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Modelling of Irrigation Water Quality of Coastal Area Using Back Propagation-Multi Layer Perceptron Artificial Neural Network

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Abstract:
Irrigation water quality is one of the main yield factor in the cultivation of agricultural and horticultural crops in arid, semi-arid and coastal areas. In past two decades, irrigation water quality and quantity problems increasing severely because of improper management and industrialization. The main aim of this study is to describe the applicability of artificial neural network that can effectively predict quality of irrigation water in the above areas. The study was conducted over 17 villages of coastal Chidambaram Taluk and about 170 samples were collected. Irrigation samples were analysed for Physico-chemical properties, various cationic and anionic constituents outlined. Based on the analysis, 70% of the samples were determined by saline and 30 percent samples were alkaline in reaction. Data obtained from chemical analysis were used in the ANN model to predict pH and electrical conductivity. The results of this study proved that MLPBP-ANN is effectively predicting irrigation water quality of coastal area.

Keywords: **Coastal area, Irrigation water quality, Prediction, pH, BP-MLP, Gradient decent algorithm**

1.0 Introduction:
In India, population is the major problem which may lead to war for food, land and water. In arid, a semi-arid and coastal area, good quality irrigation water is the very important and limited resources to affect the food production directly. The quality of water in coastal area were decline due to ingress of sea water, uncontrolled and unscientific uses (pumping and recharge) and industrialization, the above reasons lead to reduction of food production and increased malnutrition in respective areas. Management and periodical assessment of ground water quality status is essential to maintain the potential property of land for food production (Durdu et al., 2010). Many methods are available to predict the groundwater quality in coastal areas for few decades. In recent scientific advancement, modelling of groundwater quality may attain greater heights.

The artificial neural network (ANN), as its name implies, is a technique for the human brain's problem– solving process. Just as humans apply knowledge gained from experience to new problems or situations, the structure of a neural network can be applied to the powerful computation of complex nonlinear relationships. Artificial neural network (ANN) is the new approach in hydrological studies, especially predicting irrigation water quality of monthly values of dissolved oxygen and specific conductance as two water quality parameters of Delaware River, Pennsylvania(dissolved oxygen and specific conductance (Heydari *et al.,* 2013). ANN, is a biological inspired computing methodology that have the ability to learn by imitating the learning method used in the human brain, don't accompany any of the above drawback of conventional methods, physical and statistical. ANNs, especially back propagation network are closely related to statistical methods and are most suitable to predicting of ground water quality applications. ANN models are usually employed to predict or to optimize the values of qualitative parameters. (Nourani et al., 2013).

ANNs are well suited to complex problem as they belong to class of data driven approaches. ANNs are relatively in sensitive to data noise, as they have ability to determine the underlying relationship between input and output resulting in good generalization ability. The most common types of ANN used in ecology are supervised multilayer perceptron neural networks with a back propagation learning algorithm (BPN) (Maier and Dandy, 2000). Artificial Neural Networks have become the central focus of many scientific disciplines, such as groundwater modelling, assess quality of water, forecast precipitation and support other hydrologic applications(Palani et al.2008; Gazzaz et al.2012; Huang et al., 2002). Hatzikos et al., (2005) utilized neural networks with active neurons as a modelling tool for the prediction of seawater quality indicators like water temperature, pH, DO and turbidity. In Greece, ANN are used to forecast the maximum daily value of the European Regional Pollution Index as well as the number of consecutive hours of pollution during the day, 24 to 72 hours ahead (Moustris et al., 2010). No study has been conducted to use ANN for predicting pH of irrigation water of coastal village of Chidambaram Taluk. In this sense, this study aimed to predict the pH of irrigation water using MLP-BP ANN network.

