Prediction of Raw Water Turbidity at the Intakes of the Water Treatment Plants along Tigris River in Baghdad, Iraq using Frequency Analysis

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ABSTRACT

Different frequency distributions models were fitted to the monthly data of raw water Turbidity at water treatment plants (WTPs) along Tigris River in Baghdad. Eight water treatment plants in Baghdad were selected, with raw water turbidity data for the period (2008-2014). The frequency distribution models used in this study are the Normal, Log-normal, Weibull, Exponential and two parameters Gamma type. The Kolmogorov-Smirnov test was used to evaluate the goodness of fit. The data for years (2008-2011) were used for building the models. The best fitted distributions were Log-Normal (LN) for Al-Karkh, Al-Wathbah, Al-Qadisiya, Al-Dawrah and, Al-Rashid WTPs. Gamma distribution fitted well for East Tigris and Al-Karamah WTPs. As for Al-Wehda WTP Weibull distributions, was the best model. The best fitted distributions were used to forecast ten sets of monthly data for each plant that were compared with the observed data for years (2012-2014). The Kolmogorov-Smirnov test results indicated the capability of these models to produce data that has the same frequency distribution of the observed data. Moreover the frequency of occurrence of the observed and generated series in each plant indicated the capability of the model to produce results with frequency occurrence of probabilities of turbidity values > 50, 80, 100, 120, and 150 NTU.

Keywords: frequency distribution, Kolmogorov-Smirnov test, Tigris River, intakes, turbidity of raw water.

التنبؤ بعكورة الماء الخام عند مآخذ محطات تصفية الماء على طول نهردجلة في بغداد، العراق باستخدام التحليل التكراري

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الخلاصة

تم توفيق نماذج مختلفة التوزيع التكراري للبيانات الشهرية المقاسة لعكارة الماء الخام في ماخذ ثمان محطات تصفية المياه (WTPs) الموجودة على طول نهر دجلة في بغداد للفترة (2008-2014). تم استخدام نماذج التوزيعات التكرارية الطبيعي، اللوغاريتمي-طبيعي، ويبل، الأسي وغاما ذوالمعلمتين. تم استخدام اختبار كولموجوروف-سميرنوف لتقييم صلاحية المطابقة. تم استنباط النماذج باستخدام بيانات العكارة للفترة الأولى اربعة سنوات (2008-2011). كان افضل تطبيق لتوزيع (Log-Normal Distribution-LN) لمحطات تصفية ماء الكرخ، الوثبة، القادسية، آلدورة، والرشيد، وتوزيع (Gamma Distribution) لمحطة تصفية ماء شرق دجلة والكرامة وتوزيع (Weibull Distribution) لمحطة تصفية ماء الوحدة. ثم استخدمت هذه التوزيعات للتنبؤ بعشر مجموعات من البيانات الشهرية لكل محطة كل مجموعة بطول ثلاث سنوات وبالمقارنة

مع تلك البيانات المقروءة للثلاث سنوات الأخيرة من البيانات (2012-2014) التي لم تستخدم في ايجاد النماذج. اشارت نتائج المقارنة بين البيانات المقاسة والمتنبأ بها باستخدام الاختبار كولموجوروف-سميرنوف إلى قدرة هذه النماذج لإنتاج البيانات التي لديها نفس التوزيع التكراري للبيانات المقاسة. كما تم احتساب احتمالية وقوع قيم العكارة ضمن اعلى من خمسة قيم حدودية كما مبين ادناه لكل من سلسلة البيانات المقاسة والمتنبأ بها في كل المحطات واشارت النتائج إلى قدرة النماذج لإنتاج نتائج تكرار حدوث احتمالات قيم العكارة > 50، 80، 100، 120، و 150 (NTU).

الكلمات الرئيسية: التوزيع التكراري، فحص كولموجوروف-سميرنوف، نهر دجلة، مآخذ تجهيز المياه، عكارة الماء الخام.

