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Mathematical Modeling as a Novel View for Advanced Research in Ground Water

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Abstract

Water pollution has been a crucial problem in many countries and has attracted researcher's attention from all over the world. The variations in selected physico-chemical factors were investigated for twelve sampling stations to determine the water quality of Batlagundu, Dindigul District, Tamilnadu for drinking and other domestic activities. The samples have been analyzed to determine 24 physico chemical parameters. The parameters namely temperature, turbidity, pH, sulphate, potassium, phosphate, Dissolved Oxygen, Biochemical Oxygen Demand and Chemical Oxygen Demand were within the permissible limits of BIS and WHO while other parameters such as total dissolved solids, electrical conductivity, total hardness, total alkalinity, calcium, magnesium, chloride, nitrate, nitrite, fluoride, sodium and iron were found to exceed the limit. This paper proposed a mathematical model to predict the effect of various physico-chemical parameters present in ground water. The parameters chosen for modeling include electrical conductivity, temperature, sodium, Potassium, Total hardness, calcium and magnesium. Results of the modeled equations coincides favorably with the experimental values with the highest percentage deviation of 0.92% and the lowest of 0.03%.The models could serve as a tool for controlling and monitoring of environmental pollution.

Key words: Parameters, Mathematical Model, Environmental Pollution, BOD, COD, Batlagundu

I. Introduction

Water is the most important resource for human existence. Our environment is getting worsened with decrease in water supply. However our dependence on this natural resource remains. Every year, we need 270,100 million tons of water because of 90 million increasing population and approximately 25 million person die as a result of water pollution. To protect the environment and to keep water free of pollution is our global responsibility. Ground water is an essential and vital resource for the people of India. It is the major source of water for drinking in some rural areas, farming and manufacturing, especially during the dry season or when the public water supply is irregular. In rural areas, the careless disposal of industrial effluents and other wastes may contribute greatly to the poor quality of the water [1,2]. The availability of good quality water is a necessary feature for preventing diseases and improving quality of life [3].Water is a necessary element for endurance of living on earth, which contains minerals, essential for humans as well as for earth and aquatic life [4]. The abundance of organic compounds, radio nuclides, toxic chemicals, nitrites and nitrates in water may cause unfavourable effects on the human health especially cancer, other human body malfunctions and chronic illnesses [5]. Therefore, it is necessary to frequently monitor water quality, used for drinking purposes. Water quality is determined by the physical and chemical terminology of a reservoir [6] and includes all physical, chemical and biological factors of water that influence the beneficial use of the water. The changes in physical characteristics like temperature, transparency and chemical elements of water such as dissolved oxygen, chemical oxygen demand, nitrate and phosphate provide valuable information on the quality of the water.

The progress in computer technology and mathematical procedures has introduced some tools that are now essential to approach the water quality problems. These tools are the mathematical tools, which act as a representation of the reality and allow its problems to be handled without interfering directly with it. A solution can be examined in a short time and at a much lower cost if the model represents correctly the reality and all its relevant phenomena. Data collection and making them available are very important chapters in model application. Therefore, as a general statement, the mathematical models must be viewed in close relation with the availability of good and significant data and it is to be handled by selected and responsible people. A wide range of mathematical models has been developed and applied to predict water quality changes and it appears to be a useful tool for water quality management.

This paper is aimed at developing a method of predicting the effect of various constituents present in ground water, by generating an empirical model that could be used to simulate the physico chemical characteristics of water.

II. Study area

The study area is Batlagundu town panchayat in Dindigul district in the state of Tamilnadu. It is located 450km south of state capital Chennai and situated at the foot hills of the Kodaikanal mountain range. It has an average elevation of 320 meters (1049 feet). Batlagundu is also known as “BETEL CITY”. This area is endowed with 25 medium scale industries and 2000 small scale industries. The economy of the town is mostly dependent on agricultural products like betel leaf, and is a home to banana leaf commission, coconut powder exports, spinning mills, and other business. Batlagundu is geographically located at Longitude and Latitude is 77 ^{0} 45’ 33.84” E and 10 ^{0} 9’ 55.80” N . As per census 2001 Batlagundu had population of 22,007.Average temperature and humidity is 22^0 C and 86% respectively. Twelve stations were chosen for sample collection in the study area as described in Fig. 1 and description of sampling stations as given in Table 1.

