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Statistical assessment for performance of Al-Mussaib drinking water treatment plant at the year 2020

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ABSTRACT

Assessment of water quality is a major step in the water industry to ensure the suitability of water for human use. In this study, statistically evaluate the quality of raw and treated drinking water of the Al-Mussaib drinking water treatment plant, Babylon city, Iraq, from January to December 2020. Additionally, the water quality of treated water was assessed according to World Health Organization (WHO) and Iraqi standards for drinking water. The results showed the plant has a good efficiency in removing the studied parameters, such as alkaline, calcium and hardness. It is noteworthy to mention that although the measured concentrations/levels met the WHO and Iraqi standards, they were higher than the favourable limits. For example, the measured sulphate concentration in the produced water was 248 mg/L which is higher than the favourable concentration (200 mg/L) (WHO). The statistical analysis indicated significant differences between the quality of raw and treated water (p-value <0.05) in terms of turbidity, hardness, magnesium and dissolved solids concentrations, but there was no significant difference (p-value >0.05) in terms of alkalinity, pH, calcium and sulphates concentrations. The results of this work could be useful for water authorities and decision-makers in Iraq and national and international environmental agencies.

Key words: assessment, drinking water, efficiency, treatment plant

HIGHLIGHTS

- Water quality of Al-Mussaib drinking water treatment plant, Iraq was studied.
- Water quality was acceptable according to WHO and Iraqi standards.
- Significant differences between the influent and effluent turbidity, hardness, magnesium and dissolved solids concentrations.
- No significant differences between influent and effluent alkalinity, pH, calcium and sulphates concentrations.

1. INTRODUCTION

Water is an essential element for all living organisms; for example, it represents 65% of the adult human body (Abbaspour 2011). Additionally, water maintains the existence of humankind on the planet of Earth. Water has an essential and tangible connection with the development of humans and their daily needs of water in all his vital, domestic, religious, industrial, commercial and other activities, which made humans devote all possibilities to preserve their water sources from pollution. For example, in the past, civilizations were held on the banks of rivers and near their mouths; however, the pollution and depletion of water are the most important reasons for the demise of these civilizations. In fact, water pollution did not only influence the previous societies, but it also represents a major concern nowadays for the water industry and health sectors. For instance, the available reports demonstrated that water pollution is responsible for more than 5,000,000 deaths per year worldwide due to the spread of water-related diseases, which is more than the number of people killed in wars (Azizullah *et al.* 2011).

Unfortunately, the effects of water pollution/shortage are expected to increase rapidly in the near future due to many reasons; including, but not limited to, the minor quantity of freshwater (it is only 0.01% of the total freshwater quantity in and on the planet of Earth) and the considerable increase in the production of wastewaters (Hasan *et al.* 2019). As a result, it is expected that by 2025, 66.6% of the world's population will likely face a serious water shortage that leaves them without access to fresh water (Azizullah *et al.* 2011).

