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Prediction of Water Quality Index to Restore the Lake Water Quality by the Application of Adaptive Neuro Fuzzy Inference System

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Abstract

Lakes are important part of the urban environment because help to maintain ecological balance. Lake water quality is worsening as a result of environmental changes, posing a threat to biotic integrity and hence blocking ecosystem functioning. The Parakai lake water is contaminated due to the discharge of domestic wastewater from surrounding areas. In this study, box-whisker diagrams are used to assess whether physicochemical parameters can govern periodic fluctuations in contaminated lake water. Horton's formula is used to calculate the WQI of lake water for four seasons. It shows that 75% of the lake water is in good condition and 25% of the water is in poor condition. Then the lake's water quality is forecasted by the use of an intellectual based approach called ANFIS. The ANFIS structure can be produced from the input data Na, Ca, Mg, HCO_3 and TDS, by applying fuzzy logic assessment making processes and IF-THEN rules. The outcome of this structure is that the R^2 value is 0.9912, Since the R^2 values are very nearer to 1. During the summer season, the raw domestic waste water is only the source of lakes which reflects the WQI value is 75.04 and reflects the NFWQI value being high, which is 73.39. The current study examines the environmental and health effects associated with the use of polluted lake water.

Keywords: *water quality index, hybrid learning algorithm, intelligent Neuro Fuzzy logic, membership function, simulation.*

Introduction

Among the most valuable natural resources, lake water is highly valued for its recreational, aesthetic, and picturesque characteristics. Nevertheless, lakes are subject to many impacts from the surrounding area. In order to evaluate the quality of lake water, it is pertinent to determine the level of impurities present in the water (Pham Thi Minh Hanh et al. 2011). Several international initiatives are currently addressing water quality issues according to the 2030 Agenda and Sustainable Development Goals (SDGs). Goal 6 specifically aims to make water and sanitation available to everyone so that there is sustainable management of water and sanitation. Improvement in agronomy and mechanization are essential to meet the standards of human responsibility. In order to preserve the environment and to protect people's health, precautionary measures are essential. In most of the developing countries, a large percentage of raw sewage is released either on farmland for irrigation or disposed of in nearby water bodies. A lack of adequate management of domestic and industrial discharges has altered the physical and chemical properties of the Parakai Lake. Water from this source is used to irrigate nearby agricultural fields and for domestic usage. Therefore, the study aims to achieve the following objectives:

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1. A statistical approach is used to study seasonal variations in lake water quality.
2. Identify the lake's water quality index.
3. An artificial intelligent based approach must be developed for estimating the quality of lake water.
4. Based on the study, recommendations will be made to restore the quality of the lake water.

Materials and Methods

A description of the materials and methods that were used to analyze the lake water quality can be found below. It is clearly described how the study area is represented, and how the various field data were compiled from a variety of sources of lake water. In order to calculate lake water eminence and to analyze seasonal variations from the disparate sources and examine the field data, a methodology is applied.

Study area and Sample collection:

Parakai Lake is situated in the Kanya Kumari district of Tamil Nadu, India. This system tank has a storage capacity of 1.1590Mm^3 with a single main inlet and five outlets, situated in one end of the Pazhayar River, at Latitude – E 8^0 8.5" and Longitude - N 77^0 27". Here, four different seasons can be observed such as southwest monsoon season occurs from June through September, the northeast monsoon between October and December, the winter from January to February and the summer from March to May. Additionally, the lake has some sewage water inlets as well as five sluice gates that serve as a main outlet from the lake to its surrounding ayacut area. In total, 4,76,018 people lived along this riverbank, including seven villages and two urban habitations. On the basis of 135 LPCD, the supply of water is calculated, and it was 4, 55, 72, 200 L/day that was consumed, and 3, 64, 57, 832 L/day that was sewage. A lake in this area has been contaminated by sewage released without treatment. Water from this contaminated source is used for home gardening and water system maintenance. According to IS 3025 (Section I) 1987 rules, the samples were collected during the above mentioned seasons. Those samples are from the inlet water of Pazhayar Waterway, from the sewage channel of a nearby homegrown region, from the lake's center, and from its outlets aiming towards the surrounding fields.

Water quality index:

Essentially, water quality is evaluated and furthermore toxin levels are measured to determine the characteristics of a lake, river, stream, or groundwater. By using the WQI, we can monitor changes in water quality over a long time period for a particular water source. Using Horton's method, the WQI is derived.

$$WQI = \frac{\sum W_n q_n}{\sum W_n}$$

In this case, q_n is the no. of water quality parameters, and w_n is their unit weight. Table 1 shows that the water quality index range as well as varies quality of water *(Bora and Goswami 2016)*.

