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PERFORMANCE EVALUATION OF A WASTEWATER TREATMENT PLANT

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Abstract- In the present research, the performance of Al-Rustamiya wastewater treatment plant, Baghdad, Iraq, was evaluated. Six parameters were selected for evaluation, namely Total Dissolved Solids (*TDS*), Total Suspended Solids (*TSS*), Chemical Oxygen Demand (*COD*), Biological Oxygen Demand (*BOD*), Chloride ion (Cl^-), and *pH*. Input and output amounts of these parameters were collected from Mayoralty of Baghdad for the period from 2011 to 2021. The methodology included the calculations of the water quality index (*WQI*) for the performance of the plant. Also, Artificial Neural Networks (ANNs) were developed for predicting the performance of the plant in terms of the *WQI*. The recorded data showed that the average amounts of the parameters in the treated water were within the Iraqi allowable limits except the chloride which was not treated adequately and showed higher amounts than the allowable over most of the studied periods. The average yearly removal efficiency values of the plant in terms of *BOD*, *COD*, and *TSS* were mostly more than 80%. While the average removal efficiency values of the *TDS* and Cl^- from the plant are below 10% and 15% respectively. The calculated water quality index results indicated that overall water quality of the plant was in a good category. ANNs model was accurately able to predict the *WQI* with the optimum topology of the ANNs is obtained at obtained at 14 neurons in the hidden layer. Also, sensitivity analysis showed that the *TSS*, *COD*, and *BOD* were the greater influencing parameters on the *WQI*.

Keywords: *WQI*, *BOD*, *COD*, *TSS*, *TDS*, Cl^-, *pH*.

1. INTRODUCTION

Water pollution represents a significant problem around the world as a result of the increasing population and urbanization with the maximum use of limited resources. The pollution of the water occurs from the discharge of biological, physical, and chemical contaminates, which adversely impact on the environment, aquatic biota and habitats, and human's health. Therefore, the discharged polluted water should be properly treated before being released to the environment. Moreover, the shortage of clean water necessitates the increasing treatment of wastewater for future utilization [1, 2].

Wastewater treatment plant (WWTP) is a main infrastructure in urban system with its importance being gradually escalating. The efficient operation and design of WWTPs has become an engineering challenge given the workforce, costs of energy, land trends, negative environmental and health issues, and strict requirements of pollutants discharge [3]. Normally, there are three stages involve in the WWTPs, namely primary, secondary, and tertiary treatments. Typically, the reduction degree in the organic substances in terms of *COD* and *BOD* as well as *TDS* represent the basic indicator of the effectiveness of the plant. The efficiency of the WWTP function should be evaluated in terms of effluent and treatment criteria requirement, as well as determining the capacity of the plant to accommodate significant organic loadings. Facilities may then be amended for accommodating the higher pollutants and treatment standards [4, 5].

Water quality index (*WQI*) utilizes equations for providing a dimensionless value which indicates the overall quality of treated water according to specific location and time requirements depending on various parameters of water. It has been used by governments, scientists, decision makers, authorities a management tool of facilitating water issues. Various indices have been developed since 1967 for water quality assessments. Mostly, the developed *WQI*s by the National Sanitation Foundation and the Canadian Council of Environment Ministers have been utilized in studies [6-9].

Moreover, modelling of WWTPs represents a difficult task as the treatment involves complex processes. The physical, biological, and chemical stages of the treatment plants provide non-linear performance which is complicated to presented in linear models. Thus, providing an efficient monitoring technique can be accomplished by the development of non-linear model to predict the performance of the treatment plant under previous observed water characteristics. Artificial neural networks (ANNs) represent computerized non-linear models for simulating the decision-making and functions of the brain of humans. It is being used for many water quality issues. It has also been properly used in the modelling of the WWTPs for predicting wastewater characteristics, controlling stages of treatments, and providing estimation of effluent characteristics [10-12].

In Baghdad, the capital city of Iraq, Al-Rustumiya WWTP is one the main sewage water treatment facilities in the country. The plant recently has been expanded with the construction of nearby new plant for increasing capacity purposes. It releases the waters and waste in Diyala River and then into the Tigris River. According to the available pollutions in the rivers, the efficiency of the surplus water assimilation of the plant has been reduced due to the increasing demands for it [13]. Previous research indicated a reduced efficiency of the old and new Al-Rustumiya plants in terms of pollution treatments discharged into the rivers [14, 15]. Recently, the recorded specifications show a deterioration due to exceeding the design capacity regarding the quality and quantity of influents. The amount of the influent is more than 980000 m^3/day in each old and new plants while the capacity of the new plant expansion is only 600 000 m^3/day [13]. Resulting the dropping in electrical power, low maintenance of the units, increasing the amounts of pollutants discharges to the Diyala and Tigris rivers [16], it is vital to study the efficiency of the plant.