Therefore, maintaining water quality and treating polluted water/wastewater are vital processes to ensure the survival of human civilization. Previously, people relied on their senses in evaluating the quality of water in terms of taste, colour, smell and other parameters. However, these basic methods are not dependable because such methods can not be used to distinguish the presence of dissolved chemicals in water, and these methods could be affected by the abilities of the testing person and weather conditions (Dietrich & Burlingame 2020). Over time and with scientific progress, humans have turned to modern technology in evaluation and treatment processes (Gzar *et al.* 2020), such as the use of microwave sensors (Frau *et al.* 2020) and remote sensing (Elhag *et al.* 2019). Additionally, the increase in demand for clean water in recent years has made the countries of the world dedicate their efforts to organize their water resources and make good use of them in terms of preparing primary and secondary water networks, as well as constructing upper and ground reservoirs (Hussein *et al.* 2018). In this context, many studies were conducted to assess the suitability of water for human use by studying the characteristics of water before and after treatment and comparing these characteristics with local or international specifications, such as the specifications of the World Health Organization (WHO) and the Iraqi standards. In addition, there are other criteria for evaluation by studying the biological properties, toxic and carcinogenic substances. For example, Ali *et al.* (2019) assessed the efficiency of traditional drinking water treatment plants at the Al-Hussein city in Karbala Governorate, Iraq, to remove organic and inorganic pollutants, such as turbidity, temperatures, pH, Electric-conductivity, and the concentrations of Ca, Mg, Cl, Al, SO_4^{2-}, and the total dissolved salts. These parameters were tested at quick mixing, sedimentation, filtrations and disinfection units for eight months during 2017–18. The findings of their study indicated the tested parameters were not highly influenced during the treatment process, and their values were within the Iraqi limitations for drinking water. Hassen *et al.* (2021) investigated the physicochemical properties of seawater and treated and untreated water from southern Mediterranean countries (Egypt, Morocco, Algeria, and Tunisia) and compared the results found in a northern Mediterranean country (Italy) for the same period. The physicochemical tests indicated severe contamination of seawater collected from all studied countries.

In this context, the present research aims to study the properties of raw and treated water in the Al-Mussaib drinking water treatment plant to identify the suitability of produced water for human use (after treatment) and evaluate the performance efficiency of the mentioned plant.

2. RESEARCH MATERIALS AND METHODS

2.1. Research hypotheses

The study starts from the null hypothesis, which states that there are no statistically significant differences between the mean of the two samples of raw and treated water to compare their properties, against the alternative hypothesis that states the existence of these hypotheses. The inductive experimental approach was used, where the T-test was used for double comparisons. This method is one of the scientific methods that look at facts with a realistic view without the human well, human desire, or whims entered into the results. This is because it depends on the analysis of phenomena and observations on the quantitative measurement (Nasir *et al.* 2021; Abdulhasan *et al.* 2022).

2.2. Studied treatment plant

Al-Mussaib water treatment plant is located on the Euphrates River in Al-Mussaib city, Iraq, and it has a production capacity of 2,800 m^3/hr and was operated for the first time in 1998, see Figure 1. This plant is consists of the following units: (A) low-lift pumps, (B) draft tube, (C) Rapid mixing basin, in which the alum solution is added to water and mixed quickly to transfer the water to the flocculation basins, (D) Common flocculation and sedimentation basins, and (F) The four filters are of the sand filter type. After the filtration unit, chlorine is added to water at a rate of 2.5 mg/L.

2.3. Experimental work and analysis

- Water samples were taken before and after treatment from January to December 2020. Raw and treated water samples were collected twice per month (middle and end of the month). All samples were immediately transferred to the laboratory. Then, the results were summarised as the average of two readings for each month of

Figure 1 | Al-Mussaib water treatment plant.

the year. A plastic container collected samples from areas close to the surface, and they were collected at a specific time during the early morning hours each time.

- All the tests, which included turbidity, pH, alkalinity, hardness, calcium, magnesium, sulfate and total dissolved solids, were carried out in the central laboratories of the Babil Water Directorate, Iraq, according to the standard methods of water tests. The results of the tests were evaluated according to the drinking water standards of both WHO and Iraqi standards.
- The used statistical tests in the assessment of WQ were Kolmogorov-Smirnov and Shapiro-Wilk for the normal distribution to test whether the adopted variables in the research follow the normal distribution or not (Abu Allam 2009). In the case the data was not normally distributed, several techniques, such as converting data into log-log data or Quadratic, were applied. After this process, the statistical significance (*P*-value) was checked to ensure the normal distribution.
- Paired Sample T-Test or the difference test was done using a pairwise method, were performed using SPSS software. The purpose of using this test is to measure a particular phenomenon under different conditions. These tests relate to two averages of two non-independent samples (Noori *et al.* 2010).

