Application of Feed Forward Neural Network for Prediction of Optimum Coagulant Dose in Water Treatment Plant

Alka Sunil Kote, Dnyaneshwar Vasant Wadkar

Abstract*: Coagulation is anecessary process used mainly to reduce turbidity and natural organic matter in water treatment. The dosage of coagulant required is conventionally determined by carrying out jar tests which consume time and chemicals.In India, coagulant dose in a WTP remains constant during certain periods due to delay in jar testing, which may lead to under-dosing or over-dosing of coagulant. This research work is focused on applying artificial neural network (ANN) approach to predict coagulant dose in a WTP. Forty-eight months daily water testing data concerning inlet & outlet water turbidity and coagulant dose were obtained from the plant laboratory for ANN modelling. The appropriate architecture of feed forward neural network (FFNN) coagulant models were established with several steps of training and testing by applying various training algorithms vizLevenberg-Marquardt (LM) and Bayesian regularization (BR), resilient back propagation (RBP), one step secant(OSS),variants of conjugate gradient(CG) and modifications of gradient descent (GD) with evaluating coefficient of correlation (R) & mean square error (MSE). Further, best performed LM and BR training algorithm were used for development of four ANN models of FFNN for prediction of coagulant dose at WTP. FFNN coagulant model with BR training algorithm provided excellent estimates with network architecture (2-50-1) for coagulant dose with maximum value of R= 0.943 (training) and R = 0.945 (testing). Thus, ANN provided an effective diagnosing tool to understand the non-linear behavior of the coagulation process, and can be used as a valuable performance assessment tool for plant operators and decision makers.

***Keywords* :Artificial neural network, water treatment plant, coagulant dose, Bayesian algorithm.**

I. INTRODUCTION

Coagulation is the most important process in water treatment which produces clear water. In water treatment plant (WTP) jar test is used to determine the optimum dose of coagulant. Determining optimal coagulant dosage is vital, as insufficient dosage will result in unqualified water quality. Traditionally jar test and experience of operators are used to determine optimum coagulant dosage. However, jar tests are time-consuming and less adaptive to real time variations changes in raw water quality. When an unusual condition of heavy rain occurs, the storm water brings high turbidity to water source, and the treated effluent quality may be inferior due to conventional operations of WTP. An optimal modelling can be used to overcome these limitations. In India, generally in WTP due to a time delay of jar test results, coagulant dose is kept constant for that period, which may lead to under-dose or over-dose of coagulant. Hence, there is a need to develop predictive models for optimum coagulant dose in a WTP.It is difficult to model water treatment processes due to complex interactions among many chemical and physical reactions. Application of ANN is considered for the prediction of optimum coagulant dose. An ANN is a biologically inspired system consisting of a number of interconnected elements called neurons. These neurons are arranged in input, hidden and output layers. All the layers are well connected like human brain synapses where weights are optimized by using input and output variables. An ANN has the ability to learn and model non-linear and complex relationships.

Several studies for coagulant dose prediction have been performed. The delicate sensor for an evaluation in real-time of the optimal dose of coagulants in the Rocade WTP, Marrakesh, Morocco, has been developed by Larmrini*et al*. [1]. Chen and Hou [2] created a practical feedback control system for monitoring the coagulant dose policy of the Taipei water department's water purification scheme in Changhsing. The inverse ANN model for the Segama WTP in LahadDatu, Sabah, Malaysia has been developed by Robenson*et al*. [3]. Similarly, Heddam*et al*. [4] suggested a GRNN and RBNN model for the forecast of a WTP coagulating dose in Algeria for the generalized regression neural network (GRNN). Kumar *et al*., [5] created an FFNN model for the prediction of coagulant doses with LM Training and Adaptive Neuro-Fuzzy Inference System (ANFIS).

