Application of Soft Computing Techniques to Predict Reservoir Water Level

Vrushaly K. Shinglot, Monika R. Tiwari, Shardav U. Bhatt, Narendra J. Shrimali

Abstract—In this work, the reservoir water level has been predicted using one of the soft computing techniques named Artificial Neural Network. The reservoir water level is influenced by many parameters. Among which the most influencing parameters have been considered here: amount of rainfall, temperature and evaporation. For this analysis, the reservoir made on Shetrunji River Dam in Dhari, Amreli district, Gujarat, India has been chosen as it was overflown seven times in last ten years. This shows the importance of water level prediction at this particular reservoir. The Neural Network is trained using the past data collected and further used to predict water level for the unknown data. The approach of the multiple regression is also shown for its comparison with the Soft computing approach. Computations and experimental works were done by programming in software MATLAB. Such modeling is useful for planning and decision making of opening gates for reservoir operation particularly during monsoon and water scarcity.

Index Terms—Soft Computing, Artificial Neural Network, Regression, Back Propagation Algorithm, Reservoir water level Prediction

I. INTRODUCTION

A dam is a barrier constructed across a river or a natural stream to create a pond like structure at the back of this barrier for impounding water or to facilitate diversion of water from the river or to retain debris flowing in the river along with water. This pond like physical structure regulating the water at the downstream of a dam is called a Reservoir, which helps in modifying uneven distribution of water. The appropriate knowledge of water level at the reservoir results in better management of water resources. Fluctuation of water level is a function of various hydro-meteorological parameters like rain fall, temperature changes, wind speed, humidity variation, sunshine hour etc.

Out of these parameters, the most influencing parameters on water level are temperature, evaporation and rain fall [1].Rain fall is basic input to the hydrological cycle for tropical country like India. It is the only input which usually occurs in monsoon period. Evaporation and temperature are interrelated. Here, temperature is taken to study its effect as one meteorological climate parameter on water level variation. Whereas evaporation is considered to study integrated effect of various climate parameters like sunshine, wind speed, relative humidity etc.

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This paper proceeds in following manner. In section II and section III, the motivation behind doing this work has been discussed and from that objectives are determined. The methodology used in this paper is Artificial Neural Network, which is reviewed in section IV along with review of Back Propagation algorithm. In next section V, the experimental work and results are explained. Section IV concludes the paper with remarks on future work.

II. MOTIVATION

Predicting the water level appropriately, at the reservoir, results in better management of water resources. The decision of opening the gates of the dam, taken by the site in-charge officer, is crucial one as it affects public safety and emergency response. Further release of water for the planned purpose also causes some amount of water storage loss which results in water level fluctuations. In flood situation, this becomes very important decision. The decision depends on the water level. So prediction of water level in the reservoir under various circumstances is an important task.

To do so, researchers have used different techniques like regression, time series analysis and Statistical methods [1]. When the relationship between parameters is random, classical techniques fails. It does not accurately predict the water level for the variations in parameters due to seasonal variations. Soft computing techniques started becoming famous in the modern times for various other applications. These techniques handles randomness and variations in better way compared to classical methods. Hence Engineers and Scientists have started drawing their attention towards Soft computing techniques like Artificial Neural Networks, Fuzzy Logic, Genetic algorithms, etc. to establish complex and random relationships between parameters.

III. OBJECTIVE

Our objective is to establish relationship between these parameters and from the network that predicts the water level in the reservoir. The area under study is a dam site situated at Shetrunji River in Dhari, Amreli district, Gujarat, India. The parameters used here are rain fall, evaporation and temperature; which are most influencing parameters for change in water level of the reservoir. Past year data of these four parameters, taken at dam site, is available to us which are useful to establish relationship between them. The approach of Soft computing technique i.e. Artificial Neural Network is used due to randomness and variations in parameters. The data is trained in neural network using Back Propagation Algorithm and using trained network, prediction of water level is made for given values of Rain Fall, Evaporation and Temperature. Training procedure and mathematical calculation are done in terms of programming MATLAB software.

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IV. ARTIFICIAL NEURAL NETWORK AND BACK PROPAGATION ALGORITHM

A. Artificial Neural Network

Neural network is a study which is motivated by the human brain. It is a massively parallel distributed processor made up of simple processing units that has a natural ability for storing

Experimental knowledge and making it available for further use. Here, knowledge is a stored information or model used by a person or a machine to interpret, predict and appropriately respond to outside world. Knowledge is acquired by the network from its environment through the process called learning. The synaptic weights, which are inter-neuron connection strengths, are used to store the acquired knowledge [2].