1. INTRODUCTION

The identification of the maximum and minimum probable values and the likelihood of any value of a water quality parameter for water bodies like rivers and lakes, is no doubt useful for more efficient design and operation of any related water project. The probabilities of occurrence of different values of raw water turbidity at the intakes of water treatment plants, can provide the designers, planners, operators and decision maker's useful guides to deal with the consequences of water quality problems. Models of water quality parameters probability distributions over various time scales can provide useful information for proper planning, operation and design of water quality enhancement projects. The development of a frequency model starts with the historical data acquisition. The collected data samples can provide the necessary information about the time evolution variability of water quality variables if the size of the collected measured sample is of representative size. The available samples of these historical data should be divided into two sub-samples, the first one should be used for the estimation of the model parameters, while the second subsample should be used for verification. When the parameters of the best fitted frequency distribution are estimated and the model is verified, then the model results could be considered dependable and can be used for variety of applications in water resource system planning and design for quality assurance. Among these applications for example, locating areas of potential low water quality, feasibility of constructing and proper operation of a water treatment plant ...etc. Different probability distributions could be used, such as normal, log-normal, Weibull, exponential, Gamma, log-person and others. When the parameters of any distribution are found , then the probability of any event r > ro, where ro is a threshold value selected by the analyzer ,could be found, and hence provide useful information about the most probable events that could occur which can be used by planers, operators and designers to overcome its consequences ,**McCUEN, 1985**.
Water quality of the Tigris River was studied to evaluate quality indices which classify the usage of the river. **Al-Suhili** and **Nasser, 2008**, had classified water quality along Tigris River within Baghdad City during (2000-2004) by using the water quality index for Al-Karkh, Al-Wathbah and Al-Rashid water treatment plants located north, center and south of Baghdad which reflected the raw water quality at this area. Results showed a general deterioration in river water quality while the worst years were 2002 and 2003 due to the significant decrease in the flow and the simultaneous increase in agricultural and industrial development with time.

Abdul Razzak and **Sulaymon, 2009**, had studied the distribution of pollutants (BOD_5, TDS, pH, T.H., SO_4^{-2}, Na, and turbidity) in Tigris River between Al-A'imma Bridge and Al-Jumhuria Bridge. This study considered a reach about (9 km) in length within Baghdad city; which included four sewage pumping stations discharging untreated sewage to the river. Results showed that the concentrations of pollutants increased at the discharge points in the river and exceeded the acceptable limits according to the Iraqi standards specification of surface water. The turbidity reached 4.5 NTU in the study region. Sewage pumping stations should set at low discharge rates for low discharges of the river, to decrease the pollutant's concentrations in Tigris River.

Rabee, et al., 2011, had evaluated the water quality of the Tigris River for public usage, by using nine parameters from five sampling sites along the river in Baghdad city that were used for calculating the overall water quality index in the Tigris River. The results showed high values of turbidity and TDS according to World Health Organization (WHO) and Iraqi criteria, and the overall water quality index indicated that the Tigris River was in class medium, and not safe for direct domestic use in all seasons.

Al-Bayatti, et al., 2012, had studied the physical, chemical, and microbiological factors that influenced drinking water quality processed from River Tigris. From three main drinking water purification stations located at different parts of Tigris River, monthly water samples during (2009-2010), were used to evaluate water quality of Al-Shula region in Baghdad city. Physical and chemical analyses of water included determination of temperature, pH, turbidity, electrical conductivity, total dissolved solids, salinity, dissolved oxygen, and biological oxygen demand. The results of water before and after purification indicated values within the international allowable levels.

Many researches had developed models to describe water quality in the river **Al-Suhili, et al., 2008**, had used the artificial neural networks (ANNs) technique and applied to predict the turbidity at the intake of Al-Wathbah water treatment plant in Baghdad. This prediction is useful in the planning, evaluation, management, and operation of such plants, which may produce water of better quality. The available records from (1991-2000) were used for predicting turbidity in Tigris River, based on monthly maximum values of the water quality parameters near intake of the water treatment plant. The feasibility of the ANNs technique for modeling through multi-layer perceptron training using the back-propagation algorithm was used. The effect of ANN geometry and internal parameters on the performance of ANN model were investigated through a number of issues in relation to ANN construction. Results showed that ANN have the ability to predict the turbidity at Al-Wathbah water treatment plant with a good degree of accuracy (R^2 = 0.9687) and indicated that ANNs performance was relatively insensitive to the number of hidden layer nodes, momentum term, and learning rates.

