard residuals
1	0.3	5.55E-17	0.010
2	0.8	1.78E-15	0.335
3	1.3	2.22E-16	0.041
4	1.8	-1.1E-15	-0.209
5	2.3	0	0
6	2.8	-1.3E-15	-0.251
7	3.3	-1.2E-14	-2.179
8	3.8	7.55E-15	1.424

Normal Probability plot

The normal probability plot is a type of probability distribution curve which indicates real values of random variables whose distributions are not known. The linear point's pattern indicates that the normal distribution is a good model for this data set. The probability output for the device is shown in Table 4 The normal probability plot for the device is plotted and shown in Figure 14. By analysis Three dimensional comparison chart has also been shown to comapre the parameters and the most important parameter being turbidity.The fluctuations in Turbidity occurs more frequently (Figure 15-17).

Table 4 Probability Output

Percentile	Y
6.25	0.3
18.75	0.8
31.25	1.3
43.75	1.8
56.25	2.3
68.75	2.8
81.25	3.3
93.75	3.8

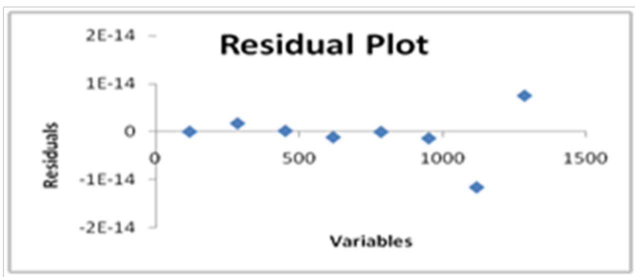

Figure 13 Residual Plot for the conductivity sensor.

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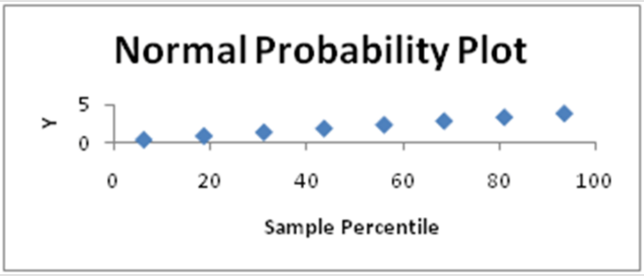

Figure 14 Normal probability plot for the conductivity sensor.

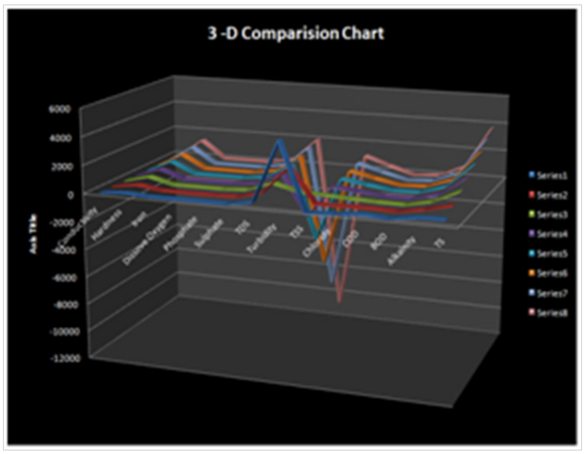

Figure 15 3-D Comparison Chart to compare all water quality parameters.

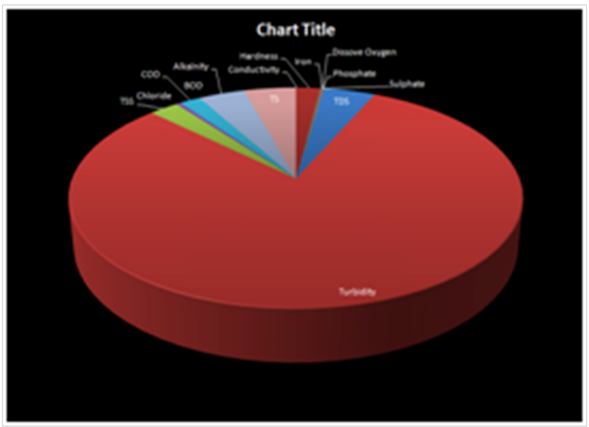

Figure 16 3-D Pi-Chart to compare water quality parameters.

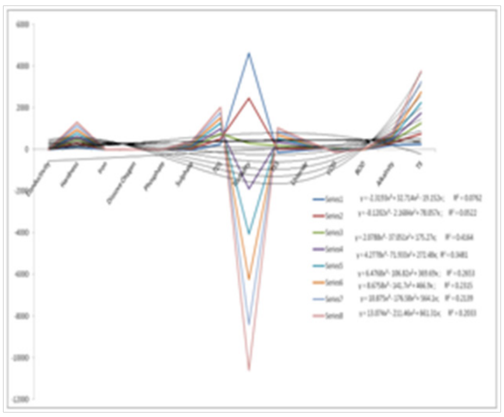

Figure 17 Trend line graph to compare water quality parameters.

Mathematical Verification

Vout = (5*d)/1023 (1)

Res = (50-10*Vout)/Vout (2)

Conductivity = 0.37/Res (3)

Here Vout = Voltage generated in the sensor

Res = Resistance of the solution

The cell constant of the sensor is fixed and its value is equal to 0.37. Thus conductivity of the solution is measured as shown in equation 3. Various analyses have been done in MATLAB to form a relationship between water quality determining parameters according to the real data.

The equations formed are shown below.

Alkalinity = (1.046+Conductivity)/0.006 (4)

Hardness = (0.056+Conductivity)/0.003 (5)

Dissolved Oxygen = (1.579-Conductivity)/0.27 (6)

BOD = (Conductivity-0.467)/0.266 (7)

COD = (1.81-Conductivity)/0.015 (8)

TS = (Conductivity-0.048)/0.001 (9)

TDS = (0.205+Conductivity)/0.002 (10)

TSS = (Conductivity-0.723)/0.003 (11)

Chloride = (Conductivity-0.489)/0.008 (12)

Sulphate = (Conductivity-0.343)/0.009 (13)

Turbidity = (1.365-Conductivity)/0.023 (14)

Phosphate = (1.41-Conductivity)/1.240 (15)

Iron = (1.330-Conductivity)/0.237 (16)

The mathematical description of the device is shown from equations 4 to 16. Conductivity is the reference parameter for determining other parameters. A conductivity sensor has been developed to measure the conductivity of a solution and is interfaced to the analog port of the microcontroller. The microcontroller used here has ten channel inbuilt Analog to Digital Converter which converts analog voltage signal to digital one and is used by the microcontroller. The sensor gives the value of the conductivity and the values of the water quality parameters are determined according to the equations formed and the results are displayed on LCD.

Result and discussion

The conductivity sensor for water quality monitoring device is tested in the lab. Various experiments for the measurements of the parameters like COD, BOD, Turbidity, TDS, Alkanity, Chloride, sulphate, Hardness and pH etc. in terms of conductivity have been performed. The results obtained by the device are in good agreement with the result obtained from the experiments. Various samples from the different sites are tested and the results obtained are verified from the experimental observed values. The device is economical, consumes low power and in the reach of a common man.

Conclusion

In this paper, we design and implement a conductivity sensor based water quality monitoring system in test lab with information

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of all water quality parameters. The proposed framework can monitor the water quality in real-time and also contains a conductivity sensor that can quickly give the value of all water quality parameters. Simulation results show that the lifetime of the proposed device framework is longer than the traditional WSN framework for water quality monitoring.

Acknowledgements

None.

Conflicts of interest

None.

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