III. Water sampling and laboratory methods

In order to determine quality of ground water samples collected from twelve sampling stations in triplicates. Samples were collected in polythene bottles and analyzed for various water quality parameters as per standard procedures [7,8] .The experimental values were compared with standard values recommended by World Health Organization and Indian standards for drinking purposes[9,10] given in Table 2.

The temperature of the water sample was recorded on the spot using thermometer. Turbidity was assessed using nephelometer. The pH and Conductivity were measured using systronics digital pH meter (Model 335) and systronics digital conductivity meter(model 1304).The chemical parameters in the water were determined using standard analytical methods for water analysis [7,8].Total dissolved solid (TDS) was determined by.evaporating methods at 185^{0}C. Nitrate was determined using the Brucine method. Sulphate was determined by Turbidimetric method. Phosphate was determined using the Stannous Chloride method. Chloride was determined by the argentometric method in the presence of potassium chromate indicator. Fluoride, Nitrite, Iron and Ammonia were determined by spectrophotometric method Total Alkalinity was determined by Acid-Base titration method. Dissolved oxygen was determined by Winkler method. Total hardness was determined by the EDTA titration method. Calcium and Magnesium were determined by the EDTA titration method. BOD was calculated by measuring the depletion of oxygen content after 5 days at 20^{0}C. COD was determined by oxidizing the sample with excess acidified potassium dichromate solution and then titrating the excess dichromate against standard ferrous ammonium sulphate solution using ferroin indicator.

IV. Modeling of Ground water

The results obtained from the analysis of water samples from twelve sampling stations are shown in Table.2. Based on the experimental and statistical analysis works from this research the following results are drawn.

1. Electrical conductivity and pH can be used as an important tool for ground water analysis based on various physico chemical parameters.
2. Electrical conductivity has linear correlation with Turbidity, TDS and Cl, exponentially correlated with temperature, sodium, potassium and sulphate and logarithmic correlation with total hardness, calcium and magnesium.
3. On the other hand pH shows only logarithmic correlation with ammonia.
4. Satisfactory workability can be maintained well with consideration of electrical conductivity. Electrical conductivity has achieved high points in ground water quality assessment compared to pH.

The electrical conductivity of a solution is a reflection of the resultant effects of the concentration of the variables present. The EC was modeled using regression tool for statistical analysis. The method of the least square was employed to fit a relationship for the model.

$$EC = f\ (Turb, TDS, Cl, temp, Na, K, SO_4, TH, Ca, Mg) \text{ -------------------- } (1)$$

Where, Turb is the turbidity, TDS is the total dissolved solids, Cl is the chloride ions, temp is the temperature, Na is the sodium ions, K is the potassium ion,SO_4 is the sulphate, TH is the total hardness, Ca is the calcium ions and Mg is the magnesium ions.

The effect of each concentration on EC was established by determining the relationship between each variables and EC through plotting of curves. The Turbidity, TDS and Cl established a first degree relationship with EC and was expressed in the form
$y = a+b.x$ to give

$$EC_1 = a_1 + b_1\ (Turb) \text{ ------------------------- } (2)$$
$$EC_2 = a_2 + b_2\ (TDS) \text{ -- ------------------------ } (3)$$
$$EC_3 = a_3 + b_3\ (Cl) \text{ -------------------------- } (4)$$

The temp, Na, K and SO_4 established an exponential relationship with EC and were expressed in the form $y = a.e^{b.x}$ which could be linearized by multiplying both sides by natural logarithm (ln), so that

$$EC_4 = a_4 \exp\{ b_4\ (Temp)\} \text{ ------------------ } (5)$$
$$EC_5 = a_5 \exp\{ b_5\ (Na)\} \text{ -------------------- } (6)$$
$$EC_6 = a_6 \exp\{ b_6\ (K)\} \text{ -------------------- } (7)$$
$$EC_7 = a_7 \exp\{ b_7\ (SO_4)\} \text{ -------------------- } (8)$$

TH, Ca and Mg established a logarithmic (log) relationship of the form $y = a.x^{b}$ and could be linearized by taking log on both sides as

$EC_8 = a_8\,(TH)^{b8}$ ---------------------------(9)

$EC_9 = a_9\,(TH)^{b9}$ --------------------------(10)

$EC_{10} = a_{10}\,(TH)^{b10}$ --------------------------(11)

The combination of the equations 1 to 11 gives the general equation 12.