This study aims examining and evaluating the efficiency of Al-Rustumiya new wastewater treatment plant. This work can assist in facilitating assessment or process control of effluent quality. The investigated characteristics of influent includes *TDS*, *TSS*, *BOD*, *COD*, chloride, and *pH* parameters. A comparison was achieved by the comparison between the selected parameters and the Iraqi standards of water quality. The quality and of the effluent parameters were determined by using water quality index.

2. WORK METHODS

This section presents a background about the study area and the Rustumiya wastewater treatment plant (3rd expansion) together with the experimental work including statistical analysis and modelling predictions using WQI.

2.1. Study Area

Baghdad is the capital city of Iraq with area approximately equaling 800 square miles [17]. Al-Rustumiya WWTP is located south-east of Baghdad on Diyala River [17]. The plant was mainly designed for the treatment of domestic wastewater which serves a population of 1500000 [17]. The plant consists of conventional activated sludge for biologically treating carbon compounds with average wastewater influent capacity equals 300 MLD [17].

2.2. Data Collection

Two locations were selected for evaluating the efficiency of the plant. Entrance station represents the input and the average of secondary tanks was taken as the output. The required data was obtained from Al-Rustamiya WWTP Administration Office Mayoralty of Baghdad, over the period of ten years from January 2011 and December 2021 on a monthly basis. The selected physiochemical parameters included *BOD*, *COD*, *TSS*, *TDS*, Cl^- and *pH*. These parameters are used for the evaluation of wastewater and treated water.

2.3. Water Quality Index (*WQI*)

The weighted Athematic *WQI* is utilized in this research. The water quality index was calculated using the following steps as per Tyagi, et al. [18] and Sener, et al. [19]:

Relative weights were assigned for each selected parameter according to their level of importance in terms of water qualify. This was based on the maximum allowable limits given by the Iraqi Central Organization for Standardization and Quality Control [20]. The lower the importance of the parameters, the higher the Iraqi allowable limit and the lower the weight. Quality rating scales (q_i) were determined by dividing observed concentration value (C_i) over a standard value of each selected parameter (S_i) using Equation (1) [18, 19]:

$$q_i = \frac{C_i}{S_i} \times 100 \tag{1}$$

Then, the relative weights (w_i) were determined using Equation (2) [18, 19] as inverse values to the rating scales as follows:

$$w_i = \frac{1}{S_i} \tag{2}$$

Water Quality sub-indices (w_{qi}) were then determined by aggregating the multiplying of the calculated weight by its corresponding scaling rate of each parameter considering its number (n) by using Equation (3) [18, 19]:

$$W_{qi} = \sum w_i q_i \tag{3}$$

The overall *WQI* was then determined by using Equation (4) [18, 19]:

$$WQI = (\sum_{i=1}^{n} W_i q_i) / \sum W_i \tag{4}$$

The results were then compared with the common classification of this type of *WQI* in order to determine the efficiency of the WWTP according to Table 1 [21], [22].

Table 1. Classification of water quality depending on *WQI* value [21], [22]

Quality	*WQI* value
> 300	Unsuitable for drinking
100-200	Poor
50-100	Good
< 50	Excellent

2.4. Artificial Neural Networks (ANNs)

The ANNs were created in MATLAB. Three models were created with 6 input and 1 output. The modelling procedure and equations were based on Ammari [23] and Alsulaili and Refaie [24]. Feedforward multi-Layered perception ANNs consist of various artificial neurons known as nodes, or processing elements. These are normally arranged in three layers; input layer, intermediate or hidden layer, and output layer. The input from a layer (X_i) was multiplied by an adjustable connection weight. The summation was performed for the weighted inputs with the addition of a threshold value. The resulted combined input was then transferred to activation function for generating the output. This output was then used as input for the next layer. Several forms are available for the activation function.