Table 1. Water Quality Index Ranges

Sl.No.	Several water-related uses	Wide range of WQIs	Quality of the Water
1.	For Drinking purpose, Irrigation and Industrial purposes	0 -25	Perfect
2.	Used for Domestic purpose, Irrigation as well as Industrial purposes	25 – 50	Good
3.	Used for Irrigation purpose and Industrial purpose	51 -70	Fair
4.	For Irrigation purpose only	71 -90	Poor
5.	Unfit for Irrigation purpose also	91 – 100	Very Poor
6.	Appropriate treatment essential before use	Above 100	Unfit for drinking

Adaptive Neural Fuzzy Inference System (ANFIS):

For the solution of function approximation problems, the adaptive neural fuzzy inference system (ANFIS) represents a neural network approach. As early as 1985, Takagi and Sugeno used the ANFIS model symmetrically in the field of prediction and inference, also they found many applications. The rule base and database were referred to as the knowledge base. Dinh Duc Nguyen and Sa-Dong Kim (2013) used IF-THEN rules combined with fuzzy logic to make the inference of ANFIS based on logical rules. In order to convert fuzzy logic values from fuzzy logic to deterministic values, a defuzzification transition was used. Typical adaptive neural networks consist of nodes with fixed or adjustable parameters that have node functions. For ANFIS, the basic learning rule is the back propagation method. In most cases, it was calculated by summing the square differences between the preferred outcome and network output. By using the different data, whether the model can give the best fit are identified. According to Sugeno & Kang (1988) the below neuro fuzzy model was used: the first rule states that x and y are different parameters, f_1 is equivalent to nx + my + r_1 and the second rule states that f_2 is equivalent to nx + my + r_2. TSK fuzzy models are zero-order if f_1 and f_2 are constants in place of linear equations.

Testing and training for ANFIS GUI Editor:

An ANFIS, a five-layer model was generated in MATLAB 2012b Version 8. During generation of the fuzzy inference system, a Gaussian type membership function (guessmf) was chosen for input and for output. There are two different clustering techniques that can be used to construct Gaussian shaped membership functions shown in figure1. The two techniques (FCM and SC) are fuzzy c-means and subtractive clustering. Statistical tests of the two ANFIS models were carried out using different criteria to further verify the conclusion. A correlation coefficient (R^2), mean-square error (MSE), and root-mean-square error (RMSE) were determined in order to calculate the following equation.

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$$R^2 = 1 - \frac{\sum_{i=1}^{n} (X_{\text{model}} - X_{\text{obs}})^2}{\sum_{i=1}^{n} (X_{\text{model}} - \overline{X_{\text{model}}})^2},$$

$$\text{RMSE} = \sqrt{\sum_{i=0}^{n} \frac{(X_{\text{obs}} - X_{\text{model}})^2}{n}},$$

$$\text{MSE} = \sqrt{(X_{\text{obs}} - X_{\text{model}})^2},$$

Modeled values, observed values, and average values are represented by the following three variables: Xobs, Xmodel, and $\overline{\text{X}}$model. Even though they are implemented differently, both strategies yield fuzzy if-then rules.

