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Investigation and Comparison of the Quantitative and Qualitative Frequency Distribution of the Rivers

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Abstract: The entrance of pollutants from human activities to the surface water has seriously threatened the quality of water. TDS is an important qualitative parameter of water that describes the water salinity by measuring the concentration of total dissolved solids. First, using TDS and discharge data of the Cuyahoga River, Ohio, the partial and annual data sets were obtained. Then, partial data with three thresholds of n, 1.64n and 2n, in which n is the number of statistical years were developed and using the Hyfa Software, the frequency distribution of the data series was done. The results showed that for most cases, the two-parameter Log-normal distribution is the best distribution. Finally, for model validation, the error corresponding to each estimation was first calculated in comparison to the real data for the corresponding return periods. Then, 1.64n partial series was considered as the optimum method suggested by Hasking and a comparison was made between the estimates and this optimum series. The results showed that the series with a length of 2n was closest to the optimum case.

Keywords: Water Quality, TDS, River Discharge, Frequency Distribution, Two-Parameter Log-Normal, Water Resources Management

Introduction

Humanity has entered the modernity for decades, an era combined with massive building, an era in which human beings felt the nature in their hands. However, by looking back, we face environmental catastrophes. Some organisms have become extinct, the water is polluted and the nature has become more manageable and vulnerable day after day. Now, after years of experience, humans want to progress alongside nature to have a clean, green world forever. Freshwater sources are essential elements of the environment and life and human life on the planet depends on the qualitative and quantitative water supply. In the past, there was a weak management and development of water resources and because of the abundance of water resources, their pollution issues, including those caused by the entrance of wastewater, were not of utmost importance. Water quality management is linked to pollution control caused by human activities. In fact, water quality management is an awareness of the quantitative and qualitative status of a water resource (Alizadeh, 2005). In general, the purpose of water quality management is to protect water resources so that the water intended can be used for uses that were already intended for it and it can be used as an economic agent for the disposal of waste in emergency situations and it should also have the capacity to mix and tolerate these materials.

In this study, TDS and discharge data of the Cuyahoga River, Ohio, USA were collected. TDS is the water salinity index and indicates the concentration of cations and anions in water as the concentration of total dissolved solids. TDS is one of the most important indices of water quality in terms of water use capability for various uses. For example, the concentration of the soluble salts in drinking water should not exceed 500 mg L^{-1}, but higher concentrations can be considered for livestock. This is more critical in plants and therefore, quality of irrigation water is very important for agricultural use. By increasing the concentration of salts in irrigation water to more than 500 mg L^{-1}, water and soil management becomes especially important in maintaining product efficiency (Al-Boodi *et al*., 2002; Raeisi-Vanani *et al*., 2017).

As noted, surface water has different salinities and most of the industrial wastewater entered to the surface water has significant amounts of salt that would add to the concentration of salts in these water resources. Rainfall runoff would also wash the salts on the surface of roads and fields and thus, a large amount of salt is discharged into surface and groundwater. In addition to the above mentioned issues, the supply of fresh water by sweetener devices will increase the salinity of the remaining water. Therefore, the volume of sweet water on the earth surface is reduced and salty waters are increased day by day (Efran Manesh and Afyoun, 2005).

In this study, HYFA statistical software was used, which is a hydrological software to estimate the maximum probable discharge for different return periods. The software can import data in the form of files or during the runtime and correct and save it. Using this program, the data is sorted and using the seven available experimental formulas, its probability of occurrence is determined (Eslamian *et al*., 2005; Ostad-Ali-Askari *et al*., 2017a). Then, the data is fitted by using the six probability density distribution functions and the distribution parameters are estimated. The software can do the followings:

- Evaluation of the statistical distribution fitting to the hydrologic data, by using both the moments and maximum accuracy methods
- Estimation of the probable discharges, calculation of the standard error and the confidence limits according to a set of selected return periods
- Performing the fit goodness test according to the Chi-square method and the Deviation method, that is one of the subsets of the Least Square method

In the present study, 12 years of qualitative and quantitative river statistics were available, which is very short. In general, the more detailed and complete the statistics are, the higher the quality of the investigation, the more accurate and reliable the results. Qualitative TDS data and quantitative discharge data of the Cuyahoga River were collected. The aim of the study was to do a qualitative and quantitative prediction and to investigate whether a comparative quantitative and qualitative analysis can be done using the frequency analysis methods and which statistical distribution should be fitted to the data for prediction and which statistical distribution can be used in practice (Eslamian and Koopani, 2002; Fakhri *et al*., 2014).