$LnEC = LnK + a_1(Temp) + a_2(Na) + a_3(K) + a_4(SO_4) + a_5\log_{10}(TH) + a_6\log_{10}(Ca) + a_7\log_{10}(Mg)$ ----------------------- (12)

In order to convert the log(x) values to Ln(x) values the log(x) functions values were multiplied by 0.4343. Now $Ln(K) = a_o$, the equation 12 becomes

$LnEC = a_0 + a_1(Temp) + a_2(Na) + a_3(K) + a_4(SO_4) + a_5\log_{10}(TH) + a_6\log_{10}(Ca) + a_7\log_{10}(Mg)$ ---------------- (13)

Ln EC is the dependent variable in the equation, $a_0, a_1, a_2, a_3,\ , a_5, a_6$ and a_7 are the constants which are needed to be determined, and temp, Na, K, SO_4, log(TH) ,log(Ca), log(Mg) are the independent variables for the desired EC.

Let E represent the square of the error between the observed EC_o and EC_p in natural logarithm, using the experimentally obtained data, which could be lineralized by multiplying both sides of equation by natural logarithm (ln) or logarithm. Relationship between natural logarithm and logarithm as given in equation 14 and 15

$Log_e N = Log_{10} N / \log_{10} e = \log_{10} N/0.4343$ --------- (14)

$Log_{10} N = Log_e N \,.\, \log_{10} e = \log_e N.0.4343$ ------------ (15)

Thus applying to equation 13, we have

$E = (LnEC_0 - LnEC_p)^2$ ----------------- (16)

Where EC_o is the observed EC and EC_p is the predicted EC value.

$E = \{ LnEC_0 - a_0 + a_1(Temp) + a_2(Na) + a_3(K) + a_4(SO_4) + a_5\log(TH) + a_6\log(Ca) + a_7\log(Mg)\}^2$ -------------------------------------- (17)

For' n' experimental values of Ln EC_o and Ln EC_p

$nE = \sum (Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)_i\}^2$ -------------- (18)

To minimize nE with respect to the coefficients $a_0, a_1, a_2, a_3, a_4, a_5, a_6$ and a_7 using the partial derivatives of nE with respect to these constant and equating them to zero we obtain the necessary condition for a minimum.

$\frac{\partial nE}{\partial a_0} = -2\sum 1\{ Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)i\} = 0$ -----------------------------(19)

$\frac{\partial nE}{\partial a_1} = -2\sum(Temp)\{ Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)i\} = 0$ -----------(20)

$\frac{\partial nE}{\partial a_2} = -2\sum(Na)\{ Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)i\} = 0$ ------------------------(-21)

$\frac{\partial nE}{\partial a_3} = -2\sum(K)\{ Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)i\} = 0$ ----- ------------------(22)

$\frac{\partial nE}{\partial a_4} = -2\sum(SO_4)\{ Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)i\} = 0$ --------------------------(23)

$\frac{\partial nE}{\partial a_5} = 2\sum \log(TH)\{ Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)i\} = 0$ ------------(24)

$\frac{\partial nE}{\partial a_6} = -2\sum \log(Ca)\{ Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)i\} = 0$ -----------(25)

$\frac{\partial nE}{\partial a_7} = -2\sum \log(Mg)\{ Ln\ EC_{0,i} - a_{0,i} - a_1(Temp)_i - a_2(Na)_i - a_3(K)_i - a_4(SO_4)_i - a_5\log(TH)_i - a_6\log(Ca)_i - a_7\log(Mg)i\} = 0$ -----------(26)

Rearranging these sets of linear equations where $\sum$ is the sum from i = 1 to n, and n = 12 Gives

$\sum LnEC_{0,I} = a_0\sum 1 + a_1\sum(Temp) + a_2\sum(Na) + a_3\sum(K) + a_4\sum(SO_4) + a_5\sum\log(TH) + a_6\sum\log(Ca) + {}_7\sum\log(Mg)$ ------------------------------- (27)

$\sum LnEC_{0,I}(Temp) = a_0\sum(Temp) + a_1\sum(Temp)^2 + a_2\sum(Na)(Temp) + a_3\sum(K)(Temp) + a_4\sum(SO_4)(Temp) + a_5\sum(Temp)\log(TH) + a_6\sum(Temp)\log(Ca) + a_7\sum(Temp)\log(Mg)$-------------(28)