2.0 Materials and Methods:

2.1 Study area:

The study area includes the coastal village of Chidambaram taluk, situated in the eastern parts of Chidambaram town. The study area lies within latitudes of 79°49'N and 79° 43° N and longitudes of 11° 33' and 11° 22' E. The Chidambaram taluk enjoys tropical climate with high rainfall during north east monsoon. The hottest and driest months of the year in this region is April-May where the temperature rises above 32.2°C. Winter is mild during November-January when the average is around 21.5°C. The mean annual temperature is about 27.8°C. The mean humidity is usually around 72 percent. Study area receives rainfall during south east monsoon, north east monsoon and summer shower. Annual rainfall is 1360.9 mm. Out of which (1000 cm) is contributed to north east monsoon and 300 mm by south west monsoon. Summer shower is only less than 5% (60 mm). The geology of Chidambaram taluk consist mostly quaternary alluvium. The alluvium of vellar river partially over lies the crotoccous and the Cuddalores. The thickness found near Sethiathope anicut is 123'. The average, thickness of aquifer is approximately 40'. It will change or lower in coastal area at 4' to 5'. A very low sand dune occurs all along the coastal belt approximately 1.5 km width. The taluk also comprises of tertiary rocks consisting of Cuddalore sand dunes underlying fluvial depositions. Remaining parts are covered with east-coast laterities. The location of the sample sites were shown in the Figure 1.

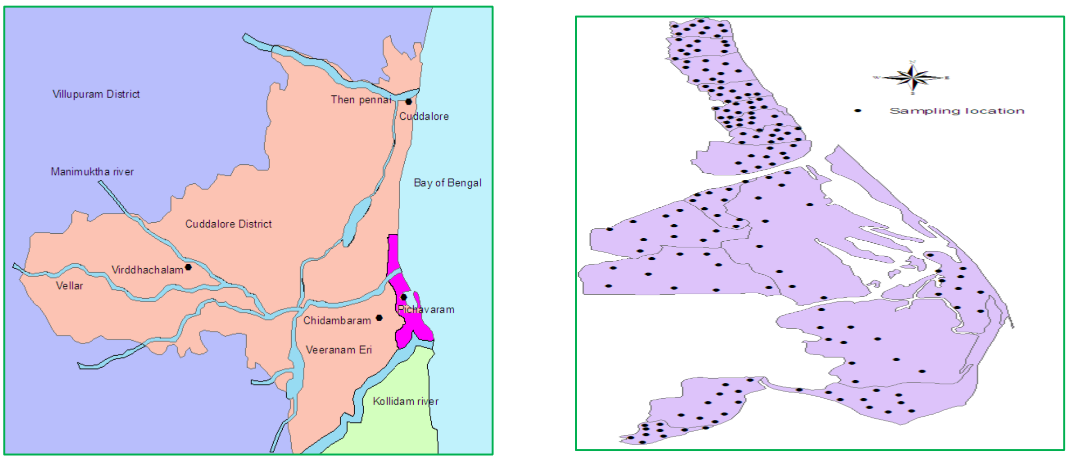

Fig 1. Map showing the study area and sample locations

2.2 Collection of irrigation water:

Irrigation water samples were collected from coastal areas of Chidambaram taluk spreading over 17 villages from Madavapallam in north and Keelthirukallipalai in the south. In each village, ten irrigation water samples constituting a total number of 170 samples were collected in clean plastic bottles during Feb-May 2004. Before that bottles were washed with sample water. A 500 mL of water was collected and 2-3 drops of toluene was added to arrest the microbial contamination.

2.3 Analysis of irrigation water :

The water samples were analysed for pH, EC and various cationic and anionic constituents. The analytical methods employed for water samples analysis are as follows. The physico- chemical properties were analysed by standard procedure (Jackson, 1973). Carbonate and bicarbonate was analysed by titration method (Jackson, 1973); chloride by mohr's titration method (Richards, 1954); sulphate by Nephelometry method (Jackson, 1973); nitrate by Bremmner method (Bremner and Keeney,1965); calcium and magnesium by Versanate method (Richard, 1954); sodium and potassium by flame photometry (Standford and English, 1943).