The most commonly known were used in this research which was hyperbolic tangent transfer and logistic sigmoid functions. The summary of the process was indicated in Equations (5) and (6) [23, 24] as follows:

Summation: $(I_j) = \sum W_{ij} x_i + \theta_i$ (5)

Transfer: $y_i = f(I_j)$ (6)

where, I_j is the level of activation at j node, W_{ij} is the weight of the connection between the nodes i and j, x_i is the ith node input and equals 0, 1, 2, …, n, θ_j is the threshold for j node, j is the j node output and $f(I_j)$ is the activation function.

Then evaluating the permanence of the inputs, mean square error (*MSE*) and correlation coefficient (*R*) was obtained after running the analysis in MATLAB.

3. RESULTS AND DISCUSSION

The results were presented and discussed in this section. These included the average collected data for the characteristics of influent and effluent wastewaters and their respective removal efficiency values, the calculated WQI for the treatment plant, and the results of ANNs modeling.

3.1. Characteristics of Influent and Effluent Waters

Figures 1-6 show the average yearly values of *BOD*, *COD*, *TSS*, *TDS*, Cl^-, and *pH* of the influent wastewater into the plant and the effluent treated water from the plant. Iraqi Standard values [5, 25] were also included in the graphs for comparison purposes.

It was indicated from the figures that the amount of *BOD*, *COD*, *TSS*, *TDS*, Cl^-, and *pH* were more than 200 mg/L, 290-620 mg/L, 200 to 620 mg/L, 1250 to 1050 mg/L, 270 to 340 mg/L, and 7.3 to 7.75 respectively. Over the studied period, all the influent parameters exceeded the Iraqi allowable limits except pH.

However, after treatment, the average amounts of all selected parameters were within the allowable limits over the studied period. This was except *BOD* in 2012, and *TSS* in 2012 for which the average amounts in the treated water were slightly higher than the allowable limits as shown in Figures 1 and 3.

This could be attributed to the improper aeration in the aeration basin, or the measurement of high concentration of settling microbial mass in the secondary clarifier as *BOD* in the effluent.

The chloride concentrations exceeded the Iraqi allowable limits for mostly all the studied period as shown in Figure 5. While, pH of the effluent was slightly higher than the pH of the influent over all the studied period as shown in Figure 6.