$\sum LnEC_{0,I}(Na) = a_0\sum(Na) + a_1\sum(Temp)(Na) + a_2\sum(Na)^2 + a_3\sum(K)(Na) + a_4\sum(SO_4)(Na) + a_5\sum(Na)\log(TH) + a_6\sum(Na)\log(Ca)) + a_7\sum(Na)\log(Mg)$ -----------------------------(29)

$\sum LnEC_{0,I}(K) = a_0\sum(K) + a_1\sum(Temp)(K) + a_2\sum(Na)(K) + a_3\sum(K)^2 + a_4\sum(SO_4)(K) + a_5\sum(K)\log(TH) + a_6\sum(K)\log(Ca) + a_7\sum(K)\log(Mg)$ ------------------(30)

$\sum LnEC_{0,I}(SO_4) = a_0\sum(SO_4) + a_1\sum(Temp)(SO_4) + a_2\sum(Na)(SO_4) + a_3\sum(K)(SO_4) + a_4\sum(SO_4)^2 + a_5\sum(SO_4)\log(TH) + a_6\sum(SO_4)\log(Ca) + a_7\sum\log(SO_4)(Mg)$ -----------------------------(31)

$$\sum LnEC_{0,I}\log(TH) = a_0\sum\log(TH) + a_1\sum(Temp)\log(TH) + a_2\sum(Na)\log(TH) + a_3\sum(K)\log(TH) + a_4\sum(SO_4)\log(TH) + a_5\sum\log(TH)^2 + a_6\sum\log(TH)\log(Ca) + a_7\sum\log(TH)\log(M\text{------------------------}\ (32)$$

$$\sum LnEC_{0,I}\log(Ca) = a_0\sum\log(Ca) + a_1\sum(Temp)\log(Ca) + a_2\sum(Na)\log(Ca) + a_3\sum(K)\log(Ca) + a_4\sum(SO_4)\log(Ca) + a_5\sum\log(Ca)\log(TH) + a_6\sum\log(Ca)^2 + a_7\sum\log(Ca)\log(Mg)\text{------------------------}\ (33)$$

$$\sum LnEC_{0,I}\log(Mg) = a_0\sum\log(Mg) + a_1\sum(Temp)\log(Mg) + a_2\sum(Na)\log(Mg) + a_3\sum(K)\log(Mg) + a_4\sum(SO_4)\log(Mg) + a_5\sum\log(TH)\log(Mg) + a_6\sum\log(Ca)\log(Mg) + a_7\sum\log(Mg)^2\text{-------------------}(34)$$

Equations 27 to 34 form a 8x8 symmetric matrix. Using Gauss Jordan elimination method the results of the summation constants were obtained. [11,12 and 13]

$\sum (Temp) = 251.9$
$\sum (Temp)^2 = 5341.61$
$\sum (Temp).(Na) = 49591.4$
$\sum (Temp).(K) = 11914$
$\sum (Temp).(SO4) = 24468.3$
$\sum (Temp).\log(TH) = 1478.642$
$\sum (Temp).\log(Ca) = 1094.973$
$\sum (Temp).\log(Mg) = 920.7656$
$\sum (Na) = 2446$
$\sum (Na)^2 = 575268$
$\sum (Na).(K) = 140840$
$\sum (Na).(SO4) = 281464$
$\sum (Na).\log(TH) = 14691.86$
$\sum (Na).\log(Ca) = 7690.8$
$\sum (Na).\log(Mg) = 9311.378$
$\sum (K) = 590$
$\sum (K)^2 = 36036$
$\sum (K).(SO4) = 68726$
$\sum (K).\log(TH) = 3516.75$
$\sum (K).\log(Ca) = 1856.146$
$\sum (K).\log(Mg) = 2219.826$
$\sum (SO4) = 1208$
$\sum (SO4)^2 = 143854$
$\sum (SO4).\log(TH) = 7236.342$
$\sum (SO4).\log(Ca) = 3800.897$
$\sum (SO4).\log(Mg) = 4574.725$
$\sum \log(TH) = 70.80339$
$\sum \log(TH)^2 = 420.1583$
$\sum \log(TH).\log(Ca) = 223.2257$
$\sum \log(TH)\log(Mg) = 263.591$
$\sum \log(Ca) = 752.50752$
$\sum \log(Ca)^2 = 119.419$
$\sum \log(Mg).\log(Ca) = 139.4563$
$\sum \log(Mg) = 44.25024$
$\sum\log(Mg)^2 = 165.8059$

