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A Review Of Soft Computing Techniques In Modelling The Water Quality Of Rivers

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Abstract: Soft Computing is one of the modern approach to develop various computational intelligence models for real life problems which are much complex and nonlinear like environmental problems. These methods utilizes nature inspired thoughts for implementing a sort of functional solutions for the complex computational problems. The Water Quality (WQ) modeling, assessment and forecasting are very interesting as well as challenging mission for water managing organizations due to the complex and nonlinear relationships between the parameters responsible for determining water quality. The main focus of this paper is to perform a comprehensive literature survey of various researches done across all around by different researchers on the application of soft computing techniques like fuzzy logic, neural network, support vector machine, neuro-fuzzy and genetic algorithms for modelling and predicting the water quality variables. The review of literature resulted in a conclusion that various soft computing techniques have become perceptible choice for researchers to solve majority of issues based on environmental problems. These methods proved to be highly proficient in water quality modelling based problems. Also, this study leads to one more conclusion that these biologically inspired techniques have ample scope in forecasting domain and because of their ability to handle imprecise data these can be applied to solve problems from other domains in an effective manner with.

Keywords: Soft Computing; Fuzzy-logic; Artificial Neural Network (ANN); Support Vector Machine; Water Quality; Forecasting.

1. INTRODUCTION

The problem solving techniques are broadly divided into two categories: hard computing and soft computing [1]. The hard computing targets in finding precise solutions while soft computing aims in finding approximate solutions. The hard computing comprised of all the traditional logic reasoning and mathematical based methods. While the soft computing approaches comprised of two broad classes as Approximation Reasoning and Randomized Search methods. The Approximation Reasoning consists of probabilistic reasoning and fuzzy logic while the another category Randomized Search methods contains

neural networks (like feed forward and recurrent networks) and Evolutionary computation based models (like genetic algorithms, swarm intelligence).

The guiding principle of soft computing as per Prof. L.A. Zadeh in 1965 is: "Exploit the tolerance for imprecision, uncertainty, partial truth, and approximation to achieve tractability, robustness and low solution cost" [2]. The role model for soft computing is the human mind. Fuzzy Logic, Neural Networks, Machine Learning, Evolutionary Computation are the key elements of soft computing. In some situations where it is sometimes enough to attain a near optimal solution rather than no solution or difficult to find practical solution these nature inspired computing techniques plays a significant role.

The Water Quality (WQ) modeling, assessment and forecasting are very challenging task for water management authorities due to the complex and nonlinear relationships between the parameters responsible for determining water quality.

These soft computing Machine Learning (ML) approach centered arrangements has been widely considered and applied over the recent three decades for scientific, research and environmental based issues which are highly non-linear and complex in nature. In this review paper, the state of the art methods for solving various ecological problems are presented.

2. LITERATURE REVIEW

A variety of analysis work in numerous fields is under development using soft computing especially machine learning methodologies utilizing the well-known approaches like fuzzy-logic, artificial neural networks, support vector machines and genetic methods. The vital contributions made by various researchers in the field of water modelling is outlined in this study.

Guoqiang Zhang, et al. [3] explained a best-in-class examination of artificial neural network (ANN) applications in forecasting. The author found various areas including financial applications, power load utilization, physics, physiology, commodity prices, rainfall, total industrial production, water demand etc. where ANNs are applied fundamentally as a forecasting tool. Most of these studies are based on the multi-layer perceptron concept.

Yanbo Huang et al. [4] reviewed several related papers involving the application of fuzzy logic and ANN concepts for solving problems in the domain of crop management, water and soil, food quality and safety, air quality and pollution etc. The applications that have been created through fuzzy logic (FL) involved modeling and prediction in 24% papers. ANNs have been applied in solving problems soil and water (14.37%). These ANN applications have been created mainly through classification (45.11%), modeling and prediction (43.97%). Most of the writing announced that modelling was used commonly for developing corresponding models. Also, authors outlined that integration of FL and ANNs is the most common method in soft computing based applications.

Nwankwo Nonso Prince [5] described the applications of Neural Networks in various fields involving recognition, forecasting, disease diagnosis etc. Author brought the fact that neural system may not generally offer the ideal response, rather a best guess is provided. He concluded the fact that, in many cases, a 99.9999999999999999% correct response in one millisecond is better than a 100% response in thirty hours. Consequently, ANN-based technique is utilized continuously in managing biological issues.