The process of acquiring knowledge is done by learning algorithms, which is most important property of neural network. Learning algorithm consists of modifying synaptic weights of neural network, in order to obtain desired design objective. The type of learning process used in our application is a supervised learning which requires the availability of target or desired response for the realization of specific input-output mapping by minimizing a cost function of interest [3].

The most fundamental unit of neural network is called Neuron, which is information processing unit. A model of neuron is as shown in Fig. 1. It consists of neurons $x_j's$, synapses $w_{kj}'s$, adder Σ and an activation function ϕ. McCulloch and Pitts outlined this model of elementary computing units in 1943. It is known as McCulloch – Pitts Neuron Model [2].

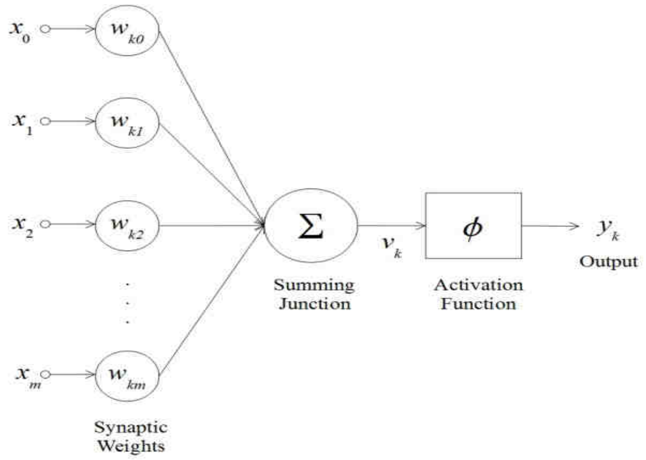

Fig. 1: McCulloch – PittsNeuron Model [2]

In Fig. 1,
$x_1, x_2, x_3, \ldots, x_m$ are inputs,
$w_{k1}, w_{k2}, \ldots, w_{km}$ are Synaptic weights,
ϕ is an activation function,
v_k isdefined as
$v_k = u_k + b_k$,
Where u_k is a linear combiner output i.e. $u_k = \sum_{j=1}^{m} w_{kj} x_j$
and b_k is a bias,
$\therefore v_k = \sum_{j=0}^{m} w_{kj} x_j$ with $x_0 = 1$ and $w_{k0} = b_k$,
y_k is the output signal, given by $y_k = \phi(u_k + b_k)$.

Various Activation functions are used. They represent output of neuron. Most commonly used activation functions are threshold functions (Heaviside) and Sigmoidal functions. The network architecture is said to be single-layerif it has only two layers: Input Layer and Output layer. It is called multi-layerif there are one or more hidden layers between input layer and output layer. In feed-forward network, the input layer directly projects onto output layer of neurons and not vice versa, but in feed-backwardor recurrent networks, the outputs are fed back to inputs. Artificial neural networks are widely used in problems involving classification, function approximation, clustering and pattern recognition [2][3].

B. Multi-layer Feed-Forward Neural Networks:

The single-layer neural networks like Perceptrons and LMS algorithms are limited to classification of linearly separable patterns. To overcome practical limitations of such single-layer network, A multi-layer feed-forward neural networks are used. The non-linear, differentiable activation function, hidden layers and high degree of connectivity makes a multi-layer network more complex and enable to solve many practical problems [4].

The multi-layer feed-forward neural network is trained by a Back Propagation Algorithm, which consists of two phases: Forward Phase and Backward Phase. In forward phase, the input signal propagates through network from input layer towards output layer, layer by layer. The synaptic weights are fixed prior to the forward propagation. At output layer, the output of network is compared with desired response which gives an error signal. The error signal back propagates from output layer to the input layer, layer by layer, simultaneously adjusting the synaptic weights by minimizing error. This idea revolutionized the study of neural networks in mid1980's. The Back Propagation Algorithm was introduced by Rumelhart & McClelland in 1986, which is a computationally efficient method for training multi-layer feed-forward networks [2][5]. The general multi-layer feed-forward network is shown in the Fig. 2.