2.4 Bp-Mlp Artificial Neural Network:

An artificial neural network is system based on the operation of biological neural network, in other words, is an emulation of biological neural system. An artificial neural network is developed with a systematic step by step procedure-which optimistic criterion commonly known as learning rule. The input / output training data is fundamental for this network as it conveys the information which is necessary to discover optimal operation point. Basically, artificial neural network (ANN) consist three distinctive layers, a set of sensory units (source nodes) that constitute the input layer, hidden layer or layers of computation nodes and the output layer of computation nodes. The input signal passes through the network in a forward direction on one layer to another layer. This neural network is called as the multilayer perceptron (MLP). In Multilayer perceptron, highly popular algorithm **error back propagation algorithm** has been used successfully to solve some challenging problems by training input variables in a supervised manner. Error back propagation learning consists of two passes namely forward and backward which through various layers of the network. The forward pass propagates through layer by layer network and an activity pattern (input vector) is applied to the sensory node of the network. Finally actual response of the network is produced from set of input. Back propagation algorithms used input vectors and corresponding vectors to train ANN. The standard BP algorithm is the gradient descent algorithms in which network weights are changed along the negative of the gradient of the performance function. The number of neurons in each layer may vary depending on the problem. The weighted sum of the input component is calculated as

$$y_j = \sum_{i=1}^{n} W_{ij} x_i + \theta$$

When y_j is the weighted sum of the j^{th} neuron for the input data receiving from proceeding layer with n neurons, W_{ij} is the weight between j^{th} ith neuron and j^{th} neuron in the proceeding layer. X_i is the output of the i^{th} neurons in the proceeding layer and θ is bias from the j^{th} neurons.

The output of the j^{th} neurons out_j is calculated with a sigmoid function. The sigmoid function, where the graph is 'S' shaped is by far the most common form of activation function used in the construction of artificial neural network. It is defined as a strictly increasing function that exhibits a graceful balance between linear and nonlinear behaviour.

$$Out_j = f(Net_j) = \frac{1}{1+e^{-(Net_j)}}$$

The training of the network is accomplished by adjusting the weights. The training process is carried out through a large number of training set and cycles. The main good training procedure is to find the optimal set of weights, which is an ideal case, could produce the right output for relative input. The output of the network is compared with desired response to determine an error. The performance of MLP-BP is measured in terms of the desired signal and criterion for convergence. It is determined by the mean squared error (MSE) and root mean squared error (RMSE) which is calculated as follows

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}(T_i - Out_i)^2$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Ti - OUTi)^2}$$

Where T_i and Out_i are the desired target and output of neural network value respectively for the i^{th} output neurons and m is the number of neurons in the output layer. n is the number of sample. A total eight parameters such as Na, K, Ca, Mg, SO_4, Cl, NO_3 and Hardness are used as input parameter of this network . The output parameter in this network pH was predicted by the input vector noticed earlier. In this study, back propagation neural network architecture which gradient decent algorithm was used to determine the relationship between input and output parameters and predict the quality of irrigation water in the coastal area of Chidambaram Taluk.

3.0 Results and Discussion:

The applicability of ANN was investigated to predict the electrical conductivity (EC) of about 170 irrigation water samples of coastal area of Chidambaram taluk. pH of irrigation water samples collected from the coastal areas of Chidambaram taluk ranged from 7.15 to 9.22 with mean of 8.52 and represented neutral to alkaline in reaction. Out of 170 water samples collected, 3 samples had pH < 7.5, 119 samples had pH 7.5-8.5 and 48 samples had pH > 8.5. Analysis of irrigation water sample for EC revealed the non-saline to highly saline nature of water. The EC of water ranged from 1.14 to 4.90 dSm^{-1} with mean of 2.77 dSm^{-1}. Out of 170 samples analysed, one sample recorded an EC value of <1 dSm^{-1}, 25 samples recorded an EC value of 1-2 dSm^{-1}, 110 samples recorded an EC value 2-3 dSm^{-1} and 34 samples recorded an EC value >3 dSm^{-1}. The CO_3^{2-} content of irrigation water collected from coastal areas of Chidambaram taluk varied from nil to 0.62 me l^{-1} with a mean of 0.015 me l^{-1}. Bicarbonate content in the irrigation water ranged from 1.8 to 14.8 me L^{-1} with mean value of 9.68 me L^{-1}. Irrigation water samples collected from coastal villages of Chidambaram taluk was found to contain a chloride content of 4.01 to 24.6 me L^{-1} with mean value of 20.5 me L^{-1}. Out of 170 samples, 2 number of samples had <5 me L^{-1}, 2 number of samples had 2-6 me L^{-1} and 166 samples had >10 me L^{-1}. The content of sulphate in irrigation water samples varied from 1.14 to 7.2 me L^{-1} with mean of 5.87 me L^{-1}. Out of 170 samples, 19 sample recorded <4 me l^{-1} and 151 samples had >12 me L^{-1}. Calcium content in coastal irrigation water ranged from 0.9 to 7.3 me L^{-1} with mean value of 3.5 me L^{-1}. The content of Mg^{2+} in irrigation water varied to the tune of 0.7 to 9.2 me L^{-1} with a mean of 3.76 me l^{-1}. The range in value of sodium in irrigation water varied from 6.8 to 47.7 me L^{-1} with mean of 27.71 me L^{-1}. The potassium content ranged from 0.09 to 2.10 me L^{-1} with mean of 0.45 me L^{-1}.