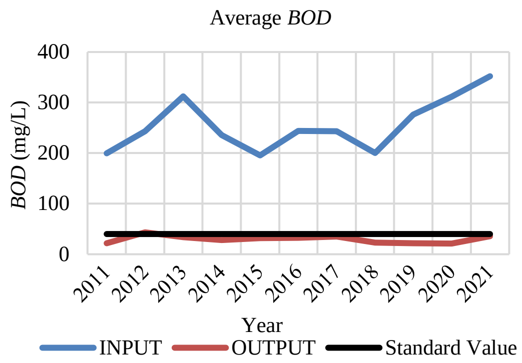


Figure 1. *BOD* input and output in and from Al Rustumiya WWTP

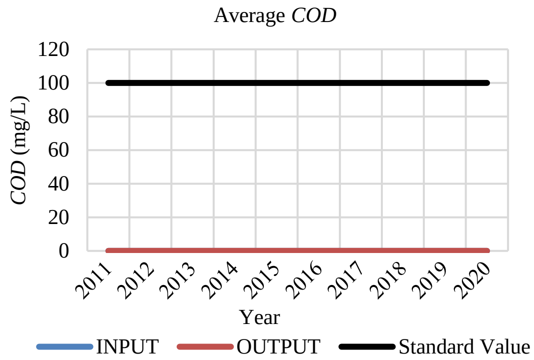


Figure 2. *COD* input and output in and from Al Rustumiya WWTP

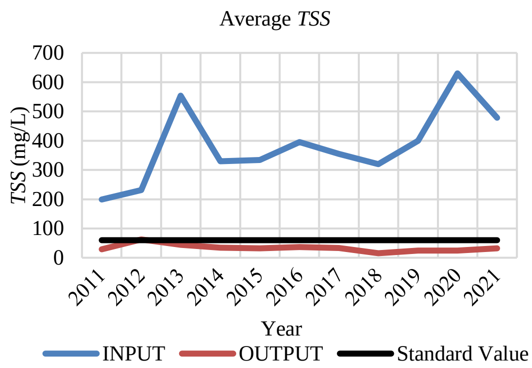


Figure 3. *TSS* input and output in and from Al Rustumiya WWTP

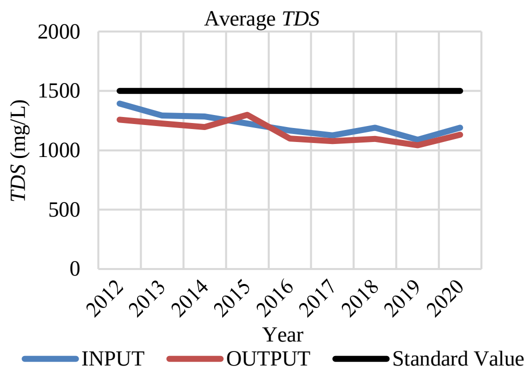


Figure 4. *TDS* input and output in and from Al-Rustumiya WWTP

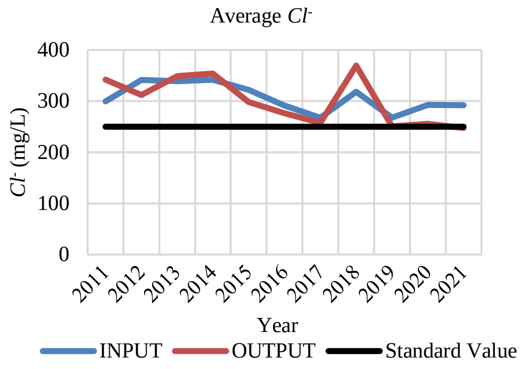


Figure 5. Cl^- input and output in and from Al-Rustumiya WWTP

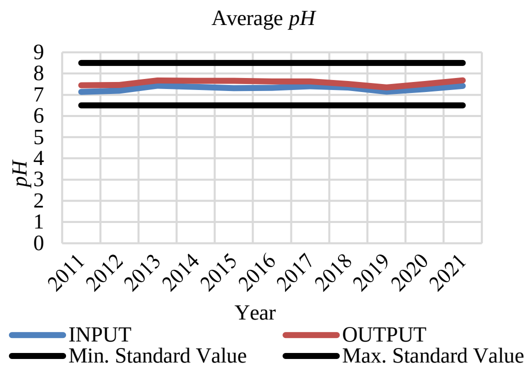


Figure 6. *pH* input and output in and from Al-Rustumiya WWTP

3.2. Removal Efficiency of the Plant

Figures 7 and 8 show the average annual removal efficiency values of *BOD*, and *COD* of the plant. The values were obtained by using the average input and output data described in the previous section. Figure 9 showed that the average removal efficiency of the *BOD* was variable and fluctuating particularly from 2011 to 2015. The lowest removal efficiency of the plant was 82% in 2012 and the highest removal efficiency of the plant was 93% in 2020.

While, the average removal efficiency of the *COD* was gradually fluctuating over the studied period. The lowest removal efficiency value of the plant was also in 2012 of about 75% and the highest removal efficiency value of the plant was also in 2020 of about 95.5% as shown in Figure 8.

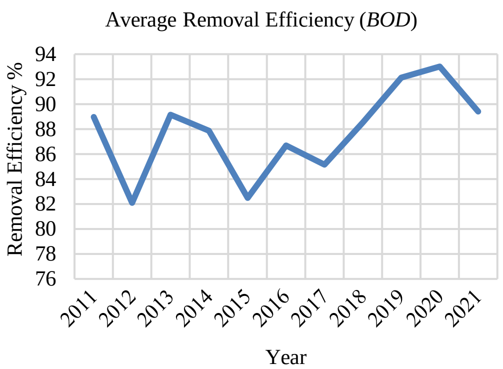


Figure 7. *BOD* Removal Efficiency of Al-Rustumiya WWTP

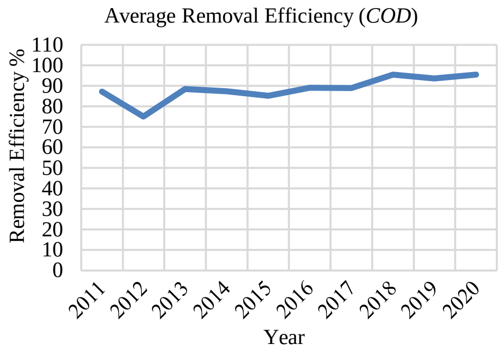


Figure 8. *COD* Removal Efficiency of Al-Rustumiya WWTP

3.3. WQI

The annual water quality index values were shown in Figure 9. The values increased from 2011 to 2012 then slightly decreased until 2019. The index value was then decreased to its lowest value in 2020 then noticeably increased in 2021. This means that the lowest performance efficiency of the plant occurred in 2012 while the greatest performance efficiency occurred in 2020. Also, the performance efficiency of the plant was nearly the same in 2014-2017 and in 2021. The minimum, maximum, mean values, and standard deviation were 52.65, 94.20, 79.95, and 11.18 respectively. These are acceptable water quality results and all the obtained water quality values were generally classified as "Good" according to Table 1.