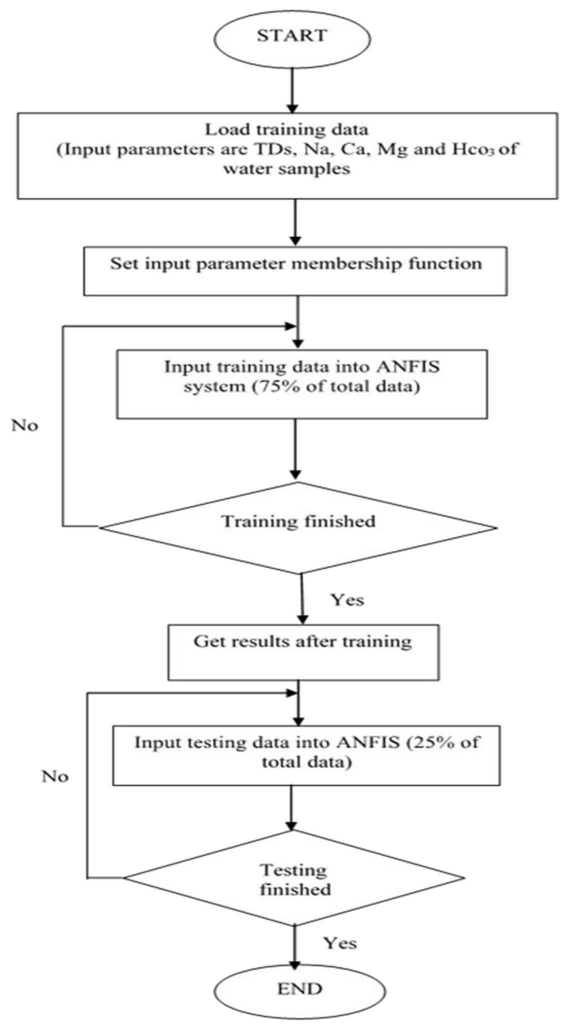

Figure 1. Flow chart for the complete approach and ANFIS algorithm

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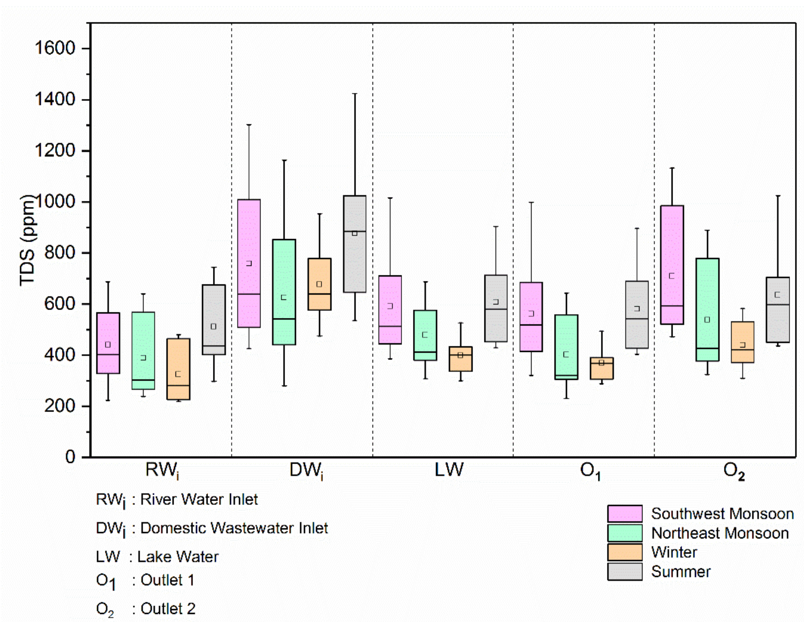
Result and Discussion

Suitability of lake water for domestic use:

The study shows that the colour of the water is brownish during summer season. At all the sampling sites, the highest value of transparency of water was occurred during winter season. Hence it is attributed to lower suspension of organic matter and poor growth of planktons (Vega et al. 1998). In Figure 2(i), the wastewater inlet (560 mg/L - 1424 mg/L) has the highest TDS content when compared to the inlet and outlet. The value of TDS is high during dry season due to higher concentration of wastewater (autumn). In the summer season, there is excess sodium and salt content in domestic wastewater inlets, as shown in (Figure 2 (ii)). Studies have shown that sodium concentration has a significant impact on irrigation water quality. Due to the excess concentration of sodium, the soil becomes harder, which reduces its permeability, making seeding impossible. In Figure 2(iii), calcium levels seem to fluctuate over the course of the investigation. It appears that Ca^{2+} was the most dominant ion at the wastewater inlet based on the molar concentrations. When calcium is combined with magnesium, the hardness of the water can be controlled. During soil coagulation due to calcium, a crumb-like structure is formed (Orzepowski & Pulikowski 2008, Pulikowski et al. 2006). Figure 2(iv) shows magnesium permissible values ranging from 17 to 43 mg/L. Based on the observation, the domestic wastewater inlet has high magnesium content. Under normal conditions, carbonate levels should range from 25 mg/L to 125 mg/L. The site near the waste water inlet has higher HCO^3 concentrations during the study period (Figure 2 (v)).



(i)