V. Results and Discussion

Temperature is a measurement of the intensity of heat stored in a volume of water .The temperature of all sampling sites is within the limit of WHO. The turbidity of any water sample is the reduction of transparency due to the presence of particulate matter such as clay or slit, finely divided organic matter, plankton and other microscopic organisms .Turbidity of all twelve sampling sites recorded within the BIS limit of 5.0NTU. The level of TDS is an important indicator for usefulness of water for various applications. For instance the recommended maximum level for drinking water is 500mg/1, poultry 2860mg/1, pigs 4290mg/1 and cattle 10100mg/1. The level of TDS in study area exceeds the permissible limit of BIS. High TDS could cause excessive scaling of water pipes, heaters, boilers and household appliances [14]. The conductivity of water is a measure of capacity of a solution to conduct electrical current through it and depends on the concentration of ions and load of nutrients. As most of the salts in water are present in ionic forms, they make water capable for conducting current. The conductivity serves as a good and rapid measure of the total dissolved solids in water . The high electrical conductivity values observed at all the sampling sites indicate the presence of high concentrations of total dissolved solid from non-point sources such as municipal and industrial effluents to a large extent the incursion of brackish water [15]. Using the pH as a water quality index, the study area has good water quality with the pH range of 6.87–8.04 since most natural waters have pH between 6.5 and 8.5 [16].

The fluctuations in pH indicate the buffering capacity of total alkalinity. The slight acidity (pH=6.8) may be due to high carbon dioxide concentration occurring from organic decomposition. High water volume, greater water retention and good buffering capacity of total alkalinity may have been the reason why pH was in neutral or moderate alkaline medium in most part of the study area. The total alkalinity of the study area is a reflection of its carbonates and bicarbonate profiles [17].The concentration of alkalinity for all the sampling sites exceed the limit of 200mg / l. Highly alkaline water often has high pH and contains elevated levels of dissolved solids. Such water is not suitable for use in boilers, food processing and municipal water systems. The major sources of hardness in ground water are calcium and magnesium carbonates. Total hardness of the study area is ranged between 220-900mg / l. The high levels of total hardness corroborates with the high levels of magnesium ions in this study. Water with hardness above 200mg/l may cause scale deposition in treatment works, distribution system pipe work and tanks within buildings; it can also result in excessive soap consumption and subsequent scum formation [14].

The concentrations of Ca and Mg at all the sampling sites were observed within the permissible limits of 75-200 mg/1 and 30-150mg/1 respectively.

Chloride is one of the most important parameter in assessing the water quality. The high concentration of chloride at all the sampling sites is due to high organic waste of animal origin except S_1,S_8,S_{10} and $S_{12.}$ High values of sulphate, could be attributed to the combined effect of the effluents from the industrial activities, leachates from the dump-site, run-offs and may also result from the formation of peat in the marshy areas of the estuary, which is characteristically rich in sulphate [18].But sulphate concentration of the study area within the permissible limit of 200mg / l. Nitrogen is a limiting nutrient especially at higher N/P and considered as an essential factors for water quality assessments. Different forms of N such as nitrate and nitrite are determined in a water body. The concentration of these parameters at all the sampling sites is observed within the permissible limit. Fluoride concentration at all sampling sites were found to be within the prescribed limits of BIS and WHO , but the sample S_2 was found to be higher than the limits needs defluoridation for drinking. In the present investigation the concentration of Iron in the ground water samples exceeds the permissible limit 0.3 mg/l as per Indian standards and WHO standards except S_9,S_{10} and S_{11} sampling sites. Sodium content adversely affect the soil nutrients up taking capacity. Water containing more than 200 mg/L sodium should not be used for drinking. In our present study except S_1 S_3,S_8 and S_{10} and all other sampling sites were found to be more than 200 mg/L. According to WHO the prescribed limit of potassium is 200 mg/L. The values of potassium for all sampling sites were found to be within the limits of WHO standard. Rast *et. al*.,[19] provided boundary ranges of phosphate phosphorus as oligotrophic, mesotrophic, eutrophic and hypertrophic aquatic systems. According to them, the ranges are 0.003-0.018 mg/l, 0.011-0.098 mg/l, 0.016-0.386 mg/l and 0.75-1.200 mg/l respectively. Therefore the phosphate level in study area ranges between 0.75-1.200 mg/l. confirms hypertrophic status of the water. Groundwater phosphorus concentrations can become elevated when the soil phosphorus holding capacity is exceeded. Dissolved oxygen is an important indicator of water quality, ecological status, productivity and health of a reservoir. This is due to its importance as a respiratory gas and its use in biological and chemical reactions. Higher dissolved oxygen recorded could be as a result of low temperature and increased mixing of water. The increase in DO levels at all the sampling sites may have resulted from high currents. The flowing water promotes turbulence and leads to greater dissolution of oxygen According to the ranking of Moore and Moore [20] water bodies with BOD levels between 1.0 and 2.0 mg/1 are considered clean, 1.0 mg/1 fairly clean, 5.0 mg/1 doubtful and 10.0 mg/1 definitely bad and polluted. The study area which has BOD concentrations between 1.0 and 2.0 mg/1 may be said to be clean. The high COD due to high rate of organic decomposition resulting from human activities which produce sewage and agricultural run-offs into the ground water and this have negative impact on the water quality. The concentration of COD at all the sampling sites is within the permissible limit of WHO.