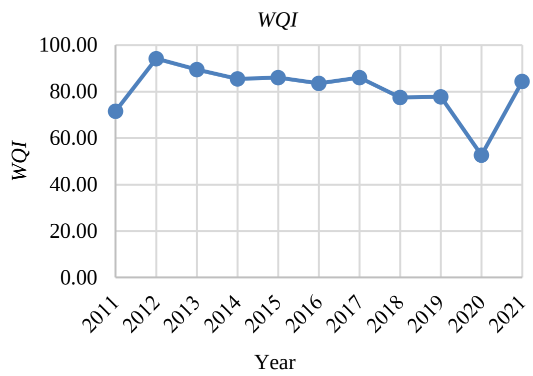


Figure 9. *WQI* of treated water from Al-Rustumiya WWTP

3.4. ANNs for WQI Modelling

The modelling result in terms of the MSE with the number of hidden layers is shown in Figure 10. The results indicated that the MSE was significantly decreased with the increase in the number of hidden neurons from 5 to 7 then gradually decreased and the minimum MSE result is obtained at 14 hidden neurons. Afterward, the training was stopped when reached 93 epochs for the Levenberg-Marquardt algorithm. This is because of the increases between the training and validation errors. A plot of Levenberg-Marquardt algorithm regression for testing, validation, and training, with correlation coefficient (*R*) is shown in Figure 12. This revealed that the *R* values were more than 0.99 for all. Thus, the optimum topology of the ANNs is obtained at 13 neurons in the hidden layer with 3.13 MSE and about 0.998 *R*.

The architectural model of the optimum topology is shown in Figure 11. This is 6:14:1, indicating the input layer with the six parameters, thirteen neurons at the hidden layers, and the output layer in terms of the removal efficiency of the *WQI*.

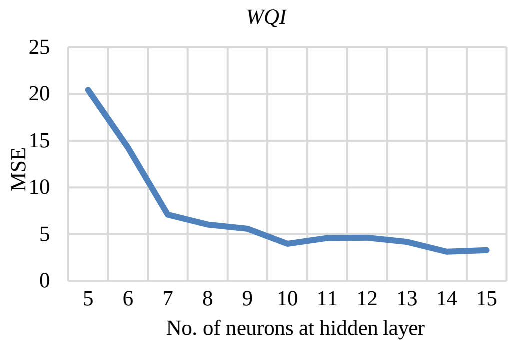


Figure 10. Mean Square Error (MSE) with different numbers of hidden layers for *WQI* of Al-Rustumiya WWTP

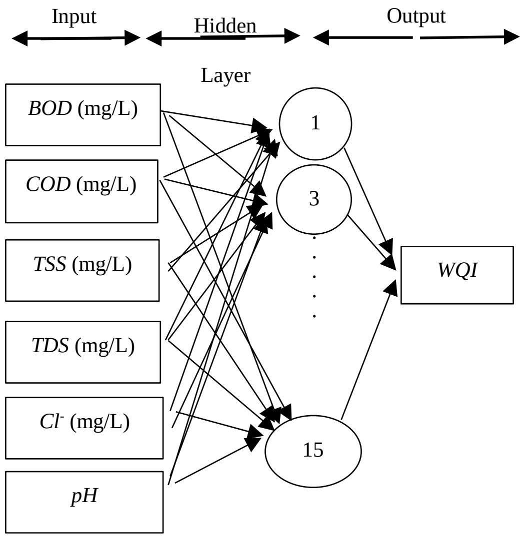
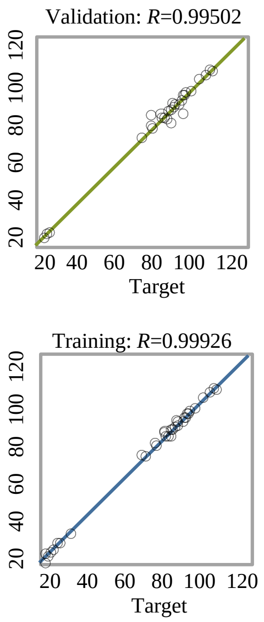


Figure 11. The architecture of the ANN model for the prediction of *WQI* of Al-Rustumiya WWTP