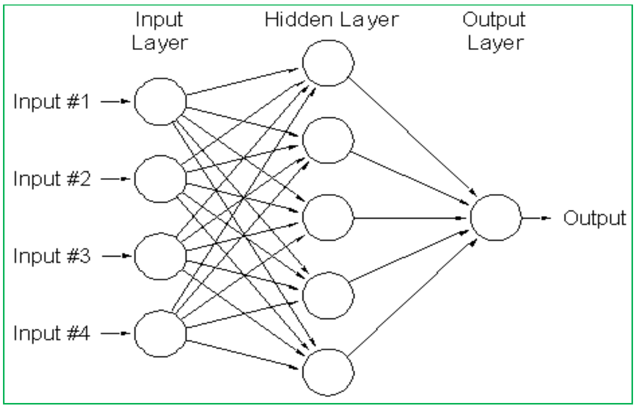

Fig 2. Architectural graph of a multilayer perceptron with one hidden layer.

Table 1. Different neural network architecture for predicting quality of irrigation water

Architecture	Fitness	Average training error	Correlation coefficient (R)	Regression coefficient (R^2)
8-1-1	14.13	0.0668	0.93	0.85
8-10-1	20.67	0.0459	0.97	0.94
8-11-1	20.77	0.0411	0.98	0.95
8-12-1	18.72	0.0371	0.97	0.94
8-20-1	18.13	0.0476	0.96	0.94

Table 2. Evaluation of model performance of irrigation quality by MLP-BP neural network

Simulation	Percentage of sample	MSE	RMSE	Correlation coefficient(R)	Determination of coefficients (R^2)
Training	121	0.004731	0.042096	0.9892	0.9775
Validation	24	0.00325	0.068509	0.9090	0.9676
Test	24	0.010879	0.072147	0.9219	0.970
All	169	0.004397	0.051706	0.9832	0.9639