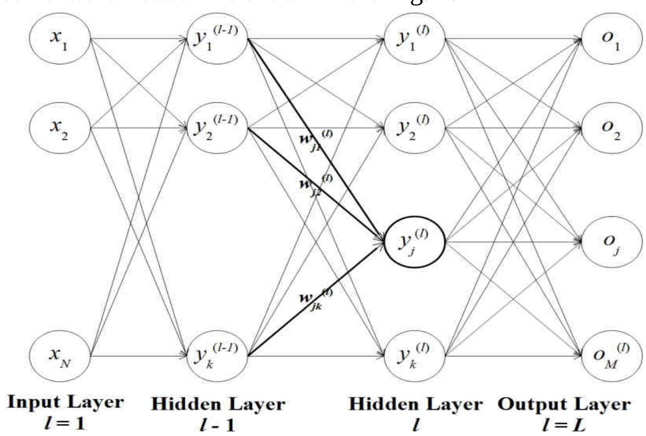

Fig. 2: A Multi-layer feed-forward network

C. Back Propagation Algorithm:

Let $\left(\vec{x}(n), \vec{d}(n)\right)$ be training pairs which consists of input signal vector $\vec{x}(n)$ applied to the input layer & desired response (desire output) vector $\vec{d}(n)$ presented at the output layer.The input signal induces local fields in network which propagates forward layer by layer. The induced local field $v_j^{(l)}(n)$ for the j^{th} neuron in l^{th} layer is

$$v_j^{(l)}(n) = \sum_i w_{ji}^{(l)}(n) y_i^{(l-1)}(n) \qquad (1)$$

here $y_i^{(l-1)}(n)$ is the output signal of i^{th} neuron in the previous layer i.e. $l-1$, at n^{th} iteration, $w_{ji}^{(l)}(n)$ is synaptic

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weight between j^{th} neuron of layer l and i^{th} neuron of layer $l-1$ at n^{th}iteration.
$i = 0$ gives $y_0^{(l-1)}(n) = +1$ and $w_{j0}^{(l)}(n) = b_j^{(l)}(n)$which is biased applied to j^{th} neuron in layer l. The output signal of j^{th} neuron in layer l, after being applied a non-linear, differential activation function ϕ (like sigmoidal and hyperbolic tan) is,

$$y_j^{(l)} = \phi_j\left(v_j^{(l)}(n)\right) \quad (2)$$

$l = 1$ refers to the first hidden layer. For $l = 0$,$y_j^{(0)} = x_j(n)$ is j^{th} element of the input vector $\vec{x}(n)$. $l = L$ refers to the output layer, $y_j^{(L)} = o_j(n)$ is j^{th} element of the output vector $\vec{o}(n)$ of the network.
The error signal at output layer is defined as

$$e_j(n) = d_j(n) - o_j(n) \quad (3)$$

where $d_j(n)$ is the j^{th} element of the desired response vector$\vec{d}(n)$.
The local gradients of the network are defined as

$$\delta_j(n) = \frac{\partial E(n)}{\partial v_j(n)} \quad (4)$$

Where $E(n) = \sum_{j\epsilon C}\left(e_j^2(n)/2\right)$ is the total error of whole network. Here set C includes all the neurons in the output layer.
Using (3) and (4) and after simplifying partial derivatives, the local gradients of the network are obtained.
For the j^{th} neuron in the l^{th} hidden layer,

$$\delta_j^{(l)}(n) = \phi_j'\left(v_j^{(l)}(n)\right)\sum_k \delta_k^{(l+1)}(n)\, w_{kj}^{(l+1)}(n) \quad (5)$$

For the j^{th} neuron in the output layer L,

$$\delta_j^{(l)}(n) = e_j^L(n)\phi_j'\left(v_j^{(L)}(n)\right) \quad (6)$$

here$\phi_j'(\cdot)$ is the differentiation of activation function with respect to the argument.

Using these gradients, the synaptic weights of the network are adjusted iteratively using

$$w_{ji}^{(l)}(n+1) = w_{ji}^{(l)}(n) + \alpha\left[w_{ji}^{(l)}(n-1)\right] + \eta\delta_j^{(l)}y_i^{(l-1)}(n) \quad (7)$$

The choice of learning rate η depends on learning problem and it is chosen experimentally, usually within range of 10^{-3} to 10. The momentum factor α is chosen between 0.1 and 0.8,one can chose $0 < |\alpha| < 1$ [4].