Materials and Methods

The study area, Cuyahoga River was located in North Ohio, USA. Native Americans named the river Cuyahoga, which means a curved or bent river due to its shape. The river is one of the young geological structures that has been formed by the advancement and withdrawal of ice layers during the ice years. The last ice withdrawal, which happened about 10,000 years ago, led to a redirection and formation of a U-shaped river. The depth of the river is between 3 and 6 feet (Gupta, 1989; Thomann, 1982; Ostad-Ali-Askari *et al*., 2015; Shayannejad *et al*., 2015a; 2015b; 2017).

The first 100 miles of the river is located around the Ceauga County. Then, the river continues toward the South to Cuyahoga Falls, as far as it turns toward the North with a steep curve and continues inside the Cuyahoga National Park and in the Cleveland toward its northern outlet and eventually discharges to the Erie Lake.

In this study, 80 TDS and discharge data from the Cuyahoga River for 12 years were available, a can listed in Table 1. The lengths of partial series data were obtained as n, 1.64n and 2n using the existing equations, where *n* is the number of statistical years. Table 2 to 5 show different cases. (Dehghan *et al*., 2017; Bahmanpour *et al*., 2017; Shojaei *et al*., 2017; Saadati *et al*., 2006; Raeisi-Vanani *et al*., 2017a; 2017b; 2015).

Table 1. Cuyahoga river characteristics

Origin	Around ceauga county
Outlet	Erie Lake, Cleveland
Outlet elevation	571 feet (176 m)
Length	160 Km
Bain area	2095 Km^2

Table 2. Annual discharge and TDS data

Year	Q(ft^3/s)	TDS(mg/L)
1974	4630	540
1975	1640	460
1976	680	620
1977	1230	580
1978	4930	710
1979	4670	700
1980	3910	570
1981	1500	620
1982	1080	500
1983	1260	510
1984	7640	470
1985	3070	500

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Table 3. Partial series with N = n = 12

m	Q(ft^3/s)	TDS(mg/L)
1	7640	710
2	4930	700
3	4670	700
4	4630	680
5	4590	670
6	3910	620
7	3810	620
8	3070	620
9	2340	580
10	1640	570
11	1500	560
12	1500	550

Table 4. Partial series with N = 2n = 24

m	Q(ft^3/s)	TDS(mg/L)
1	7640	710
2	4930	700
3	4670	700
4	4630	680
5	4590	670
6	3910	620
7	3810	620
8	3070	620
9	2340	580
10	1640	570
11	1500	560
12	1500	550
13	1400	550
14	1260	540
15	1230	540
16	1080	530
17	1080	520
18	1060	520
19	1020	510
20	920	510
21	777	500
22	750	500
23	741	500
24	736	500

To calculate the probability of the experimental data, the experimental probabilistic Weibull $\left(P = \frac{m}{n+1}\right)$ formula was used.

To study the accuracy of the calculations, the relative error, E, percent can be obtained using the following formula:

$$E = \left((Q_T - Q)/Q_T\right)*100 \tag{1}$$

where, Q_T and Q are the obtained fitted and observed discharge values, respectively.

Table 5. Partial series with N = 1.64n = 20

m	Q(ft^3/s)	TDS(mg/L)
1	7640	710
2	4930	700
3	4670	700
4	4630	680
5	4590	670
6	3910	620
7	3810	620
8	3070	620
9	2340	580
10	1640	570
11	1500	560
12	1500	550
13	1400	550
14	1260	540
15	1230	540
16	1080	530
17	1080	520
18	1060	520
19	1020	510
20	920	510

In this study, seven well-known distributions of normal, two-parameter Log-normal, three-parameter Log-normal, Pearson Type III, Log-Pearson Type III, Gumbel or the extreme value Type I and two-parameter Gamma were used.

Given that the two-parameter Log-normal distribution was the dominant distribution in the study area based on the obtained results, the distribution is presented here after.

If the normal logarithm of the random variable X, LnX, has a normal distribution, the random variable X has a normal logarithmic distribution. In this case it can be written:

$$P(X) = \frac{1}{X\sigma_y\sqrt{2\pi}} e^{\frac{\left(Ln(X)-\mu_y\right)^2}{2\sigma_y^2}} \tag{2}$$

where, μ_y and σ_y are the average and standard deviation of the normal logarithm of X, respectively.