Mohd Fahmi Mohd Nasir et al. [6] highlighted the modeling concept of Malaysian River Juru considering the dataset collected over a four years of time period. There were two models that are implemented in their study recognized as Model A and Model B. The model A consist of two models, the first model involves thirty parameter as inputs with three hidden layers and one output (WQI) while the second model explains six significant parameters after conducting the sensitivity analysis. Meanwhile, Model B was developed by considering the six parameters proposed by DOE. This study proved that ANNs are undoubtedly capable to be an alternative method in order to predict WQI rather than using conventional method (WQI equation) which is currently being used by DOE. This study proved that ANNs are able to be an alternative prediction method to predict Water Quality Index (WQI) rather than using traditional approach base on WQI equation. They inferred that the forecasts from their created models can be exceptionally valuable for aiding chiefs in waterway executives.

Gholamreza Asadollahfrdi et al. [7] forecasted the water quality variable of the Chalghazi River, Iran over the dataset for the period of 1998-2009. The input parameters of the MLP network was pH, discharge, sulfate, sodium, calcium, chloride, magnesium and bicarbonate, and output was predictive of the SAR.70%of the data was used for training, 5% for validation and 25% was used for testing of the model.The results highlighted a high correlation coefficient 0.976 between actual and predicted values, which means the accuracy of the model was acceptable. They concluded that multilayered perceptron becomes a powerful tool for estimation of WQ variables because of its high accuracy.

Samira Nemati et al. [8], modeled Total Dissolved Solid (TDS) values at the Simineh River, Iran on the basis of ANNs. The input parameters of the ANNs model taken as Calcium (Ca), Chloride (Cl), Magnesium (Mg), Sodium (Na), Bicarbonate (HCO3), Sulfate (SO4), and water discharge (Q) from 1993 to 2011. They investigated the impact of variation of the hidden layer neurons on RMSE, MAE and other factors in training and testing periods. When 14 hidden neurons were selected the model performed well. Their results presented that the ANNs models provide high correctness in case of modelling the WQ variables.

M. Niroobakhsh et al. [9] made the forecasting model for the WQ of the Jajrood River, Iran. They have computed the total dissolved solids utilizing the data collected over a period of 40 years. The calibration (or training) and validation (or testing) of data subsets comprised many division such as (60 and 40%), (65 and 35%), (70 and 30%), etc., on each sample, respectively. A non-linear transfer function, sigmoid tangent (tansig) was applied in the hidden layer and linear transfer function, pure line (purelin) in the outer one. They used three data partition strategies: 60:40%, 65:35% and 70:30% in order to carry out calibration i.e. training and validation i.e. testing respectively. The selected ANN for the TDS model composed one input layer with five input variables, two hidden layers with eighteen neurons and one output layer with one output variable. The Scaled Conjugate Gradient (SCG) training function was used to perform the training. The results outlined that both methods of ANN were found to be highly accurate in simulating the water quality with an accuracy of more than 90%.

M.J. Diamantopoulou et al. [10] developed the neural network models for estimating the water quality parameters of Axios River, Greece over the period of 1980-1984 considering the monthly data of 12 water quality variables. The data partition method of 90:10% was adopted. A feed-forward and supervised algorithm called cascade correlation used for training of NNs. Different network structures tested for finding the optimal numbers of hidden layers and the

number of nodes in every layer. The networks were designed by putting weights between neurons by using the hyperbolic-tangent function of training. The obtained results were found reasonable.

A. Clementking et al. [11] configured a backpropogation neural network method for the prediction of water quality in the districts Tirunelveli and Tuticorin, Tamilnadu. They have described the development of Back Propagation Neural network model with obtained variations of water quality attributes variations. Using a supervised Neural Network back-propagation method the 9:9:2 model was proposed for training the given dataset to perform the WQ predictions. The gradient of the error function was computed and used to correct the initial weights. The results were found to be satisfactory and useful for the water resource management authorities in the decision-making procedure.

Alireza Shakeri Abdolmaleki et al. [12] examined ANN method for forecasting Concentration of copper in water of Chahnimeh Reservoir, Iran. The Levenberg–Marquardt was applied to train the three layered ANN architecture. The network designs comprising 4:7:1 i.e. 4 inputs, 7 hidden neurons and 1 output was reported to be appropriate for developing the best model. The result showed the potential of the ANN for producing models capable of efficient forecasting of Cu concentration.