The experimental values were compared with standard values recommended by World Health Organization (WHO) and BIS are given in Table 2.The comparative values of the experimental and model EC values are presented in Table 3. The modeled values for other parameters derived are presented in Table 4.

VI. Conclusion

One of the tools that are used to solve problems of water pollution is modeling of water quality changes. Such a model can be used to predict water quality, taking into account the changes that affect water quality factors or changes in their intensity. The accuracy of environmental assessment using models depends on the understanding of processes which occur in the environment and on appropriate choice of mathematical equations that describe them. On the other hand, it depends on available data sets, namely results of the measurement of water quality indicators, on which the estimation of parameters and coefficients of the model is based. This paper presents an overview of mathematical models for assessment of water quality in Batlagundu. The model of analysis of water quality was adequate to act as a tool to aid decision making for management and planning of water resources. Despite the short series of data obtained, it was considered that the model was successfully calibrated for the various parameters in the study area.

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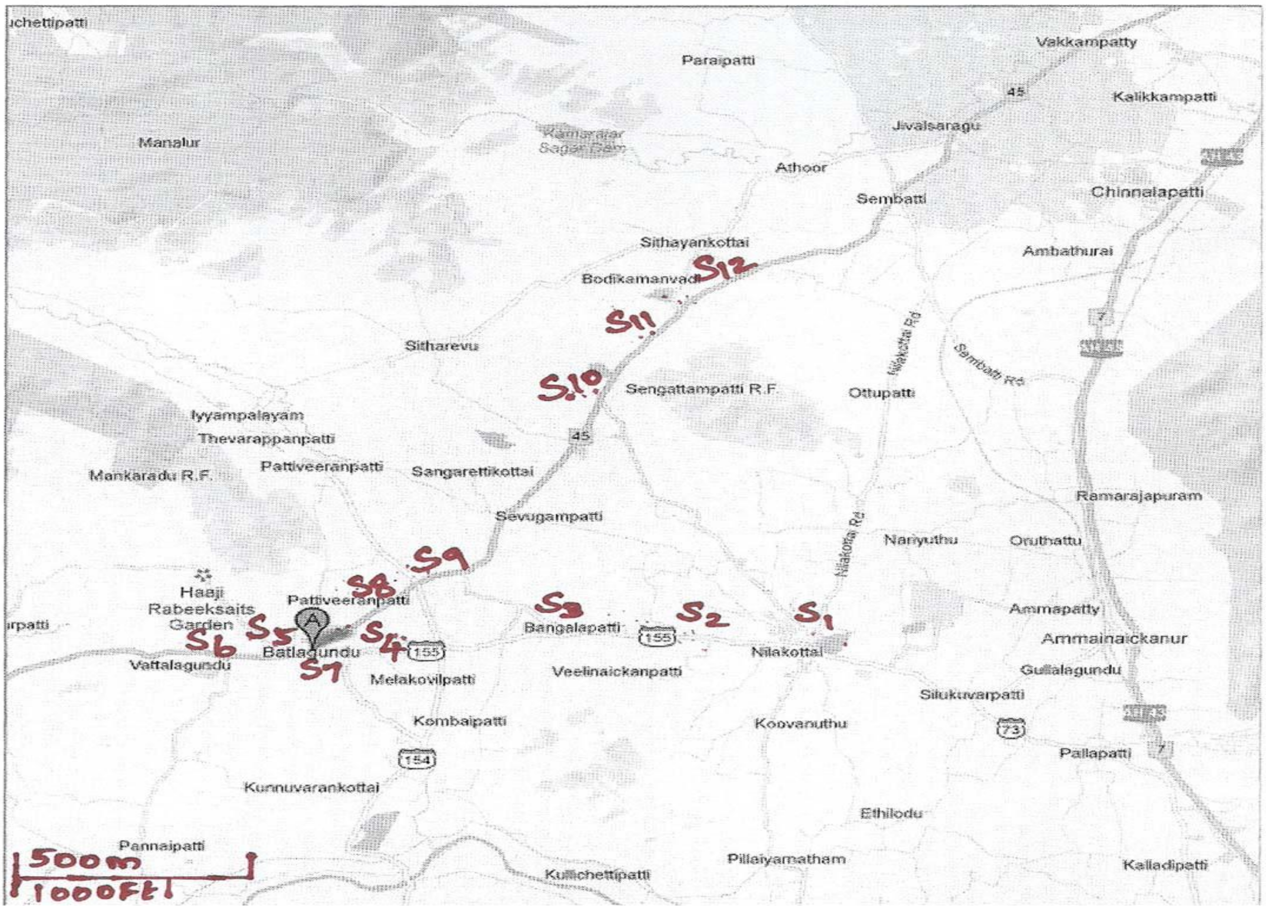