If Ln (X) variable is used as follows:

$$T = \frac{Ln(X) - \mu_y}{\sigma_y} \tag{3}$$

The standard normal variable, t is obtained with the desired probability density function:

$$P(t) = \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}} \tag{4}$$

The following equation can be used to calculate the frequency factor of the distribution:

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$$K = \frac{e^{\left[\left[Ln\left(1+Z^2\right)\right]^{\frac{1}{2}} t - \left[Ln\left(1+Z^2\right)\right]/2\right]} - 1}{Z} \tag{5}$$

$$Z = \left(e^{\sigma_y^2} - 1\right)^{1/2} \tag{6}$$

There are simple methods to determine the best frequency distribution of data and therefore, a more accurate estimation of the data occurrence probability can be obtained.

For fitting the hydrologic data with theoretical distributions, there are various methods from which three methods are used in hydrology. These methods include the use of distribution parameters estimation, distribution coefficient and graphical method. The first method is used in this study and is discussed below (Ostad-Ali-Askari *et al*., 2015; 2016; Eskandari *et al*., 2017; Ostad-Ali-Askari *et al*., 2015a; 2015b; 2015c; 2015d; 2015e; 2015f; 2015g; 2016h).

The most basic method is to use the distribution parameters. Several methods are used to estimate the parameters, which include Method of Moments (MOM), Maximum Likelihood Method (MLM), Probability Weighted Moment (PWM) Method, Least Squares (LS), Maximum Entropy Method (EMT), Mixed Moments Method (MIX), Generalized Moment Method (GMM) and Incomplete Average Method (ICM). Three methods of the above methods are commonly used including Method of Moments, Maximum Likelihood Method and Probability Weighted Moment method (Ostad-Ali-Askari *et al*., 2017b; Soltani-Todeshki *et al*., 2015; Ostad-Ali-Askari *et al*., 2015; 2016).

The tor Method of Moments is a simple method, but with a few number of data, it will result in a less accurate result. MOM estimates are usually of low quality and generally, it is used less than the MLM estimates. It is not a suitable method particularly for the distributions with a large number of parameters, such as three-parameter distributions and more, whose higher order moments are likely to be skewer in relatively small samples 9 (Eslamian and Koopani, 2002).

The parameters of a probability distribution function are estimated using the MOM method by equating the sample moments with the probability distribution function moments. For a distribution with K parameter, α_1, α_2,… and α_K must be estimated. Then, K sample moments are equated with the moments that are determined based on the unknown parameters. After that, K is simultaneously solved for unknown parameters of α_1, α_2,… and α_K.

The Maximum Likelihood Method is highly accurate and seems to be one of the most efficient methods, because it provides the least sampling variance of the estimated parameters. However, the calculations are very complicated and time-consuming, which can be solved using high-speed computers (Table 6).

Table 6. General framework of the Hyfa software output data

Distribution	Fitted method	Mean related.dev	Mean sq.Rel.dev
Normal	Moments	30.6	2003.7
	Max. Likelihood	30.6	2003.7
Lognormal	Moments	27.91	941.76
	Max. Likelihood	27.91	941.76
Lognormal	Moments	23.1	810.21
	Max. Likelihood		

Results and Discussion

By using the Hyfa software, different distributions were fitted to the data and the dominant distribution was selected. For example, the results of an annual discharge data series using the Hyfa software are presented here.

In continue, the best distribution for each of the available data series, including annual and partial n, 1.64n and 2n data series was separately obtained. The best distribution can be selected in two ways (Sayedipour *et al*., 2015). The first method is to consider the mean related dev. columns and select the minimum calculated value using the Moments Method as the best distribution. The second method is to consider the means.sq.Rel.dev. column and select the minimum calculated value using the Maximum Likelihood method. The two methods result in the same value in many cases. In Table 7, the obtained results for the annual discharge series are typically listed and, finally, the final results for selecting the best distribution are presented.

As can be seen from the best distribution Table 8, the two-parameter normal distribution is the dominant distribution of the area. Upon selection of the best distribution, the accuracy of the calculations can be examined by determination of the relative error percent.

The above calculations suggested that the 1.64n and 2n series as well as the Maximum Likelihood method are of higher accuracy. The results of the TDS partial series with a length of 2n as well as the Moment method are typically presented.