Vinayak K Patki et al. [13] estimated the WQI in the distribution system for Solapur, Maharashtra by developing different models based on ANN. Cascade feed forward ANN models have been developed by using pH, Alkalinity, Hardness, (TS) and MPN as the input variables. Different ANN models were developed using training data set and tested in order to determine optimum number of neurons in the hidden layer and best fitting transfer function. The training was performed on the basis of two years of data and testing was done using one year dataset. The ANN Architecture composed of one input layer with six input variables, one hidden layer in which number of neurons varied from one to ten and one output layer with one output variable. Out of twenty nine zones in the study area for thirteen zones Logsigmoidal, for ten zones Purelinear and for remaining six zones Tansigmoidal transfer function performed better. Hidden layer structure with seven neurons performed better. The overall results were found to be adequate.

Qinghua Luan et al. [14], assessed the water quality in Suzhou River, China by proposing a Back-Propagation (BP) NN model and model based on Radial Basis Function. Performance comparison has performed using different topologies of BP neural network. Performance comparison has performed using different topologies of RBF neural network. The BP neural network has delivered a high precision than RBF model while RBF neural network presented a fast convergence than BP neural network.

S. Areerachakul [15] compared the performances of ANN and Neuro-Fuzzy based models in estimating Biochemical Oxygen Demand (BOD). There were 828 records of data from the 2004 to 2011. A fuzzy inference system with two inputs x and y, and one output was assumed. The training and the testing datasets were selected as per the ratio of 70:30% respectively. The architecture of the network used was 5-8-1. The results were found to be much agreeable. The experimental results showed that the artificial neural network model provided higher correlation coefficients (R=0.73) and lower mean square error (RMSE=4.53) than the adaptive neuro-fuzzy inference system model.

Emrah Dogan et al. [16] assessed the Biological Oxygen Demand (BOD) based on ANN. Various input variables like chemical oxygen demand, temperature, dissolved oxygen etc. were collected in the Melen River, Turkey during 2001-2002. About 51% of the dataset was applied into training while testing accomplished by the remaining 49% of data. Their result was agreeable and proved the role of ANN in modelling the water vaiables.

Sayyed Ali Moasheri et al. [17] suggested an ANN based estimation of the Groundwater Nitrate and applied the Genetic Algorithm for optimization. The groundwater data of Birjand plain, Iran was gathered from 35 wells in every 6 months from 2008 until 2010 comprising of various input parameters. The outcomes of running the network with transition functions and hidden layers revealed that the MLP network with 2 hidden layers and Tanaxon activation function with R=0.81 and MSE=7.587653 has a higher correlation coefficient. Thus the results were found satisfactory.

Talib A. et al. [18] forecasted Biochemical Oxygen Demand (BOD) to determine the river pollution based on ANN. In this study the datasets were collected over 2001 to 2008 from Pulau Pinang, Malaysia. The network was trained and tested by applying the method of "trial and error". ANN model comprised of the 16-4-1 architecture and conjugate gradient descent as training algorithm was chosen. The number of iterations equal to 5000 was selected as a criteria to stop the training. The available dataset was divided into 68% for training, 16% for validation and remaining 16% for testing. The forecast for the merged model was quite good with R^2 values of 0.66. Merging of datasets from two sampling stations has presented an improved prediction of BOD, due to increased training data. The authors outlined that the best results depends on sample size of dataset where large sample results in enhanced generalization.

Rashid Atta Khan et al. [19] inspected the use of Principal Component Analysis (PCA) and ANNs in predicting the index WQ for Langat River, Malaysia. A total of 254 samples were used for the analysis. Out of the 23 principal components generated, only six PCs with eigenvalues higher than 1 were selected for the ANN input parameters. A three layer back-propagation ANN structure was developed by adopting one hidden layer with a variation from 1 to 10 hidden neurons. A differentiable Sigmoid (S-shape) function was used. With 3 to 6 neurons in the hidden level effective performance was obtained. ANN models based on 6 principal components can predict WQI with greater accuracy as compared with other model developed using the 23 original features as input.

Faris Gorashi et al. [20] created a WQI prediction model for the Gombak River, Kuala Lumpur, Malaysia on the basis of eight years of dataset. Based on neural network an iteration process applied over the data samples. An accuracy of 99.39% was achieved. The proposed approach was implemented successfully for water quality forecasting and prediction.

Ming Xue [21] developed a novel Water Quality Assessment (WQA) model by combining the Neural Network approach with and Fuzzy System. Total five classes were considered for classifying the water quality. The water quality parameters predicted by the system included dissolved oxygen, total phosphorus, ammonia nitrogen, nitrate nitrogen, permanganate index and BOD. The target outputs were 0.1, 0.3, 0.5, 0.7, and 0.9. The results of the experiments were found satisfactory.