Models to find the probability distribution function and hydrological variables were also been tested. **Al-Suhili** and **Khanbilvardi, 2014** had developed different frequency distributions models which were fitted to the monthly rainfall data in Sulaimania region, north Iraq. Three rainfall gauging stations data were used, Sulaimania city, Dokan Dam, and Derbendikhan Dam metrological stations, for the period (1984-2010). The distribution models fitted were Normal, Log-normal, Weibull, Exponential and two parameters Gamma type. The Kolmogorov-Smirnov test was used to evaluate the goodness of fit. The fittings were done for the overall data and for each month separately. The Gamma, Exponential and Weibull distributions were found as the best fits for the three stations for the overall models, while for the monthly models different distributions type were found as the best fit for each month and each station, however the Gamma distribution was found to have the highest percent of best fit. The best fitted distributions were used to forecast three sets of monthly rainfall data for each station and compared to the observed ones for the last 7-years of data. The t-test, F-test and Kolmogorov-Smirnov test indicated the capability of these models to produce data that has the same frequency distribution of the observed one.

The aim of this study is to develop different frequency distributions models which were fitted to the monthly Turbidity of the Tigris River.

2. THEORETICAL ASPECTS OF FREQUENCY DISTRIBUTIONS

The estimation of the probabilities of any measured variable need the mathematical definition of the probability density function (PDF) of the selected distribution. The mathematical description of these density functions used in this paper ,**McCUEN, 1985**.

1- Normal Distribution:
For a variable x normally distributed the probability density function PDF is given as below:

$$f(x|\sigma,\mu) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (1)$$

Where: μ is the mean value and σ is the standard deviation, called as the Location and Scale parameters of the distribution, respectively.

2- Log-Normal Distribution:
For a variable x that Log(x) is normally distributed the PDF is:

$$f(x|\sigma,\mu) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(logx-\mu)^2}{2\sigma^2}} \qquad (2)$$

Where: μ is the mean value of log(x) and σ is the standard deviation of this variable, called as the Scale and Shape parameters of the distribution, respectively.

3- Exponential Distribution:
For a variable x that distributed exponentially the PDF is:

$$f(x|\mu) = \frac{1}{\mu} e^{\frac{x}{\mu}} \qquad (3)$$

Where, μ is the Scale parameter of the distribution.

4- Weibull Distribution:
The PDF of this distribution is given by:

$$f(x|a,b) = \frac{a}{b^{-a}} x^{a-1} e^{-(\frac{x}{b})^a} \qquad (4)$$

Where: a and b are the Shape and Scale parameters respectively.

5- The Gamma Distribution PDF is:

$$f(x|a,b) = \frac{1}{b^a}\left(\frac{1}{\Gamma(a)}\right)x^{a-1}e^{(\frac{x}{b})} \qquad (5)$$

Where: a and b are the Shape and Scale parameters respectively, and $\Gamma(a)$ is the Gamma Function.

The parameters estimation methods of these distributions are well known. The most used two methods are the moments and the maximum likelihood methods. The parameters were estimated in this paper using the SPSS software, Version 20.

3. DATA AND METHODS

Tigris river water is considered the only source of potable water for the city of Baghdad, and the river divides the city into right (Karkh) and left (Risafa) sides with a flow direction from north to south. The study area within Baghdad City is located in the Mesopotamian alluvial plain between latitudes 33°14'-33°25' N and longitudes 44°31'-44°17' E, 30.5 to 34.85 m at sea level (a.s.l). The area is characterized by arid to semi-arid climate with dry hot summers and cold winters; the mean annual rainfall is about 151.8 mm ,**Al-Adili, 1998**.

In Baghdad city, a tremendous increase in freshwater demand is required due to the rapid growth in population and accelerated industrialization. As well as the pollution increases in the river reach due to effluent discharges by various uncontrolled sources as domestic, industries, agriculture along the downstream stretch. Therefore river water quality investigation is necessary to evaluate the water quality for different purposes. Many researches and studies were made to evaluate the water quality of Tigris River suffering from the effect of conservative pollutants within Baghdad city, **Al-Shami, et al., 2006**.

The monthly turbidity data of the river used in this study were taken from the intakes of eight water treatment plants (Al-Karkh, East Tigris, Al-Wathbah Al-Karamah, Al-Qadisiya, Al-Dawrah, Al-Rashid, and Al-Wehda), from upstream to downstream on the Tigris river within Baghdad city. The locations of these projects are shown in **Fig. 1**.