Given that the partial series with 20 data presented a higher accuracy than the other series, a comparison between the data with the same return periods in different series with the partial series with 20 data was done. The calculations results indicated that the partial series with 24 data provided the closest estimates to the partial series with 20 data and the lowest accuracy was obtained in the partial series with a length of *n*. Some of the calculations are typically presented below (Table 9-11).

Table 7. Annual discharge series

	Maximum Likelihood			Moments	
	Mean.relat.dev	Mean.sq.rel.dev		Mean.relat.dev	Mean.sq.rel.dev
Normal distribution	30.6009	2003.774		30.6009	2003.774
Two-parameter log-normal distribution	27.91879	941.7617		27.91879	941.7617
Three-parameter log-normal distribution	N/A	N/A		23.13012	810.2175
Two-parameter gamma distribution	19.72729	594.9233		18.79443	545.3525
Pearson type 3 distribution	N/A	N/A		N/A	N/A
Pearson type 3 logarithm distribution	N/A	N/A	Direct	N/A	N/A
			Indirect	22.46792	869.4399
Gambel distribution or final values of type one	21.00091	692.8792		22.33247	375.205

Table 8. TDS annual series

	Maximum likelihood		Moments	
	Mean. relat.dev	Mean. sq.rel.dev	Mean. related.dev	Mean. sq.Rel.dev.
Normal distribution	3.24947	15.78051	3.24947	15.78051
Two-parameter Log-normal distribution	3.13445	19.41524	3.13445	19.41524
Three-parameter Log-normal distribution	N/A	N/A	3.15476	22.5043
Two-parameter Gamma Distribution	3.11434	16.68818	3.11993	17.50947
Pearson type 3 distribution	N/A	N/A	N/A	N/A
Pearson type 3 logarithm distribution	N/A	N/A	N/A	N/A
Gambel distribution or final values of type one	3.88466	32.33394	3.81883	33.94466

Table 9. Selection of the best distribution for the qualitative and quantitative data

TDS annual series	Two-parameter gamma distribution	Normal distribution		Two-parameter gamma distribution	Normal distribution
TDS partial series with N	Normal distribution	Normal distribution		Pearson type 3 distributions	Pearson type 3 Distribution
Discharge partial series with N = 1.64n	Two-parameter Log-normal distribution	Two-parameter Log-normal distribution		two-parameter Log -normal distribution	Two-parameter Log -normal distribution
TDS partial series with N = 1.64n	Gambel distribution or final values of type one	Two-parameter Log -normal distribution	Direct	A/P	A/P
			Indirect	Pearson logarithm distribution	Pearson logarithm distribution
Discharge partial series with N = 2n	Two-parameter Log -normal distribution	Two-parameter Log -normal distribution		Two-parameter Log -normal distribution	Two-parameter Log -normal distribution
TDS Partial Series with N = 2n	Two-parameter Log -normal distribution	Two-parameter log -normal distribution		Two-parameter log -normal distribution	Two-parameter log -normal distribution

Table 10. Error calculation (in %)

T	TDS	T	TDS	$((Q-Q_T)/Q_T)*100$
1.05	493.724	1.04	500	1.25
1.11	508.183	1.13	510	0.35
1.25	527.861	1.25	520	1.51
2	574.145	2.00	560	2.52
5	636.420	5.00	680	6.40

Table 11. A typical comparison with 1.64n partial series

	Maximum likelihood (Two-parameter log-normal)			
T	Q_T	T	Q_{20}	$((Q-Q_T)/Q_T)*100$
1.05	562.740	1.08	763.5950	26.30
1.11	846.040	1.18	962.2820	12.07
1.25	1299.77	1.30	1273.250	2.080
2	2569.91	2.10	2175.536	18.12
5	4477.12	4.30	3717.226	20.44

Conclusion and Recommendations

According to the obtained results, it can be concluded that fitting the hydrologic data with the theoretical distributions can be a suitable method in the qualitative analysis in order to determine the best distribution and use it for estimations. In addition, in quantitative terms, different number of data in the partial and annual series were analyzed and in each case, the obtained error was used as a quantitative indicator for selection of the best number of the data series. According to what was obtained in this study, the partial series with 2n data provides a better result than a series with n data, which is suggested to be used in the quantitative and quantitative estimations. It is recommended that the Linear Moment method would be used in future research instead of the Maximum Likelihood method, which is expected to yield more accurate results.

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Authors Contribution

All authors contributed to design the study, write and revise the manuscript. The present study and ethical aspect was approved by Isfahan University of Technology.

Ethics

The present study was approved by Isfahan University of Technology.

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