Shrivastava Kriti et al. [22] proposed a modelling scheme for the Shyamala water works, Bhopal, MP, India for the prediction of optimum coagulant (alum) dose. There were total 250 data points in the dataset divided into training, testing and validation. All the computations were performed using Microsoft Excel 2007 and MATLAB R2007b. The Levenberg-Marquardt algorithm (LMA) was used for training consisting of 7:15:1 architecture of the MLP model. For the Actual Alum Dose and Predicted Alum Dose the value of R was found to be 0.99 which shows a good correlation between them.

N. A. Rahim et al. [23] constructed a prediction model for the WQ of Malaysian River Perak. A total 1008 samples of data were used from March 2000 until November 2004. The normalization process was done using MATLAB 7.11.0 (R2010b), using the predefined and built-in normalization function. There were 30 water quality parameters available including physical and chemical parameters. The normalization process was done using MATLAB 7.11.0 (R2010b), based on built-in normalization function. The log-sigmoidal (logsig) and linear transfer function (pureline) were used as training function. Learning rate was set to 0.05 with 1000 epoch and 0.001 for goal. ANN prediction model showed the best performance for COD outputs and its generalization was also improved with the reduced number of input parameters.

Sarala Thambavani et al. [24] developed a prediction scheme for the quality of irrigation water in Batlagundu, Nilakottai Taluk, TamilNadu using multilayer perceptron back-propagation neural system. They considered a sample of size 150 on a monthly basis from 2012 to 2013 along the 18 sampling sites. Out of 150 samples, 70% of the samples were used for training, 15% of the samples were used for validation and the remaining 15% of the samples were used to test the developed ANN model. Performance of models were tested by using correlation coefficient and MSE. The 7-3-1 network architecture is given high correlation coefficient (r=0.93) and low mean squared error (0.0038). Their proposed model concluded that with the help of ANN, it is possible to manage irrigation water resources effectively.

Ritu Ahlawat [25] performed ANN based analysis of rainfall data of Betwa river, MP, India. The analysis was based on data collected from secondary sources like central level departments and state-level organizations for a period of at least 30 years. A genetic feed forward algorithm was used to get the result form the same data wherein again seven stations were identified as most sensitive to mean values of the catchment. An initial population of networks was randomly created with each having a different set of parameters to initiate genetic training. Best network results were obtained in 3rd run having lowest error value.

Mehrdad Fereydooni et al. [26] compared ANNs and stochastic models in developing the prediction model for the monthly flow in the River Ghara-Aghaj, Iran. Monthly data of rainfall from September 1974 to September 2008 was taken. The models used were, multiple perceptron using back-propagation algorithm (MLP/BP), recurrent neural network (RNN) and autoregressive moving average (ARMA). Train**ing** was performed using the 32 years of data while the remaining 2 years data was taken for validation. A variation in architecture of the neural networks was tried and tested. The neural networks (MLP-RNN) and ARMA models were validated in terms of correlation coefficients (R), root mean square errors (RMSE) and scatter indexes (SI). The results showed that the MLP (R = 0.92, RMSE = 2.4, SI = 0.56) and RNN (R = 0.9, RMSE = 1.95, SI = 1.25) techniques outperform the ARMA (1,13) (R =0.68, RMSE = 5.37, SI = 1.25) model. The results showed that ANN performed better than stochastic models.

Hafizan Juahir et al. [27] applied the ANN approach for model development to predict the water quality index in the Malaysian River. Levenberg-Marquardt back-propagation method was applied**.** Multiple Linear Regression (MLR) was applied to eliminate independent variables that exhibit the lowest contribution in variance. They found that the correlation coefficient was 0.92 obtained when six independent variables were while it was 0.91 when four independent variables were applied which revealed the importance that ANN is capable of predicting water quality with adequate accuracy even by reducing the number of input factors.

Lazaros S. Iliadis et al. [28] proposed an ANN approach for hilly water-resource management. The authors predicted the average annual water supply using standard BPA. Data sample was taken from 1965-1993**.** The authors estimated the Average Annual Water Supply using standard BPA with Tangent Hyperbolic activation function. Total 120,000 iterations had been performed by developing the structure of network as 5-15-1. They concluded that their results are much satisfactory and also revealed the fact that ANN model can become an important decision support tool for water management authorities.

Liao et al. [29], presented a WQ evaluation method based on multiclass Support Vector Machine. The experiments were concerned with the behavior of fish on the basis of vision technology based classification method utilizing support vector machine approach. The pollution can be regulated by observing the organic process like the fish responses. Authors reported the fact that the biological monitoring methods are providing a minimum participation of human and a cost effective solution.