Back Propagation Algorithm is an iterative procedure. So above calculations (1) to (7) are iteratively calculated. The new weights, obtained using (7) for a one pattern, are used for new pattern in next epoch. So Weights are adjusted epoch by epoch and iteration by iteration such that it gives minimum error between desired output $\vec{d}$ and calculated output $\vec{o}$at the output layer of the network. The process is continued till the desired stopping criterion is met. The Back Propagation Algorithm is considered to have converged when the Euclidean norm of the gradient vector reaches a sufficiently small gradient threshold. Also if the rate of change in the average squared error per epoch is sufficiently small, the training process is stopped [2].

According to the Universal approximation theorem, a single hidden layer is sufficient for a multilayer network to compute uniform approximation to a given training set represented by set of inputs and desired outputs [4][7].The above equations are used to train the network in MATLAB. It uses $trainlm()$ as a training function which follows improved version of Back Propagation Algorithm which is based on Levenberg Marquardt method [7].

D. Levenberg Marquardt Back Propagation Algorithm

The supervised learning of multi-layer feed-forward network is a kind of numerical optimization problem. The error obtained at output layer between desired response and network output response is a non-linear function of weight vector $\vec{w}$. This error is to be minimized [2].

In Back Propagation Algorithm, weight change is given by

$$\Delta\vec{w}(n) = -\eta\vec{g}(n)$$

$$\text{i.e. } \Delta\vec{w}(n) = -\eta\left.\frac{\partial E_{av}(\vec{w})}{\partial\vec{w}}\right|_{\vec{w}=\vec{w}(n)} \quad (8)$$

Here E_{av} is error averaged over all the training samples. Equation (8) gives only first order information about the error surface. This results in slow rate of convergence. So considering the second order information, equation (8) can be written as

$$\Delta\vec{w}(n) = \boldsymbol{H}^{-1}(n)g(\vec{n}) \quad (9)$$

Here $H^{-1}(n)$ is the inverse of the Hessian

$$\boldsymbol{H}(n) = \left.\frac{\partial^2 E_{av}(\vec{w})}{\partial\vec{w}^2}\right|_{\vec{w}=\vec{w}(n)} \quad (10)$$

Equation (9) is further modified with Levenberg Marquardt method. This method compromises between

1. *Newton's method*, which converges rapidly near a local or global minimum but they may diverge.
2. *Gradient descent method*, which assures the convergence depending on suitable step size, but converge slowly.

According to Levenberg Marquardt method, the weight change in the multilayer feed-forward network is given by

$$\Delta\vec{w} = [\boldsymbol{H} + \lambda\boldsymbol{I}]^{-1}\vec{g} \quad (11)$$

Here is $\boldsymbol{I}$ is the identity matrix having sameorder as$\boldsymbol{H}$ and λ is the step size or regularizing parameter. Equation (11) is modification of (9) which results in faster and better convergence of multi-layer feed-forward Back Propagation algorithm [2].

Thus weight updation is considered as an optimization problem in terms of error minimization, in which weights can be updated using (11) which implements Levenberg Marquardt method and as a result it gives better convergence of Back Propagation algorithm.

V. EXPERIMENTAL WORK AND RESULT:

As discussed in section III, the objective is to determine water level (in m) in Shetrunji Reservoir built on Shetrunji River using Dam in Dhari, Amreli District, Gujarat, India. For this, three factors are considered i.e. average temperature of the day (°C), daily rain fall (in mm) and daily evaporation (in mm).The past data for these three factors along with data of daily water level is available to us for the years 2001–2010 for the area under consideration. The water level for given values of temperature, evaporation and rain fall is to be predicted. Two mathematical approaches have been considered to fulfill this objective i.e. multiple regression and soft computing. For the multiple regression, the general equation satisfying given data with minimum error is to be determined. For the soft computing approach, a Neural Network is to be constructed which acquires given data in terms of knowledge by training. The experimental work for both approaches in done in MATLAB software.

For the multiple regression approach, an inbuilt funtion $regress()$ is used and for the soft computing approach, an inbuilt function $newff()$ .The function$regress()$ takes input as given data and from that it

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determines an equation fitting the data giving minimum error. Here three parameters rainfall, temperature and evaporation are taken as inputs to determine regression equation. The $newff()$ function takes inputs, desired outputs, number of hidden layers and number of hidden neurons as argument and using this it constructs a network with random weights. Rainfall, temperature and evaporation are used as inputs and water level is used as desired output. Three hidden layers were considered having 20 neurons each. The training of the created network is done using function$train()$. Levenberg Marquardt Back Propagation and equations described in section IV are implemented here. The weights are adjusted such that there is a good correspondence between inputs and desired outputs. After training the network, using function $sim()$ of MATLAB, the trained network is used to predict the water level from the unknown values of parameters.