The models were applied to the monthly Turbidity data of the case study described above for seven years (2008-2014). The data for the first 4-years (2008-2011) were used for building the models, while the last 3-years data were used for verification, (2012-2014).

The goodness of fit test used in the present analysis is the non-parametric Kolmogorov-Smirnov test (D_n), which is as follows **McCUEN, 1985**:

$$D_n = Max|F_n(y) - F(y)| \qquad (6)$$

Where:

$$F_n(y) = \frac{\Pi(\{i \in \{1,2,.,.,n\}: y_i \leq y\})}{n} \qquad (7)$$

$$F(y) = \int_0^y f(x)dx \qquad (8)$$

Where:

$F_n(y)$ is the empirical cumulative probability of observing a value less than or equal to y as shown in **Eq. (7)**.

F(y) is the theoretical cumulative probability at y estimated by the frequency distribution function f(x), with the estimated parameters. A smaller value of D_n means a better fit between the observed and theoretical distributions, for a fixed number n of observations.

4. RESULTS AND DISCUSSION

The data were divided into two sub-samples as mentioned above, the first for years (2008-2011) for building the models, while the second sub-sample (2012-2014), was used for validating the obtained models. Before starting the model parameters estimation, the two sub-samples should be checked for homogeneity. Homogeneity means that the division of data is made such that the two sub-samples are not significantly different, i.e., they have the same frequency distribution, **McCUEN, 1985**. The SPSS software was used to make the analysis. **Tables 1** and **2** give the minimum, maximum, mean and standard deviations of the monthly turbidity of the raw water at the intakes of the selected water treatment plants in Baghdad, for the first and second sub-samples, respectively. **Table 3** shows the Sigma (SIG.) value of the t-test for means and the F-test for variance to test if there are significant differences between these two parameters of the two sub-samples. The results indicate that the data is homogeneous since all the SIG. values are greater than 0.05, then we accept the null hypothesis of no differences in mean and variances of the two sub-samples.

The SPSS software gives the SIG. value of the test which is the test parameter that should be greater than 0.05 then the null hypothesis that fits the data so the distribution is not rejected, (otherwise the distribution does not fit). From the Kolmogorov-Smirnov test, as the (Dn) value decreased, SIG. increased and hence higher SIG. values give better fitting. For each WTP five distribution were tested to fit the data of the monthly turbidity of the first sub-sample (2008-2011). The Normal, Log-Normal (LN), Exponential, Weibull and the Gamma frequency distributions, respectively. **Table 4** shows the parameters estimated for each WTP and each distribution, with the calculated SIG. values of the Kolmogorov-Smirnov test. The best distribution was selected that gave the maximum SIG. values (SIG. greater than 0.05). The shaded values indicate the maximum SIG. value for each parameter which indicates that the best fitted distribution was Log-Normal (LN) for Al-Karkh, Al-Wathbah, Al-Qadisiya, Al-Dawrah, Al-Rashid WTPs as LN(42.404,0.763), LN(36.545,0.732), LN(39.945,0.751), LN(53.032,0.907) respectively. Gamma distribution fitted well for East Tigris and Al-Karamah WTPs are Gamma (1.318, 0.019) and Gamma (1.605, 0.024) respectively. As for Al-Wehda WTP Weibull distributions was the best model, Weibull (75.025, 1.076). Some of the WTPs have the same maximum SIG. values for two distributions, such as for the East Tigris WTP Weibull and Gamma distributions both gave the maximum SIG. value of (0.957). Similarly Al-Rashid WTP the Log-Normal and the Exponential distributions gave the maximum SIG. value of 0.687 as shown in the table. In these cases any of the distributions can be used.

As previously mentioned, the second subsample data for 3-years (2012-2014), were left for models verification. For each WTP three randomly generated series of monthly turbidity for the three years were obtained using the best fitted distribution found above. **Table 5** shows the Kolmogorov-Smirnov independent two sample test results that checked the best fit of the generated series with the observed ones. All of the SIG. values shown in this table were > 0.05 which indicate that the generated series are of the same frequency distribution of the observed data. This indicates that these models are capable of generating data series that are probable to occur for the turbidity of the raw water at the selected WTPs, and hence can be used by planners, decision makers and designer and WTP operators.