Fig 1 Description of the sampling sites

S_1 - Nilakottai
S_2 - Mallanampatti
S_3 - Anna Nagar, Usilampatti road
S_4 - Anna nagar, Batlagundu
S_5 - Middle Street, Batlagundu
S_6 - Periyakulam Road Batlagundu
S_7 - Batlagundu
S_8 - Batlagundu
S_9 - M.Vadipatti
S_{10} - Salaipudur
S_{11} - Bodikamanvadi
S_{12} - Near Bodikamanvadi

Table 1 Description of water quality sampling sites

Longitude	Latitude	Description	Place	Site No
77 ^{0} 51’ 11.60” E	10 ^{0} 9’ 53.01” N	Near Pushpak Perfume Industry ,	Nilakottai	S_1
77 ^{0} 45’ 40.24” E	10 ^{0} 10’ 0.32” N	Near Village Primary Health Centre	Mallanampatti	S_2
77 ^{0} 45’ 41.99” E	10 ^{0} 11’ 9.98” N	Near Land fill	Usilampatti Road,	S_3
77 ^{0} 45’ 42.39” E	10 ^{0} 11’ 10.23” N	Near drainage	Anna Nagar, Batlagundu	S_4
77 ^{0} 45’ 33.84” E	10 ^{0} 9’ 55.80” N	Residential area	Middle Street, Batlagundu	S_5
77 ^{0} 45’ 33.99” E	10 ^{0} 9’ 56.05” N	Near agriculture field	Periyakulam Road, Batlagundu	S_6
77 ^{0} 45’ 33.84” E	10 ^{0} 9’ 55.80” N	Vegetable Market	Batlagundu	S_7

76 ^{0} 44’ 48.02” E	11 ^{0} 53’ 22.08” N	Near coir Industry	Batlagundu	S_8
77 ^{0} 57’ 39.65” E	10 ^{0} 5’ 03.54” N	Residential Area	M.Vadipatti	S_9
77 ^{0} 33’ 41.70” E	8 ^{0} 28’ 46.54” N	Yendal Nursery	Salai pudhur	S_{10}
77 ^{0} 49’ 16.82” E	10 ^{0} 15’ 37.05” N	Food processing Industry,	Bodikamanvadi	S_{11}
77 ^{0} 47’ 16.80” E	10 ^{0} 16’ 33.05” N	Poultry farm	Near Bodikamanvadi	S_{12}

Table 2. Analysis of physico chemical factors of water samples at 12 sampling stations of Batlagundu.