The hypothesis on which the pairwise comparison test process is based on the fact that the samples whose averages are compared are not independent. This type of test aims at getting rid of the largest possible number of external factors that lead to disparity together by making similar pairs for several variables, and instead of performing analysis for each section of observations separately, the difference between each pair of observations is used and considered a specific variable assuming that these differences are random and withdrawn from a normally distributed population.

The T-test format is (Abu Allam 2009):

$$\mathrm{T} = \frac{\bar{D} - \mu_d}{S_d/\sqrt{n}} \tag{1}$$

where T is the test value for the double coupler, S_d is the standard deviation of the sample difference, $\mu_{d\ is}$ the arithmetic mean of the variances of a community, $\bar{D}$ is the arithmetic mean of the sample variances, n is the number of sample views.

The plant removal efficiency of a specific pollutant was obtained from the following formula (Gzar *et al.* 2020):

$$\%E_R = \left(\frac{X_1 - X_2}{X_1}\right) \times 100 \tag{2}$$

where E_R is Plant Removal Efficiency, X_1 is the annual average of a given characteristic for raw water, X_2 is the annual average of this characteristic for treated water.

The formula obtained the target efficiency we would like to have for a particular characteristic:

$$\%E_T = \left(\frac{X_1 - C_P}{X_1}\right) \times 100 \tag{3}$$

where E_T is the target Efficiency, X_1 is the annual average of a given characteristic for raw water, and C_P is the highest preferred concentration for that characteristic

The degree of pollutants removal (R) was obtained using the formula below:

$$\%R = \frac{E_R}{E_T} \tag{4}$$

The two relationships, 3 and 4, were invented and used for the first time by the researchers where the degree we get from applying the latter relationship is unacceptable, acceptable, average, good, very good, excellent.

3. RESULTS AND DISCUSSION

The following points can be noticed from the observations of the values of the properties of treated and raw water, shown in Figures 2–9:

- There is a clear variation in the values of properties for both raw and treated water in the Al-Mussaib drinking water plant throughout the months of the year, and this variation is small in some months and is clear in other months of the year.
- The turbidity, alkalinity, and magnesium values in raw and treated water are within the WOH and Iraqi specifications in most of the years.
- The values of hardness and calcium exceeded the permissible limits in raw and treated water in some months of the year.
- There is an increase in the values of some properties after treatment, such as pH, sulphates and dissolved solids. This is attributed to the increase in the use of alum (Aluminum Sulphate) use during the flocculation process.
- The turbidity values between May and September in Figure 2 were less than the turbidity for the rest of the year, which is attributed to the spring and autumn solstices in Iraq. The phenomenon of thermal inversions occurs in these seasons because of the difference in temperature between the water at the surface and bottom of the river, which results in quick mixing of the water column along the river, causing an increase in the turbidity level.

Data were tested for all parameters, which include turbidity, PH, hardness, alkalinity, calcium, magnesium, Sulphates, dissolved solids; according to Kolmogorov-Smirnov and Shapiro-Wilk, tests for normal distribution were found:

A- The turbidity, pH, calcium, alkalinity, sulphate parameters follow the normal distribution because *P*-Value is greater than the level of significance (0.05) according to Kolmogorov-Smirnov and Shapiro-Wilk tests, thus do not

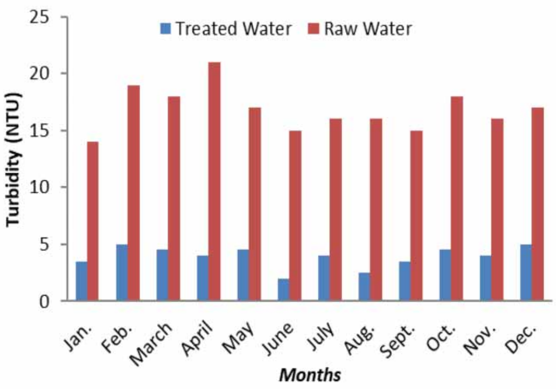

Figure 2 | Turbidity level before and after treatment.