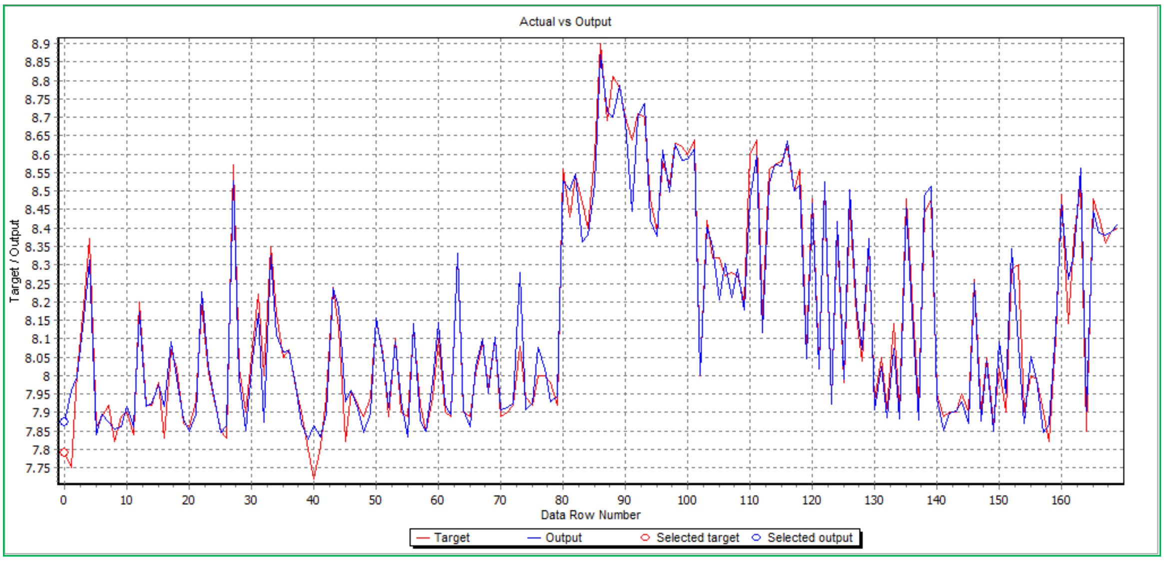

Fig 3. Actual and predicted value of pH by training set data in multilayer perceptron back propagation artificial neural network.

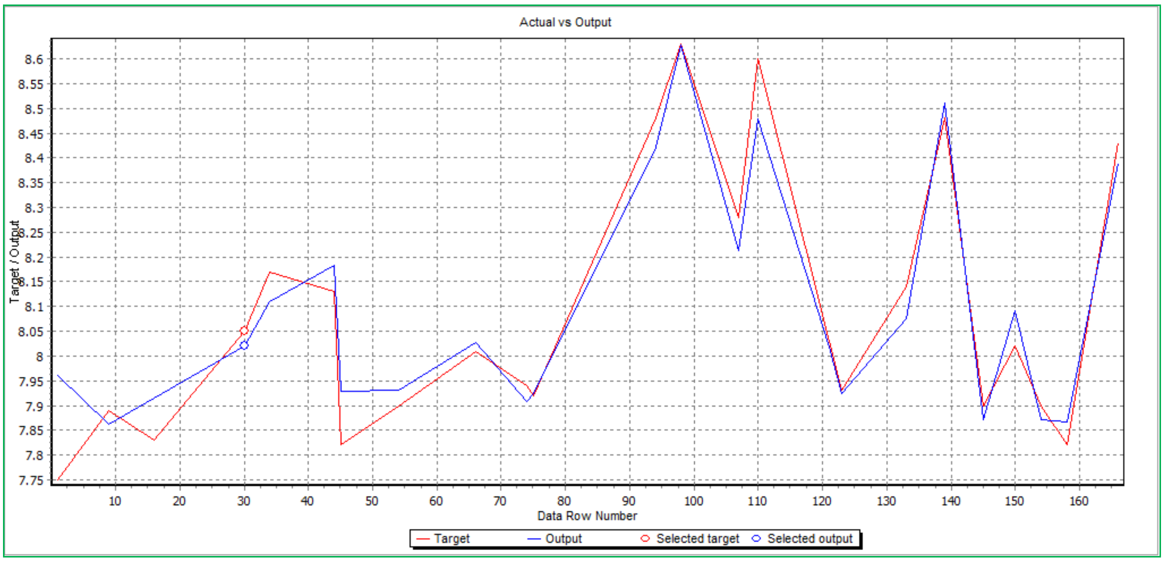

Fig 4. Actual and predicted value of pH by validation set data in multilayer perceptron back propagation artificial neural network.