Malek et al. [30], predicted the DO for the lakes in Malaysia using SVM based approach by considering data taken from period 2005 to 2009 comprising 11 water quality variables. An accuracy of 74% was obtained which was acceptable. They reported that SVM proved to be a powerful tool in prediction.

Junping et al. [31], proposed a quality evaluation model for the groundwater based on the SVM approach. They have developed the model by using eight evaluation factors. The results were found satisfactory and consequently showed the usefulness of SVM for solving the ecological problems efficiently.

Liao et al. [32], applied SVM and bio monitoring in order to find the quality of water. The behavior of zebra fish was studied considering the contaminated surroundings. On the basis of four kinds of metal ions a severe harmfulness environment based experiments were conducted on zebrafish. The results were found to be adequate with an attainment of 80% classification accuracy and as a result this was concluded as satisfactory method while accessing the WQ.

Tan et al. [33], applied three different techniques for modelling the WQ of rivers by predicting the phosphorus. First one was Back-Propagation then Radial-Basis Function and last one Least-Squares Support Vector Machine to develop the models. It was revealed from the results that the LS-SVM based model outperforms the other two models w.r.t. the prediction accuracy. The results have also highlighted that the SVM based approach is more beneficial as compared to the ANN based model when the size of sample is small. Thus SVM is used progressively in dealing with the ecological problems

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Aiswarya Vijayakumar et al. [34], investigated the quality of ground water in Kudankulam, district Tirunelveli, Tamil Nadu using variety of classifier like Naive Bayes (NB), KNN and SVM over the sample collected during a period of 2011-2012. These three models were implemented in PYTHON 3.6. The experimental dataset was divided into 75% to 25% ratio where the training was accomplished with the 75% of samples while the left over data were used for testing. The effectiveness of the model estimated on the basis of confusion matrix involving precision, accuracy and other performance parameters. The result showed that the SVM based approach outperforms the others.

Abobakr Saeed Abobakr Yahya et al. [35], examined the performance of WQ prediction model based on SVM for the River Langat, Malaysia considering a dataset comprising of six water quality parameters obtained from Malaysian department of environment over a period of 2006 to 2016. The performance evaluation of various predictive models involving these kernels was done using mean square error. The predictive model developed using the RBF kernel reported the best results.

Juntao Fan et al. [36], analyzed the effect of aquatic organisms on environment in the river of China by utilizing method of SVM in order to have important steps for the restoration the river. For SVM modelling the dataset was divided into 90% to 10% ratio where training was achieved via 90% of dataset while remaining 10% were used to perform the testing. The results were found to be satisfactory and subsequently proved the significance of SVM based modelling.

Ehsan Olyaie et al. [37], proposed and compared different computation based intelligence methods like ANN and SVM for the estimation of DO in Delaware River (USA). The dataset was taken from 2007 to 2014. Out of which training was performed by considering 75% of data and 25% was used for testing. The models were developed by considering various combinations of four input parameters and their performances were measured by RMSE, R and MARE performance metrics. Their results reported that the SVM model outperforms the model based on ANN in DO prediction. Overall the results indicated that the soft computing techniques are the effective methods for DO modelling.

The review of literature resulted in a conclusion that various machine learning based computation methods like Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs) has become attention-grabbing choice for researchers to solve majority of issues based on environmental problems like rainfall prediction, water quality assessment, or any other time-

series forecasting. It was concluded from the literature survey that a little bit attention has been paid for modeling Indian River conditions and state of affairs for prediction or time series forecasting problems. Hence a more research is required towards this direction. Furthermore, yet no study have been reported for assessment of WQ of the Ganga River using ANN, SVM or any other machine learning techniques to the best of knowledge.

3. CONCLUSION AND FUTURE SCOPE

This paper outlined various soft computing techniques applied in the domain of ecology known as water quality of rivers. A comprehensive literature survey of various researches done across all around by different researchers on the application of soft computing techniques like fuzzy logic, neural network, support vector machine, neuro-fuzzy, genetic algorithms for modelling and predicting the water quality variables. The review of literature resulted in a conclusion that various soft computing techniques has become appreciable choice for the wider research communities to solve majority of issues based on environmental problems. These biologically inspired techniques proved to be highly proficient for modelling the water quality problems. As more and more data is generated every moment accordingly demand for the data oriented approaches like neural networks, support vector machines are increasing day by day.

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