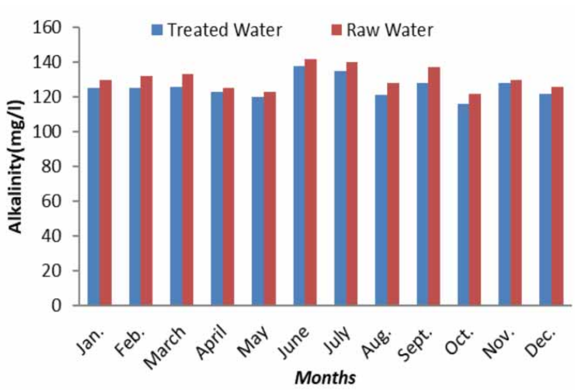

Figure 3 | Alkalinity values before and after treatment.

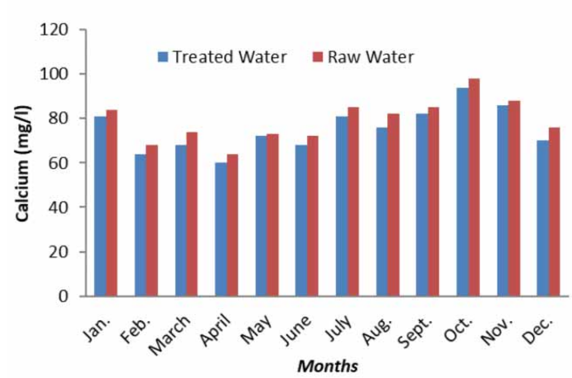

Figure 4 | Calcium values before and after treatment.

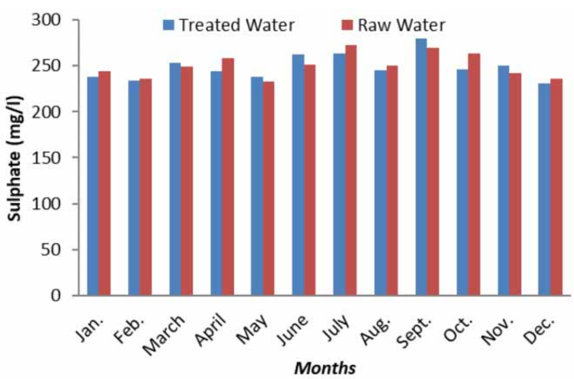

Figure 5 | Sulphates values before and after treatment.

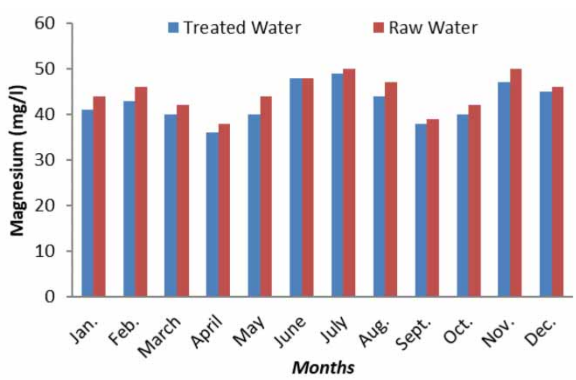

Figure 6 | Magnesium values before and after treatment.

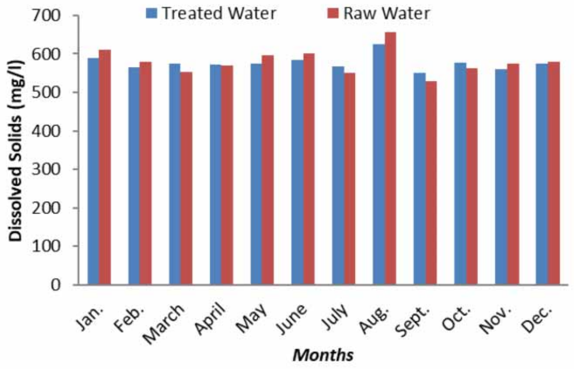

Figure 7 | Dissolved solids values before and after treatment.