Even though the models were verified as can produce data of similar frequency distribution when compared to a set of observed data that are not contributed into the process of obtaining the model, it is more efficient to check the performance of the model to obtain the frequencies of occurrence of turbidity values that exceed more than a certain value (ro). The obtained and verified frequency distributions for the eight WTPs were used to generate monthly turbidity series of three years length, ten series for each. From these series and the observed one the probability of occurrence for turbidity of greater than (ro = 50, 80, 100, 120, and 150) were obtained and compared. **Tables 6 to 13**, show the number of values greater than the ro selected value for the observed and three of the generated series. These three series are the most repeated values out of the ten generated series for each project .These tables indicate the ability of the models to generate data series that give very close probabilities to the obtained ones. **Table 14** shows the probabilities of the monthly turbidity at the selected WTPs intakes water of exceeding the five above mentioned threshold values, the values indicates that the models can generated data of almost the same probabilities as the observed one.

5. CONCLUSIONS

The analysis of the models developed and verified in this paper indicates that the best fitted distributions were Log-Normal (LN) for Al-Karkh, Al-Wathbah, Al-Qadisiya, Al-Dawrah, Al-Rashid WTPs as LN(42.404,0.763), LN(36.545,0.732), LN(39.945,0.751), LN(53.032,0.907) respectively. The best distributions fitted for East Tigris and Al-Karamah WTPs were Gamma (1.318, 0.019) and Gamma (1.605, 0.024) respectively. As for Al-Wehda WTP Weibull distribution was the best model, Weibull (75.025, 1.076). The t-test for differences between means and the F-test for differences between variances of the two subdivided data series one for the model parameters estimation and the other for verification, indicates that there is no significant differences for both means and variances, since all the test values are less than the corresponding critical test values at the 95% level of significance. The Kolmogorov-Smirnov test values for the comparison of the frequency distribution of the three generated series with the observed data indicates that those series has the same frequency distributions. The probability analysis of the observed and generated series gives very close results for the probabilities of turbidity values that exceeds different threshold values.

REFERENCES

- Abdul Razzak I.A., Sulaymon A. H., 2009, *Effect of Discharging Sewage of Baghdad to Tigris River on Water Quality*, Eng. and Tech. Journal, Vol. 27, No.16, PP. 2903-2920.

- Al Bayatti K. K.,Al Arajy K. H., and Al Nuaemy S.H., 2012, *Bacteriological and Physicochemical Studies on Tigris River Near the Water Purification Stations within Baghdad Province*, Journal of Environmental and Public Health, Vol. 2012, Article ID 695253, PP. 1-8.

- Al Shami, A., Al-Ani, N. and Al Shalchi, Th., 2006, *Evaluation Of Environmental Impact of Tigris River Pollution Between Jadirriya and Dora Bridges*, Journal of Engineering, Vol. 13, No.3, PP. 844-861.

- Al-Adili, A. S., 1998, *Geotechnical Evaluation of Baghdad Soil Subsidence and Their Treatments*, Ph.D. Thesis, University of Baghdad, Iraq.

- Al-Suhili R.H., and Khanbilvardi R., 2014, *Frequency Analysis of the Monthly Rainfall Data at Sulaimania Region, Iraq*, American Journal of Eng. Res, Vol. 3, Issue 05, PP. 212-222.

- Al-Suhili R.H., and Nassir N.O., 2008, *Water Quality Indices for Tigris River in Baghdad*, Journal of Engineering, Vol. 14, No.3, PP. 2656-2668.

- Al-Suhili R.H., Kassim W.M. , and Yousif, Y.M., 2008, *Prediction of Turbidity in Tigris River using Artificial Neural Networks*, Journal of Engineering, Vol. 14, No. 2, PP. 2483-2493.

- McCUEN, Richard H., 1985, *Statistical Methods for Engineers*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

- Rabee A. M.,Abdul Kareem B. M., and Al-Dhamin A.S., 2011, *Seasonal Variation of Some Ecological Parameters in Tigris River Water at Baghdad Region, Iraq*, Journal of Water Resource and Protection (JWARP), Vol. 3, No. 4, PP. 262-267.