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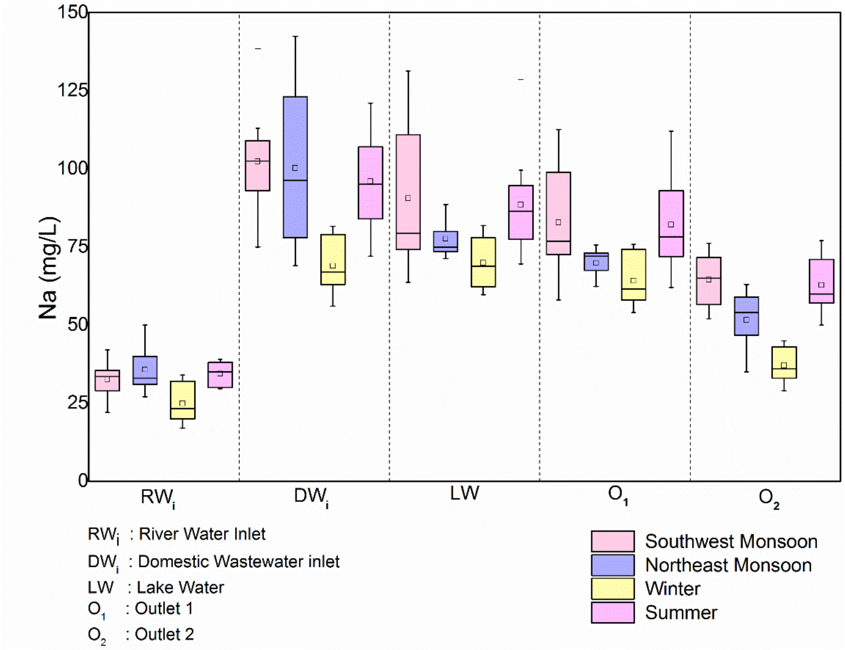

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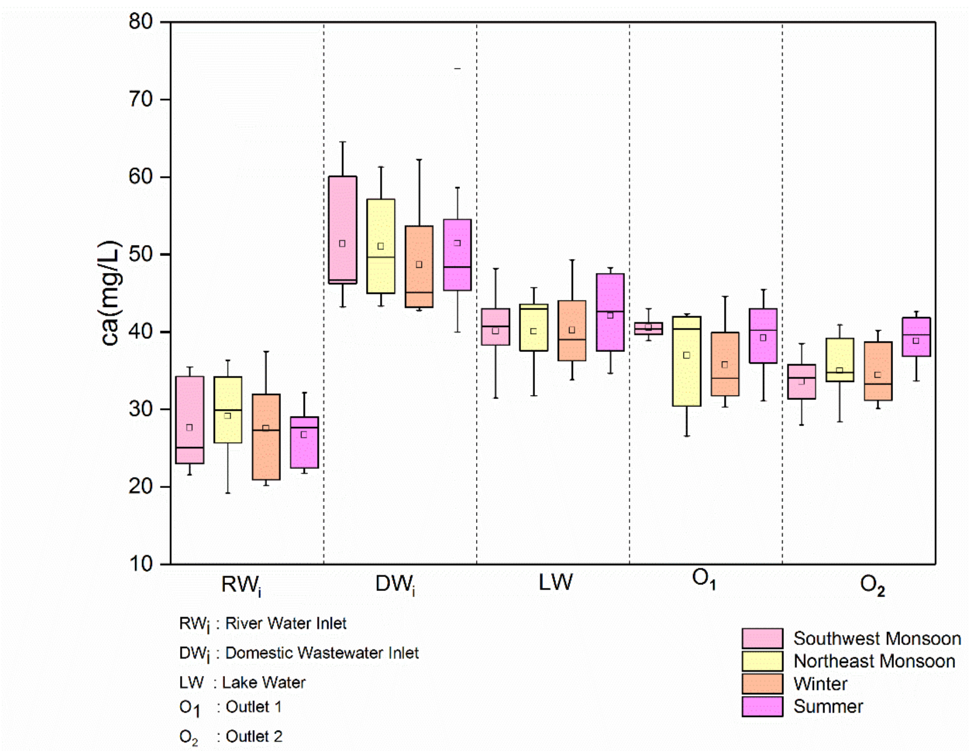