In the multiple regression approach, the regression equation was obtained as $y = -0.0078x_1 + 1.8380x_2 - 3.1703x_3$. Here x_1 is daily rain fall, x_2 is daily average temperature, x_3 is daily evaporation and y is the predicted water level in the reservoir. Using this equation, the average error between actual data and regressed data is calculated, which is of the order 10^1. The higher order of error is expected due to randomness in data due to seasonal variations. To overcome this issue, Soft computing approach was considered. In this approach, the trained network is obtained which is shown in the Fig. 3.It gives error of order10^{-4}.

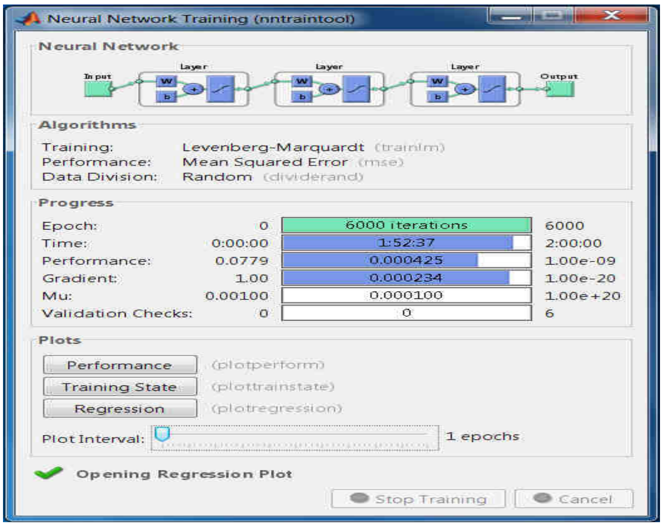

Fig. 3: Results obtained after Training, Error is 4.25×10^{-4}

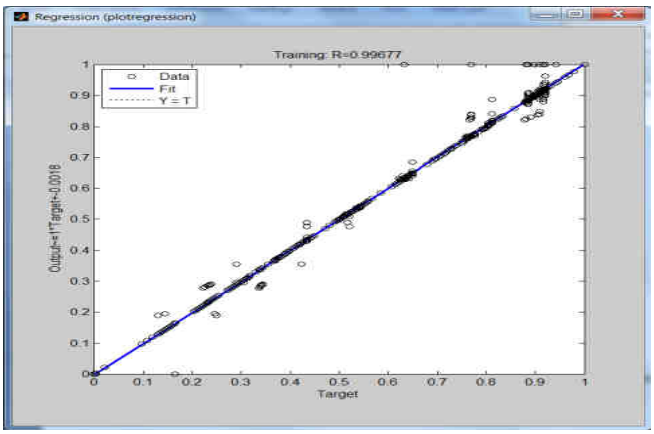

Fig. 4: Value of $R = 0.99677$

In the above plot, the dotted line represents the targets, the solid blue colored line represents the best fit linear regression line between outputs and targets. The value of R is an indication of the relationship between outputs and targets. If R=1, this indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets.

For this particular result, the training data is concluding a good fit. The value of R=0.9967, being very much near to 1, is also supporting the conclusion.

VI. Conclusion and Future Work

We have predicted the water level of the reservoir built on Shetrunji river using dam in Dhari, Amreli district, Gujarat, India. The approaches of multiple regression and soft computing i.e. Artificial Neural Network are used. The data of various parameters like amount of rainfall, temperature and evaporation of ten years for the given dam site is considered. The Neural Network is trained using Back Propagation Algorithm. The trained network is further used to predict water level for the unknown data. It is concluded that the approach of soft computing is better compared to the multiple regression approach since the error between actual data and predicted data is less using Artificial Neural Network. Such modeling is useful for dam operators to take decision for opening gate in critical situation like flood for the water release.

In future, this work can be extended to include more number of influencing parameters to make network to follow more realistic situations. The network can give better output if the data for more number of years is considered. Other Artificial Neural Network techniques can be used for this work like Radial Basis Function Networks, Support Vector Machines, Extreme Learning Machines etc, which is our future work.

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