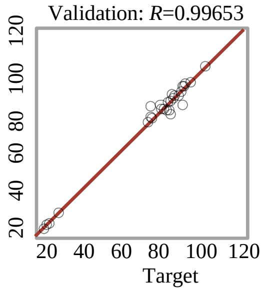


Figure 12. Training, validation and testing regression for the Levenberg-Marquardt algorithm for *WQI*

3.5. Importance of Water Quality Parameters

A study of sensitivity analysis was applied for assessing the importance of the six selected parameters on terms of the *WQI*. This refers to the assessments of the input parameters in the constructed model for *WQI* prediction. Garson in 1991 [26] provided equation for determining the importance of the parameters by the sensitivity analysis which related to the neural net weight matrix:

$$I_J = \frac{\sum_{m=1}^{m=Nh} \left(\frac{\left(\left|w_{jm}^{ih}\right|\right)}{\sum_{k=1}^{k=Ni} \left(\left|w_{jm}^{ih}\right|\right)} \times \left|w_{mn}^{ho}\right| \right)}{\sum_{k=1}^{k=Ni} \left\{ \sum_{m=1}^{m=Nh} \left(\frac{\left(\left|w_{km}^{ih}\right|\right)}{\sum_{k=1}^{N=Nh} \left(\left|w_{km}^{ih}\right|\right)} \times \left|w_{mn}^{ho}\right| \right) \right\}} \quad (7)$$

where,
I_j represents the input significance of the *j*th parameter
N_i is the neurons' number in the input layer
N_h is the neurons' number in the hidden layer
w is the weight connection,
i, *h*, *o*, represents the notations for input, hidden, and output layers, respectively
k, *m*, *n*, represent the notations for input, hidden, and output neurons, respectively.

After calculations of the importance, the results were shown Figure 13. It can be seen from the chart that the *TSS* was the highest impacted parameter at 36% followed by *COD* at 34%, and *BOD* at 14%. The impact of *pH* and chloride were about the same at 7%, and 6% respectively. Finally, *TDS* was the least impacted parameter on the *WQI* at only 3%.

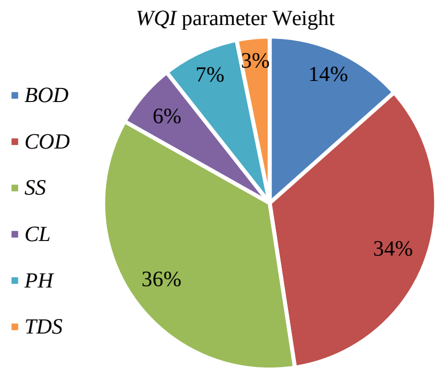


Figure 13. Importance weight of input parameters for *WQI* prediction model of Al Rustumiya WWTP

4. CONCLUSIONS

From the results, the following conclusions are drawn:
1) The average amounts of *BOD*, *COD*, *TSS*, and *Cl* in the influent wastewaters exceeded the Iraqi allowable limits. However, after treatment, the average amounts of all selected parameters were within the allowable limits over the studied period. This was except *BOD* in 2012, and *TSS* in 2012, and most of influent and effluent chloride. It is highly recommended to improve the efficiency of the plant in terms of the chloride removal by the utilizers of the plant and ensuring appropriate operation and maintenance of the plant.
2) The average annual removal efficiency values of the plant in terms of *BOD*, and *COD* are mostly more than 80%.
3) The water quality index classified the treated water as "Good" for all the studied period which means generally a good performance of treatment for the treatment plant.
4) The results of the ANNs modelling for the prediction of *WQI* were accurately able to predict the *WQI* of Al-Rustumiya WWTP by the use of raw dataset. The optimum topology of the ANNs is obtained at 14 neurons in the hidden layer at 3.13 MSE and about 0.998 *R*.
5) The calculations of the importance of the parameters indicated that the *TSS* was the highest impacted parameter on *WQI* at 36% followed by *COD* at 34% and *BOD* at 14%. The impact of *pH* and chloride were 7% and 6% respectively and *TDS* was the lowest impacted parameter on the *WQI* at 3%.

NOMENCLATURES

1. Acronyms

WWTP	Wastewater Treatment Plant
mg/L	Milligram per Litre

2. Symbols / Parameters

WQI: Water Quality Index
COD: Chemical Oxygen Demand
BOD: Biological Oxygen Demand
TDS: Total Dissolved Solid
TSS: Total Suspended Solid
Cl^-: Chloride
pH: Potential of Hydrogen

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