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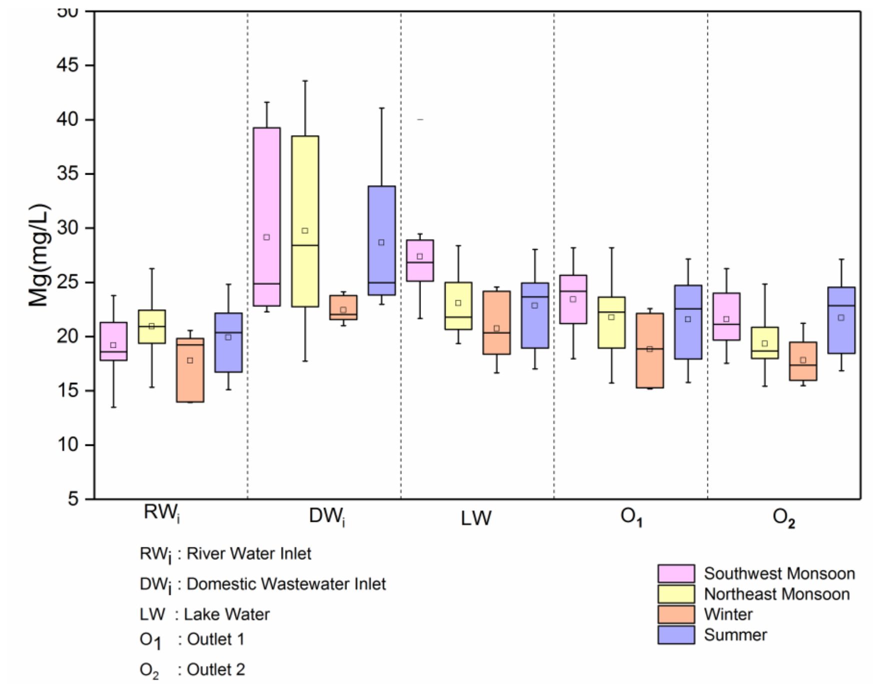

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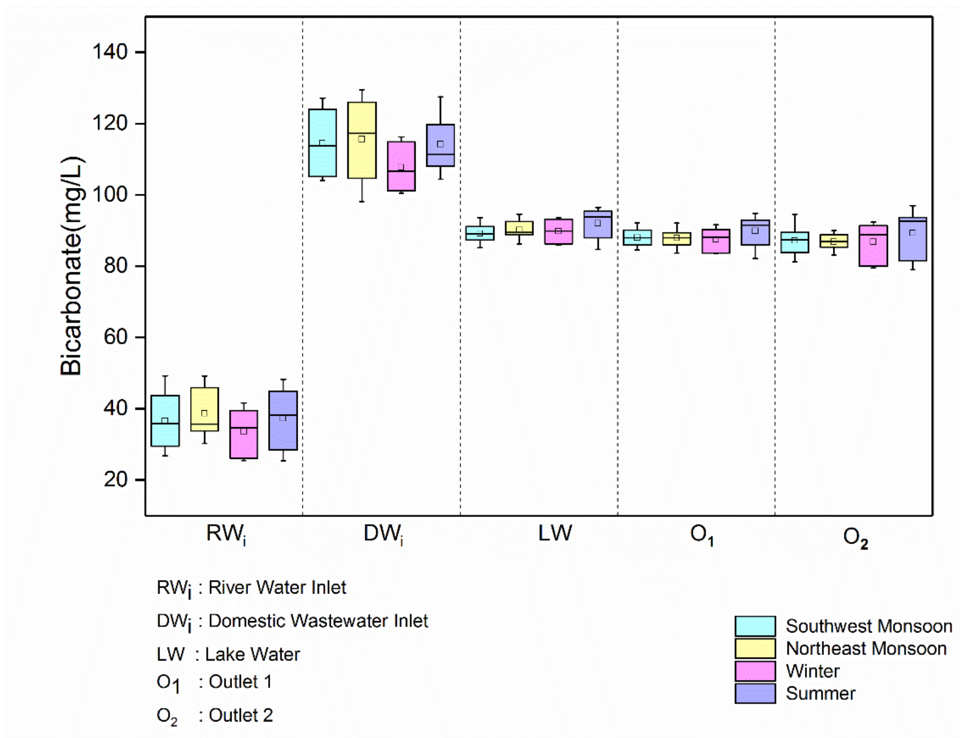


(v)

Figure 2. The seasonal variation of water quality parameter (i)TDS, (ii) Na, (iii) Ca, (iv) Mg and (v) HCO_3 ***is*** presented by Box-Whisker diagram.

There is a fluctuation in condition throughout the winter period, having 90% of the water being good and 10% being exceptional for drinking. During monsoon seasons, the situation changes, with 90% of the water falling into the excellent level and 10% falling into the fair category. During the summer season, 80% of water is falling under poor category and remaining 20% falling into good. The water in the lake has been deemed to be appropriate (Table 2).