In addition, Bello *et al*., [6] suggested various predictive control models for coagulant dose based on a blurred switching strategy. In the coagulation method in Akron WTP, Ohio, USA, Kennedy *et al*., [7] have assessed ANN models in predicting organic dissolved matter and turbidity. In both seawater and brackish waters, Gao Larry *et al*. [8] have created a real-time dose strategy using ultrafiltration therapy. Coagulant dose prediction with adaptive neural fuzzy inference systemby Wu.*et al*.[9], multiple model predictive control scheme based on fuzzy weightingby Bello *et al*.,[10] and fuzzy weighting multiple model predictive control by Bello *et al*., [6] was sighted with multi-variant models including multi-step and multi-site models.

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From literature, it was found that many ANN and fuzzy approaches are available for prediction of coagulant dose for a particular WTP, whereas the same approach cannot give the same prediction efficiency for other WTP. Therefore, this paper presents coagulant dose modeling using feed forward neural network for a WTP of Pimpri-Chinchwad Municipal Corporation (PCMC), Maharashtra (India)

II. MATERIAL AND METHODS

A. Study area

The WTP under study is located in Pimpri-Chinchwad Municipal Corporation (PCMC), Maharashtra (India) and has the global coordinates of 18° 37' 33.87" N latitude and 73° 48' 43.76" E longitude. This city has an average water supply of 170 Lpcd with 59 elevated storage reservoirs and 117,936 water connections. This WTP supplies 428 MLD of water to an area of 177 km^2.

B. Methodology

The purpose of this study is to establish an efficient artificial network model based on multi-layer FFNN so that it could be applied for determination of coagulant dose for variable values of water turbidity. Input parameters such as inlet and outlet water turbidity, and coagulant dose as output parameter are identified for coagulant dose neural network (CDNN) model. The CDNN model is established with inlet and outlet water turbidity in input layer whereas output layer predicts coagulant dose as shown in Fig. 1.

Methodology includes manily : 1) Data collection and division, 2) Identification of best training algorithm, 3) Development of ANN models by trial and error method, and 4) Establishment of best model using error statistics and standard statistics.Daily data of input and output parameters spanning four years *namely* year 2014 to year 2015 are obtained from the plant laboratory. The database of input and output parameters required for the ANN modelling consists of 11688 data points. The data interval is three hours starting from 7 am current day to 7 am of next day.The data series is close to the normal distribution, therefore by changing the training algorithm and by rigorous training better results can be achieved. Various training algorithms such as Levenberg-Marquardt (LM), Bayesian regularization (BR), resilient back-propagation (RP), BFGS Quasi-Newton (BFG), one step secant (OSS), conjugate gradient back-propagation (CGB), conjugate gradient back-propagation with Fletcher-Powell (GCF), variable learning rate gradient descent (VLRGD), gradient descent (GD), and gradient descent with momentum (GDM) areused for development of FFNN.

During training, the best performing training algorithm is selected for model development. Best combination of training algorithm, number of neuron in the hidden layer and the number of epoch for highest R is determined. The trained neural network further tested using test data set for computing the final network error. The model results are then compared with the observed series for standard statistics *viz*.mean($\bar{x}$), standard deviation (σ), skewness(ɣ1), andkurtosis (ɣ2) in training and testing periods.Best model is determined based on standardstatistics and time series and scatter plot of observed & predicted models.