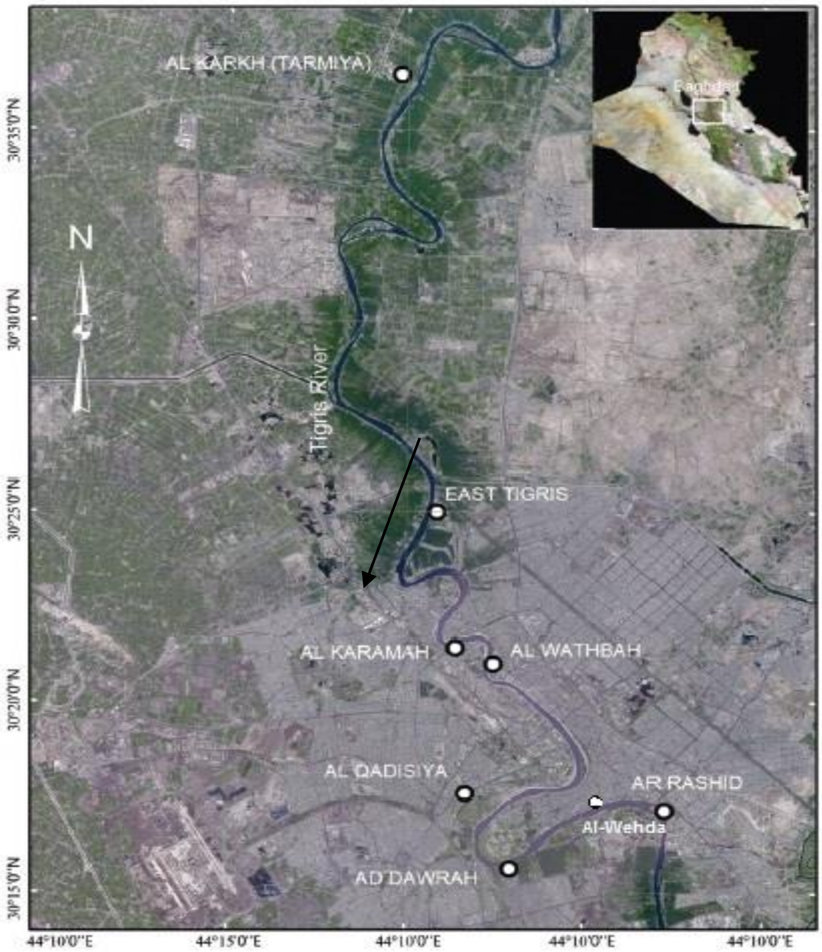

Figure 1. Locations of the eight selected water treatment plants, Baghdad, Iraq.

Table 1. Descriptive statistics for the monthly turbidity at Tigris river-WTPs intakes in Baghdad, Iraq, 2008-2011.

WTP	N	Minimum	Maximum	Mean	Std. Deviation
Al-Karkh	48	6.00	391.00	69.9919	70.93492
East Tigris	48	7.44	300.00	68.3425	59.52308
Al-Wathbah	48	7.00	240.00	56.1042	45.62858
Al-Karamah	48	10.00	199.00	66.3125	52.33816
Al-Qadisiya	48	7.00	130.00	46.4167	31.42626
Al-Dawrah	48	10.23	151.00	52.0465	37.73779
Al-Rashid	48	9.26	346.00	79.3410	77.64671
Al-Wehda	48	.00	361.00	74.0567	76.16803

Table 2. Descriptive statistics for the monthly turbidity at Tigris River -WTPs intakes in Baghdad, Iraq, 2012-2014.

WTP	N	Minimum	Maximum	Mean	Std. Deviation
Al-Karkh	36	12.00	517.00	80.0000	103.53329
East Tigris	36	13.00	470.00	79.1111	97.82281
Al-Wathbah	36	14.00	428.00	70.5278	76.53925
Al-Karamah	36	15.00	247.00	61.5833	54.32935
Al-Qadisiya	36	11.00	168.00	46.3611	35.97233
Al-Dawrah	36	13.00	358.00	60.1667	71.26590
Al-Rashid	36	19.00	619.00	108.1944	142.23558
Al-Wehda	36	18.00	941.00	133.1389	251.19249

Table 3. Test of homogeneity between the two sub-samples of monthly turbidity at Tigris river water supply projects intakes in Baghdad, Iraq, 2008-2011 and 2012-2014.