Table 2. WQI and water quality for season wise

Sl.No.	Samples	South west Monsoon		North East Monsoon		Winter		Summer	
		WQI	Water Quality	WQI	Water Quality	WQI	Water Quality	WQI	Water Quality
1.	River Water Inlet (Sample 1)	21.95	Excellent	28.53	Good	24.17	Excellent	46.25	Good
2.	Domestic Waste Water Inlet (Sample 2)	39.23	Good	51.34	Fair	46.04	Good	74.04	Poor
3.	Lake Water (Sample 3)	30.01	Good	44.28	Good	47.56	Good	59.63	Fair
4.	Outlet1 (Sample 4)	33.94	Good	49.08	Good	49.21	Good	61.72	Fair
5.	Outlet2 (Sample 5)	34.52	Good	47.50	Good	48.74	Good	63.16	Fair

Modeling with ANFIS:

. The ANFIS input parameters considered are; TDS, sodium, calcium, magnesium and bicarbonate. The WQI value is the output. The training data is used to train ANFIS. The checking data is utilized to verify the ANFIS that has been found. The testing data was used to assess the model's performance. The first data set which consists of 75% of the records was used as training data and the remaining 25% of the records were used as testing data.

Table 3. Evaluation of water quality using FCM and SC model

Achieving performances	Fuzy c-means -ANFIS	subtractive clustering - ANFIS
R^2 - training	0.8761	0.9120
R^2 - Testing	0.8340	0.9457
Mean square error - training	1.0589	0.8264
Mean square error - testing	5.8922	2.7407
Root mean square error-training	1.0452	0.8156
Root mean square error- testing	1.9281	0.8623
all data – correlation coefficient	0.9811	0.9912

Table 3 contains information on numerous parameters and the values used for modelling uses two clustering algorithms which was mentioned previously. The error measure is lowered with each epoch, and it is based on the squared difference between what is actually produced and what is desired. When the WQI was calculated based on the discovered premise parameter values, it was a linear combination.

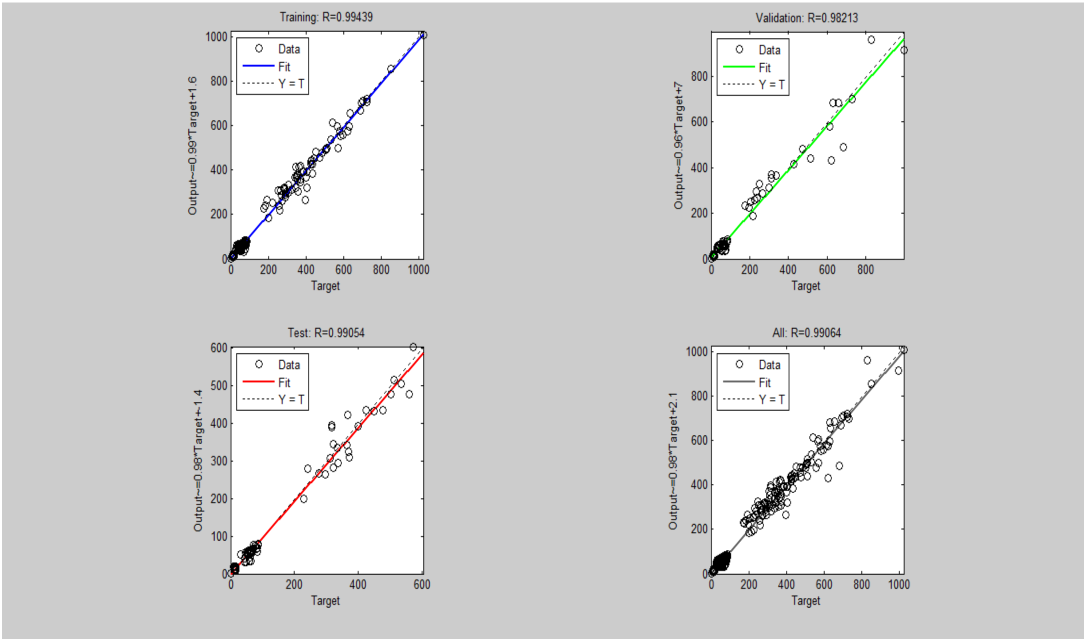


Figure 3. Fitness of the ANFIS-WQI prediction model.

The R^2 value of all data are 0.9912 for SC-ANFIS model and 0.9811 for FCM-ANFIS model which shows that subtractive clustering method is very close to the investigation values. Figure 3 shows the plotting of predicted WQI values versus the measured ones, which depicts the SC-ANFIS method's overall fitness.