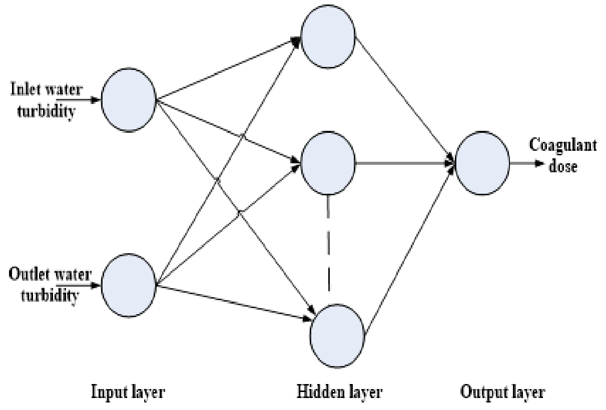

Fig.1.Coagulant dose neural network model

III. RESULT AND DISCUSSION

Based upon methodology discussed in section II (B), numbers of training algorithms are analyzed for prediction of coagulant dose. Summary of the performance of training algorithms for model development are shown in Fig. 2. It is noticed that most training algorithms showed good performance while some model showed negative correlation thereby indicating in-capabilities in modelling. From Fig. 2., it observed that BFG, NRP, CGB, CGF, OSS, GDX, GDM, and GD required only one epoch and 15 hidden nodes; whereas for LM and BR training algorithm epoch is varied from 12 to 7228 and hidden node varied from 15 to 60. However feed forward neural network coagulant dose (FFNNCD) model with LM (R = 0.944) and BR (R = 0.945) training algorithms are more effective than other training algorithms listed in methodology. The BR training algorithm is able to efficiently address the issue of over fitting and penalize complicated models. It includes probably distribution of network weights in comparison to standard network training in which optimum weights are selected by minimizing an error algorithm. The algorithm utilizes Jacobean matrix to calculate the output as a total of square error.

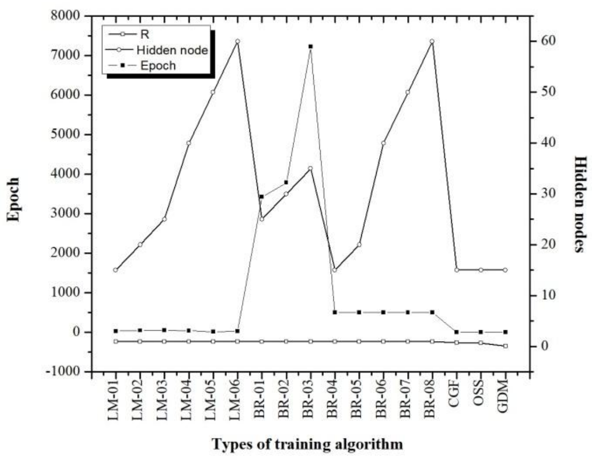

Fig.2.Performance of training algorithms for FFNNCD model

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It can train any network as long as its derivative features include weight, net input and transfer algorithms.

A. Feed Forward Neural Network Coagulant Dose Model using Levenberg–Marquardt Training Algorithm

FFNN coagulant dose model using LM training algorithm (FFNNCD1) is developed with one hidden layer in MATLAB software. This model developed with LM that updates weight and bias values according to LM optimization. LM is often the fastest back-propagation algorithm and is highly recommended as a first-choice supervised algorithm, although it does require more memory than other algorithms. This model resulted maximum 'R=0.944' with hidden node = 60 and its other properties are shown in Table I.

Table -I:Properties of best FFNNCD1 (2-60-1) model

Type of network	Training Algorithm	No of Epoch	No of hidden node	R	MSE
FFNN	LM	26	60	0.944	185

Test vectors are used to stop training early if the network performance on the test vectors fails to improve or remains the same for maximum epochs in a row. Test vectors are used as a further check that the network is generalizing well but do not have any effect on training.

The standard statistics of FFNNCD1 (2-60-1) model is shown in Table II, where observed and predicted $\bar{x}$ and $\gamma 1$ are closely matching during training and testing periods. The percentage change between observed and predicted σ values are 5.47 % and 52.75 % during training and testing period, respectively. Similarly, the percentage change between observed and predicted $\gamma 2$ values had 7.33 % and 980.51 % during training and testing period, respectively.

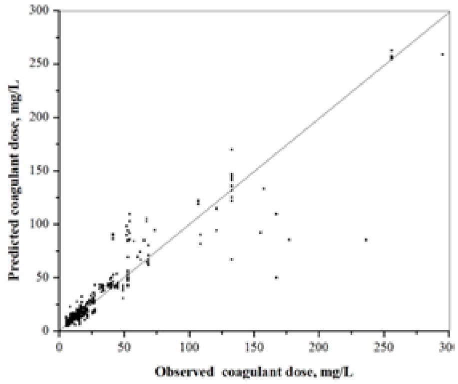
Table -II:Standard statistics of FFNNCD1 (2-60-1) model