WTP	F-Test Variance	Sigma for F-Test Variance	T-Test for Means	Sigma for T-Test for Means
Al-Karkh	0.483	0.489	0.499	0.62
East Tigris	1.083	0.301	0.584	0.561
Al-Wathbah	1.861	0.176	1.005	0.320
Al-Karamah	0.558	0.466	0.401	0.690
Al-Qadisiya	0.006	0.963	0.007	0.994
Al-Dawrah	1.728	0.192	0.621	0.573
Al-Rashid	3.591	0.062	1.1	0.276
Al-Wehda	8.27	0.05	1.365	0.18

Table 4. Estimated parameters and SIG. values for Kolmogorov-Smirnov test for the selected seven water supply projects, Baghdad, Tigris River, Iraq (2008-2011)**.**

Distribution	Parameters	Al-Karkh	East Tigris	Al-Wathbah	Al-Karamah	Al-Qadisiya	Al-Dawrah	Al-Rashid	Al-Wehda
Normal	μ	69.992	68.343	56.104	66.312	46.417	52.046	79.341	74.140
	σ	70.935	59.523	45.629	52.338	31.426	37.738	77.647	76.080
	SIG	0.1	0.161	0.518	0.249	0.018	0.161	0.161	0.161
Log Normal	μ	45.213	47.278	42.404	49.053	36.545	39.945	53.032	44.607
	σ	0.965	0.909	0.763	0.798	0.732	0.751	0.907	1.116
	SIG	0.847	0.518	0.957	0.368	0.847	0.687	0.687	0.687
Weibull	a	71.417	72.331	60.666	71.683	51.352	57.217	81.886	75.025
	b	1.234	1.325	1.573	1.486	1.657	1.553	1.298	1.076
	SIG	0.687	0.957	0.518	0.368	0.368	0.100	0.018	0.957
Exponential	μ	0.014	0.015	0.018	0.015	0.022	0.019	0.013	0.013
	SIG	0.160	0.847	0.100	0.059	0.005	0.249	0.687	0.100
Gamma	a	0.974	1.318	1.512	1.605	2.182	1.902	1.044	0.949
	b	0.014	0.019	0.027	0.024	0.047	0.037	0.013	0.013
	SIG	0.518	0.957	0.518	0.689	0.687	0.386	0.368	0.368

Table 5. Kolmogorov-Smirnov test SIG. values for three generated series of the seven water treatment plants in Baghdad, Iraq, frequency distribution models and that observed for years (2012-2014).

Data Series	Al-Karkh	East Tigris	Al-Wathbah	Al-Karamah	Al-Qadisiya	Al-Dawrah	Al-Rashid	Al-Wehda
Generated 1	0.211	0.336	0.504	0.336	0.504	0.878	0.699	0.211
Generated 2	0.504	0.211	0.878	0.699	0.699	0.878	0.699	0.211
Generated 3	0.211	0.336	0.336	0.504	0.979	0.878	0.699	0.699
Distribution	LN(45.213,0.965)	Gam(1.318,0.019)	LN(42.404,0.763)	Gam(1.605,0.024)	LN(36.545,0.732)	LN(39.945,0.751)	LN(53.032,0.907)	Wieb(75.025,1.076)

Table 6. Frequency analysis comparison between observed and generated monthly turbidity of Al-Karkh WTP intake (out of 36), (2012, 2014).

Data	P>50	P>80	P>100	P>120	P>150
Observed	16	8	6	6	3
Generated 1	15	8	6	6	4
Generated 2	16	9	7	6	4
Generated 3	14	8	6	7	3

Table 7. Frequency analysis comparison between observed and generated monthly turbidity of East Tigris WTP intake, (out of 36), (2012, 2014).

Data	P>50	P>80	P>100	P>120	P>150
Observed	16	8	7	5	3
Generated 1	17	8	7	5	3
Generated 2	16	7	6	5	2
Generated 3	16	8	8	4	4

Table 8. Frequency analysis comparison between observed and generated monthly turbidity of Al-Wathbah WTP intake, (out of 36), (2012, 2014).

Data	P>50	P>80	P>100	P>120	P>150
Observed	15	9	7	5	3
Generated 1	16	10	6	4	2
Generated 2	15	8	7	5	4
Generated 3	16	9	7	5	3

Table 9. Frequency analysis comparison between observed and generated monthly turbidity of Al-Karamah WTP intake, (out of 36), (2012, 2014).