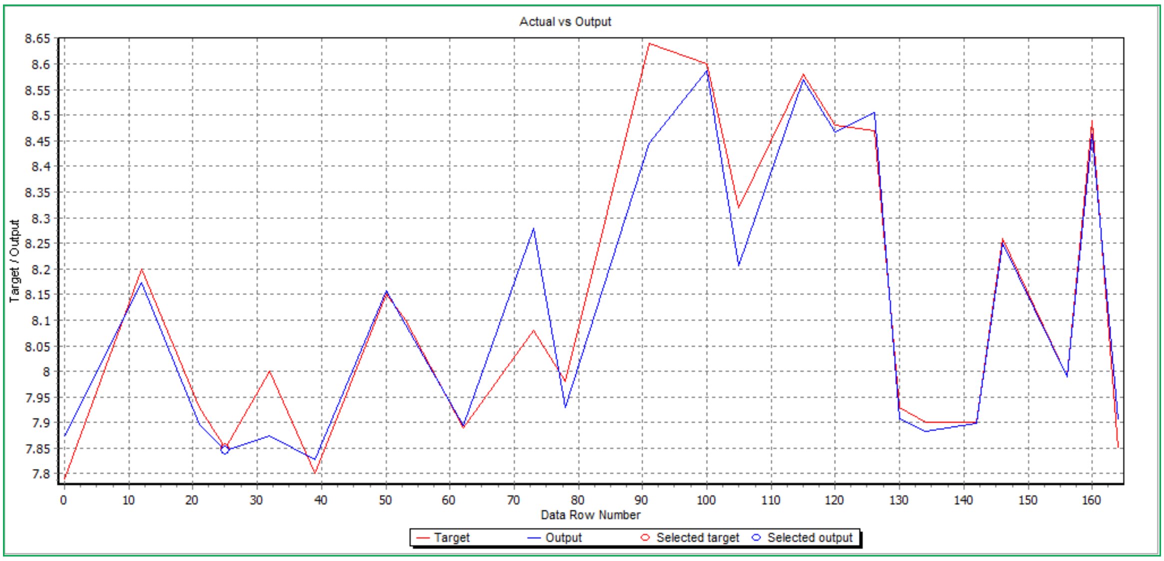

Fig 5. Actual and predicted value of pH by test set data in multilayer perceptron back propagation artificial neural network.

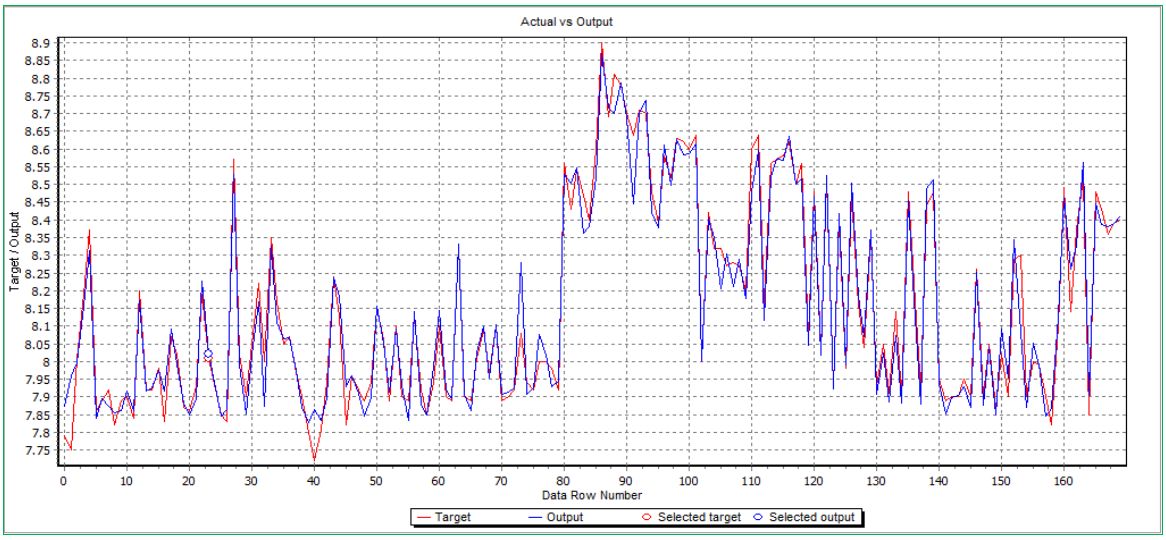

Fig 6.A total Actual and predicted value of pH by multilayer perceptron back propagation artificial neural network.