Simulation of WQI by using ANFIS:

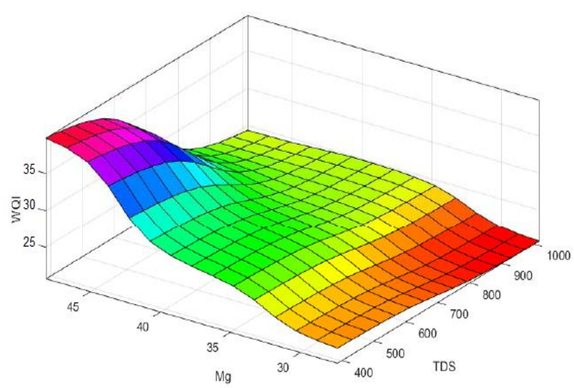
The first stage in modelling a system is to classify the input and output variables. The inputs have a significant impact on the output (Masrur Ahmed, A. A., and Syed Mustakim Ali Shah, 2015). Water sample data provide the variation and distribution of actual and predictable WQI using fuzzy logic. The logical nature of data in the distribution is assessed by training and testing of data plots and FIS output. Figure 4 depicts the surface plots for WQI data sets. The surface encompasses the entire terrain as well as decision space. During summer, sewage water disposal is high, resulting in higher NFWQI values (Table 4). The 75 percent of water samples falling into the "good" category and the remaining 25% falling into the "bad" category. So the water cannot be used for irrigation or portable purposes. The water analysis is used to evaluate the model's sufficiency. The parameters are calculated based on actual and forecasted water quality index data. During the summer, all the parameters have higher values. The WQI with Lake quality characteristics shows non-linearity as a result of the difference between the actual and anticipated WQI in the model. There is no rainfall or river water inflow into the lake during the summer season so that NFWQI value is high.

Table.4 Results of WQI and water quality predictions for the four seasons

Samples		Inlet water from river (Sample 1)	Inlet water from domestic wastes (Sample 2)	Lake Water (Sample 3)	Outlet1 (Sample4)	Outlet 2 (Sample5)
SW	WQI	20.47	38.54	31.72	32.18	33.87
	Quality	Excellent	Good	Good	Good	Good
NE	WQI	30.92	49.87	43.12	49.01	46.73
	Quality	Good	Good	Good	Good	Good
winter	WQI	25.16	45.94	47.04	48.021	46.93
	Quality	Good	Good	Good	Good	Good
Summer	WQI	45.41	73.39	60.01	60.37	62.46
	Quality	Good	Poor	Fair	Fair	Fair

These findings show that the water in Parakai Lake is contaminated due to the disposal of home waste water into the lake on a regular basis, which cannot be used for human consumption or irrigation. Management approaches should be unregularly the lake water pollution and the recommendations formulated for the restoration of lake water are as follows:

- The lake water must be treated before distributing it to the irrigation land.
- The primary cause of lake eutrophication is sewage effluents.
- Waste diversion improves the lake's water quality.
- Domestic wastewater must be treated in a stabilization pond before dumping into the lake.



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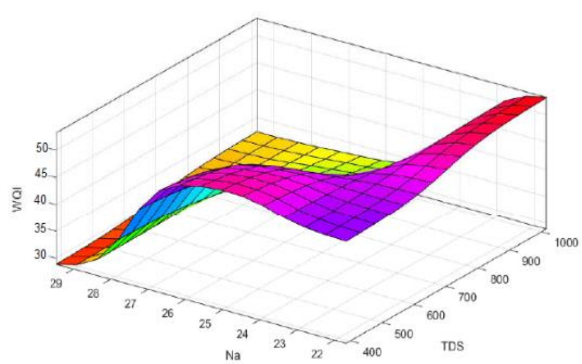

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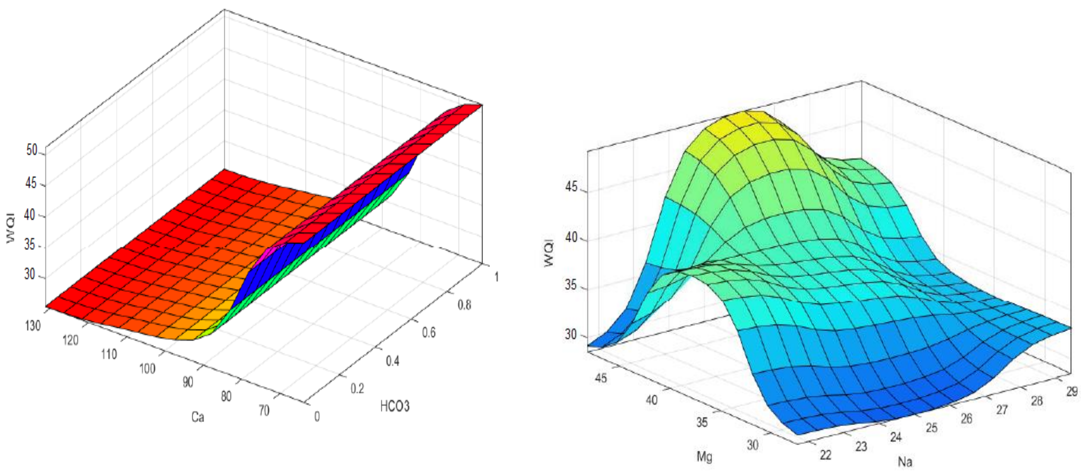