ANN Model	Training period			
	$\bar{x}$	σ	ɣ1	ɣ2
Observed values	20.157	32.486	5.284	31.601
FFNNCD1 (2-60-1)	20.109	30.711	5.361	33.919

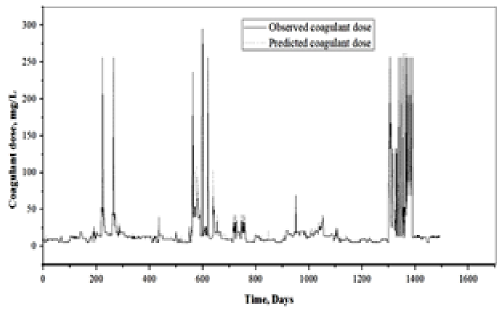
ANN Model	Testing period			
	$\bar{x}$	σ	ɣ1	ɣ2
Observed values	8.899	1.493	1.233	0.171
FFNNCD1 (2-60-1)	9.067	2.280	1.212	1.851

B. Feed Forward Neural Network Coagulant Dose Model using Bayesian Regularization Training Algorithm

FFNN coagulant dose model using BR training algorithm (FFNNCD2) model is created with one hidden layer in MATLAB software. By varying values of the hidden node after ending epochs, different R and MSE values are obtained. It is observed that hidden nodes are increased from 5 to 15 where R and MSE values are changed accordingly. There is no change in performance of the model for hidden nodes above 20 to 60. Similarly, it is observed that the best prediction obtained against hidden node 50 with R = 0.945. The time series and scatter plot of FFNNCD2 (2-50-1) model during testing period is shown in Fig. 3(a) and (b) indicate best fit.



(a)



(b)

Fig. 3(a) and (b) Time series and scatter plot of FFNNCD2 (2-50-1) model duringtraining and testing period

The standard statistics of FFNNCD2 (2-50-1) model is shown in Table III,

Table-III:Standard statistics of FFNNCD2 (2-50-1) model

ANN Model	Training period			
	$\bar{x}$	σ	ɣ1	ɣ2
Observed values	20.157	32.486	5.284	31.601
FFNNCD2 (2-50-1)	20.175	30.811	5.314	33.240

ANN Model	Testing period			
	$\bar{x}$	σ	ɣ1	ɣ2
Observed values	8.899	1.493	1.233	0.171
FFNNCD2 (2-50-1)	9.051	2.302	1.200	1.612

Peak values are poorly captured because most of the time on WTP observed coagulant dose is kept constant. Thus rigorous training has captured this trend but failed in testing period. Even though low and normal values are well captured by rigorous training of network.

The standard statistics of FFNNCD2 (2-50-1) model is shown in Table III, where observed and predicted $\bar{x}$ and γ_1 are close during training and testing period. The percentage change between observed and predicted value of $\sigma = 5.16$ % and 54.21% during training and testing period respectively. Similarly, the percentage change between observed and predicted γ_2 values had 5.19 % and 841.39 % during training and testing period respectively. Thus FFNNCD2 (2-50-1) model with BR training algorithm performed better than the FFNNCD1 (2-60-1) model, especially in prediction of peak and the low values of the coagulant dose.

IV. CONCLUSIONS

Determination of optimal coagulant dose is vital as insufficientdosing will result in undesirable treated water quality.In this paper, twenty-two ANN models were developed to predict the coagulant dose in a major WTP of PCMC. These models were developed using various training algorithms, where BR training algorithm provided better prediction as comparedother training algorithms. All LM and BR ANN modelsperformed well especially for lower and higher values of coagulant dose. The FFNNCD2 (2-50-1) model with BR training algorithm (R = 0.945) provided the best prediction for coagulant dose as compared to all other models. Thus, ANN provides a useful diagnosing tool to understand the non-linear behavior of the coagulation process, and can be used as a valuable performance assessment tool for plant operators and decision makers. The plant operators will be able to furnish expected outgoing water turbidity based on the inlet water turbidity of the plant.Insummary, ANN is a good choice and a powerful tool for modeling the coagulant dosage in WTPs.

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