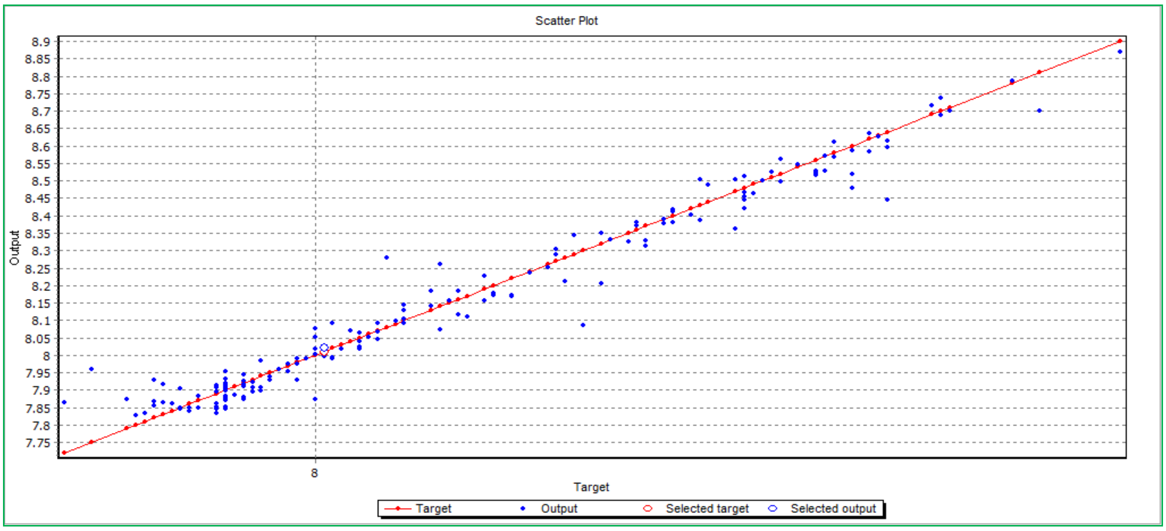

Fig. 7. Scatter diagram of actual and predicted value of pH multilayer perceptran back propagation artificial neural network.

3.1 Simulation Results:

Out of these, some parameters are used to predict the pH of irrigation water viz., carbonates, bicarbonates, sulphate, chloride, sodium, calcium, magnesium and potassium. The parameters were selected based on factor analysis (Sathiyamurthi and Saravanan, 2013). Out of 170 samples, 70 per cent of the samples were used to train ANN model and 15 per cent of samples were used to validate the ANN model. Remaining 15 per cent samples were used test the ANN model. To find out the best ANN architecture, several possibilities were considered (table1). ANN architecture, the number of nodes in the input layer and output layer was fixed at 8 and 1 respectively. A total 5 network were selected by trial and error method. Out of this network 8-11-1 network architecture is given positively significant coefficient (r=0.98) and coefficient of determination R^2 (0.95). A plot of actual and estimated value of pH by training set data was presented in fig3. . This model shows that nonlinear relation between the actual input parameter and desired output parameter. The coefficient of determination R^2 was 0.989 and determination of coefficient was 0.977. This is an acceptably high accuracy is considered to pH of irrigation water. The performance of the model was validated using independent validation dataset. A plot of actual and estimated pH of irrigation water in validation set data was presented in fig 4. It shows fairly good fit with correlation coefficient r= 0.907 and determination of coefficient was 0.967. The performance of the model further evaluated using the independent test data. A plot of actual and estimated value of pH of test data set was present in fig 5. In test dataset this model performs in better manner ie correlation coefficient was r=0.92 and determination coefficient was 0.970. A plot shows that overall performances of the model i.e. train, validation and test data set. This plot having significant correlation coefficient (r= 0.98) and coefficient of determination (R^2=0.9 3). In order to evaluate the best model was descried by minimum MSE and RMSE presented in table 2.

4.0 Conclusion:

pH of irrigation water of coastal area of Chidambaram taluk was predicted by eight variables of 170 samples. pH can be easily predicted with the designed, trained, validated neural network model. pH was found to be most significant parameter with input parameters used in the modelling. The developed model gave satisfactory fit to the experimentally obtain easy data in 170 samples. Hence, with the proposed model applications, it is possible to manage irrigation water resources in very effective manner.

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