Data	P>50	P>80	P>100	P>120	P>150
Observed	15	8	6	2	2
Generated 1	16	8	7	3	2
Generated 2	15	7	6	3	2
Generated 3	15	7	6	2	2

Table 10. Frequency analysis comparison between observed and generated monthly turbidity of Al-Qadisiya WTP intake, (out of 36), (2012, 2014).

Data	P>50	P>80	P>100	P>120	P>150
Observed	9	4	3	3	1
Generated 1	8	5	4	3	1
Generated 2	10	6	4	3	1
Generated 3	9	4	3	2	0

Table 11. Frequency analysis comparison between observed and generated monthly turbidity of Al-Dawrah WTP intake, (out of 36), (2012, 2014).

Data	P>50	P>80	P>100	P>120	P>150
Observed	10	6	4	3	3
Generated 1	9	5	3	3	2
Generated 2	10	5	3	2	2
Generated 3	9	6	4	3	3

Table 12. Frequency analysis comparison between observed and generated monthly turbidity of Al-Rashid WTP intake, (out of 36), (2012, 2014).

Data	P>50	P>80	P>100	P>120	P>150
Observed	16	11	9	7	5
Generated 1	16	10	8	7	5
Generated 2	15	11	9	6	5
Generated 3	16	10	9	7	4

Table 13. Frequency analysis comparison between observed and generated monthly turbidity of Al-Wehda WTP intake, (out of 36), (2012, 2014).

Data	P>50	P>80	P>100	P>120	P>150
Observed	14	10	8	6	5
Generated 1	15	11	9	6	4
Generated 2	14	10	8	7	5
Generated 3	14	11	8	7	5

Table 14. Probabilities of turbidity over a selected different threshold values of the observed and three generated series of the eight selected WTPs raw water, using the obtained frequency models, (2012-2014).

WTP	Data Series	P>50	P>80	P>100	P>120	P>150
Al-Karkh	Observed	0.444	0.222	0.166	0.166	0.083
	Generated 1	0.416	0.222	0.166	0.166	0.111
	Generated 2	0.444	0.25	0.194	0.166	0.111
	Generated 3	0.388	0.222	0.166	0.194	0.083
East Tigris	Observed	0.444	0.222	0.194	0.138	0.083
	Generated 1	0.472	0.222	0.194	0.138	0.083
	Generated 2	0.444	0.194	0.166	0.138	0.055
	Generated 3	0.444	0.222	0.222	0.111	0.111
Al-Wathbah	Observed	0.416	0.25	0.194	0.138	0.083
	Generated 1	0.444	0.277	0.166	0.111	0.055
	Generated 2	0.416	0.222	0.194	0.138	0.111
	Generated 3	0.444	0.25	0.194	0.138	0.083
Al-Karamah	Observed	0.416	0.222	0.166	0.055	0.055
	Generated 1	0.444	0.222	0.194	0.083	0.055
	Generated 2	0.416	0.194	0.166	0.083	0.055
	Generated 3	0.416	0.194	0.166	0.055	0.055
Al-Qadisiya	Observed	0.25	0.111	0.083	0.083	0.027
	Generated 1	0.222	0.138	0.111	0.083	0.027
	Generated 2	0.277	0.166	0.111	0.083	0.027
	Generated 3	0.25	0.111	0.083	0.055	0
Al-Dawrah	Observed	0.277	0.166	0.111	0.083	0.083
	Generated 1	0.25	0.138	0.083	0.083	0.055
	Generated 2	0.277	0.138	0.083	0.055	0.055
	Generated 3	0.25	0.166	0.111	0.083	0.083
Al-Rashid	Observed	0.444	0.305	0.25	0.194	0.138
	Generated 1	0.444	0.277	0.222	0.194	0.138
	Generated 2	0.416	0.305	0.25	0.166	0.138
	Generated 3	0.444	0.277	0.25	0.194	0.111
Al-Wehda	Observed	0.388	0.277	0.222	0.166	0.138
	Generated 1	0.416	0.305	0.25	0.166	0.111
	Generated 2	0.388	0.277	0.222	0.194	0.138
	Generated 3	0.388	0.305	0.222	0.194	0.138