Parameters	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	WHO	BIS
Temp(^{0}C)	22.8	20.2	20.7	20.7	18.3	21.2	22.5	21.2	24.5	16.8	19.2	23.1	40±5	-
Turbidity(NTU)	2	5	1	4	6	3	2	2	3	1	2	2	5	5
TDS	701	1472	1610	1453	2130	1216	1198	779	2039	664	1191	703	1000	500
EC(µS/cm)	1030	2164	2300	2136	3132	1788	1762	1146	2999	976	1751	1034	-	-
pH	7.9	8.03	7.7	8.1	7.7	7.9	7.16	7.64	7.75	7.66	8.04	6.87	6.5-8.5	6.5 - 8.5
Total hardness	252	384	900	360	660	288	328	260	712	220	252	280	500	300
Total alkalinity	300	260	400	260	296	232	220	332	252	280	200	292	-	200
Ca	56	80	200	77	136	61	69	56	152	51	58	64	-	75
Mg	27	44	96	40	77	33	37	29	80	22	26	29	30	30
Cl	96	470	525	450	780	370	330	144	725	100	350	110	250	250
$S0_4$	49	119	106	146	125	116	150	25	139	46	136	51	400	200
NO_3	19	13	10	14	20	10	10	05	09	13	09	06	10	45
NO_2	0.32	0.27	0.30	0.24	0.38	0.22	0.12	0.11	0.16	0.18	0.14	0.28	-	0.06
F	0.6	2.0	0.4	0.4	0.4	0.6	0.4	0.6	0.6	0.8	1.0	1.2	1.5	1
Na	104	272	198	264	336	240	212	124	284	96	232	84	200	-
K	26	78	12	66	84	60	54	26	76	24	60	24	200	-
Fe	0.71	0.52	0.50	0.61	0.98	0.94	0.38	0.57	0.22	0.29	0.26	0.33	0.3	0.3
NH_3	0.73	0.45	0.30	0.57	0.86	0.36	0.25	0.36	0.34	0.21	0.38	0.18	-	-
PO_4	0.59	0.80	1.0	0.69	0.98	0.69	0.48	0.3	0.31	0.59	0.41	0.30	5	-
DO	5.5	5.2	6.3	5.6	6.3	6.0	6.9	5.0	5.1	8.1	7.6	8	>5	-
BOD	2	2	2.3	2	2	1	2	2	1	1	1	1	5	-
COD	5	6	6.9	5	6	4	5	6	3	4	4	3	20	-

*All parameters in mg/l

Table 3.Comparison of EC values from experiment with mathematical model

Sampling sites	Experimental value	Model EC	Percentage error
S_1	1030	1034.00	0.39
S_2	2164	2153.18	0.5
S_3	2300	2290.67	0.4
S_4	2136	2141.15	0.52
S_5	3132	3150.00	0.58
S_6	1788	1771.71	0.92
S_7	1762	1751.45	0.6
S_8	1146	1136.04	0.87
S_9	2999	2977.98	0.7
S_{10}	976	976.04	0.03
S_{11}	1751	1740.10	0.62
S_{12}	1034	1025.15	0.86

Table 4.Physico chemical parameters obtained from mathematical model

Sampling sites	Temperature(^{0}C)	Sodium	Potassium	Sulphate	Total Hardness	Calcium	Magnesium
S_1	22.8	103	26.18	48.77	251.94	56	26.71
S_2	20.2	272	78	119	84.41	80	44
S_3	20.68	200.45	11.18	107.22	901.99	199.57	96.25
S_4	20.7	263.88	66.02	145.97	358.76	77	39.99
S_5	18.29	344.22	84.57	126.59	644.74	136.02	77
S_6	21.2	239.96	60	116	288.67	61	32.99
S_7	21.2	212.22	53.98	150	326.96	68.98	36.99
S_8	24.5	124	26	25	262.88	56	290.20
S_9	16.80	283.89	76	139.21	707.62	151.95	80
S_{10}	23.2	96	23.61	46	219.93	50.03	21.99
S_{11}	19.23	231.97	61.16	134.54	251.13	58.17	25.99
S_{12}	23.09	84	23.78	51	278.87	63.99	29.01

All parameters in mg/l