(iii) (iv)

Figure 4. The surface plot of WQI in (i) SW monsoon, (ii) NE monsoon, (iii) Winter and (iv) summer season

Therefore, stabilization ponds naturally contribute to the purification of water and it improves the quality in an ecological manner. Domestic wastewater should be treated before entering into the lake. The best restoration of lake water occurs when the physico-chemical parameters values are similar to those of drinking water and the water samples from the lakes are having 98% in good condition (Figure 5).

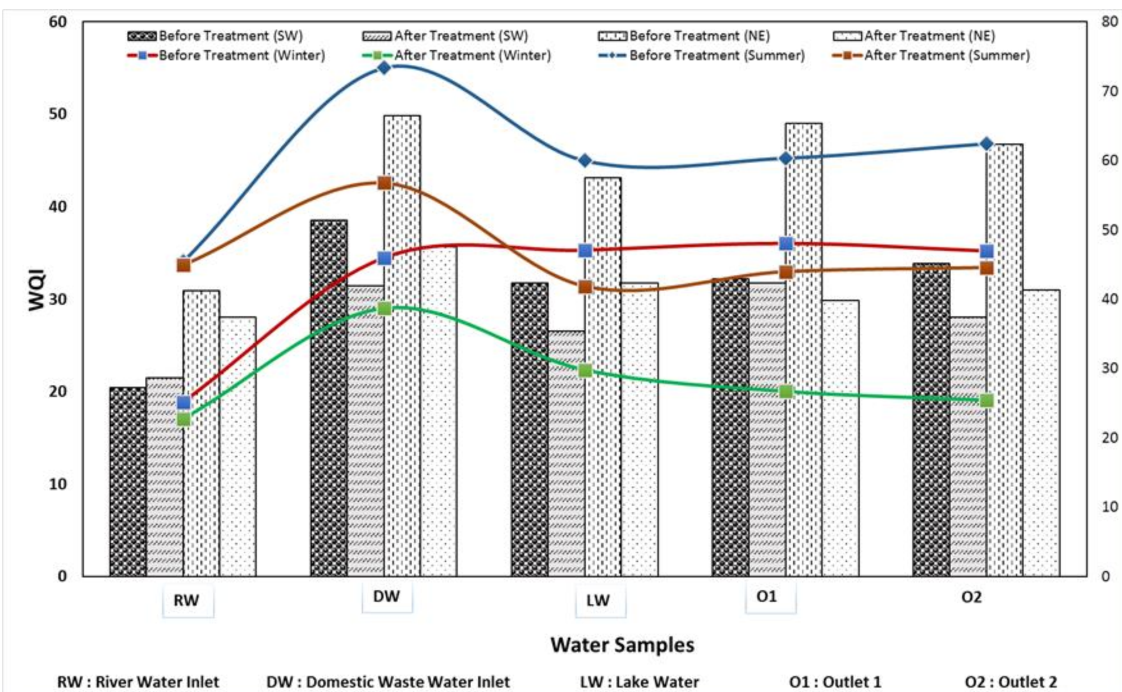

Figure 5. Chart for Comparison of WQI for treated and untreated water quality

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Conclusions

In the Parakai Lake, the effects of pollution will be noticed in the form of eutrophication and a significantly lower rate of dissolved oxygen concentration. It demonstrates a rise in nutrients due to increased human activity level in the lake, environment and home waste output, leading to an increase in eutrophication. According to the current study, the lake water is contaminated extremely throughout the summer months, so it cannot be used for domestic, irrigation, or for the survival of life forms without treatment measures. The various physicochemical properties of water sources are classified using pollution inventory methods based on functional variables and contamination concentrations. Artificial intelligence approaches are highly suggested in model characteristics for high learning speed, improved expected precision and strong heftiness utilized to determine the effects of lake water quality on the ayacut area. This model can be effectively encountered for the management necessary in severe contamination areas and to forecast water quality efficiently. The expected and calculated data were correlated to prove the reliability of the constructed model, thereby demonstrating that it can be used as a powerful tool for forecasting the quality of water in the lake. According to this study, domestic wastewater must be treated at each home itself before being discharged into the lake while employing a stabilization pond. Adoption of efficient techniques for treating sewage wastes and recycling it into manure as well is necessary.

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