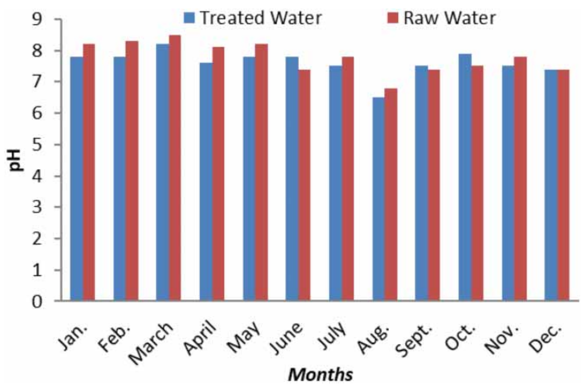

Figure 8 | pH values before and after treatment.

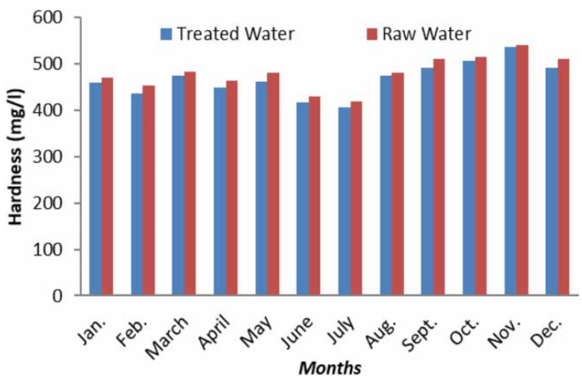

Figure 9 | Hardness values before and after treatment.

reject the null hypothesis, as the differences are insignificant. This was done for the two tests above, as shown in Table 1.

B- The magnesium follows the normal distribution according to the Kolmogorov-Smirnov test only because the value of *P*-value is greater than the level of significance (0.05), thus does not reject the null hypothesis, as the differences are not significant, as shown in Table 1.

C- The original data for the two variables hardness and dissolved solids do not follow a normal distribution, so the following has been done:

- The hardness variable data were converted to quadratic data; thus, the normal distribution was included according to the test (Shapiro-Wilk) only as it was found that *P*-Value is greater than the level of significance (0.05), thus does not reject the null hypothesis, as the differences are not significant as shown in Table 1.

Table 1 | Test of normality

Kolmogorov-Smirnov test			Shapiro-Wilk test			
Statistic	Df	Sig. (*P*-Value)	Statistic	df	Sig. (*P*-Value)	Property
0.142	12	0.21	0.910	12	0.218	Turbidity
0.187	12	0.23	0.902	12	0.176	pH
0.108	12	0.20	0.973	12	0.962	Alkalinity
0.173	12	0.22	0.852	12	0.036	Hardness
0.171	12	0.24	0.923	12	0.340	Calcium
0.209	12	0.139	0.840	12	0.032	Magnesium
0.210	12	0.187	0.915	12	0.263	Sulfates
0.289	12	0.005	0.881	12	0.094	Dissolved Solids

- The dissolved solids variable data were converted into logarithmic data. Thus it was covered by the normal distribution according to the Shapiro-Wilk test only, where it was found that the *P*-value is greater than the level of significance (0.05). Thus the null hypothesis is not rejected, as the differences are not significant, as shown in Table 1; therefore, according to the two tests above, all research variables with normal distribution were included, sometimes with both tests or one of the two tests at other times. Table 1 illustrates this.

Paired Samples T-Test was applied for the raw and treated water, and the results were following in Table 2.

Significant differences were found in the turbidity levels of raw water and treated water, where it was found that the *P*-value is smaller than 0.05, as shown in Table 2. Thus the null hypothesis was rejected. Furthermore, the turbidity removal reached 82%, i.e. the average turbidity of raw water was 16.8 NTU. In contrast, the average turbidity of the treated water was 3.9 NTU, which means the produced water meets the specifications of the WHO and Iraq for drinking water (5 NTU) (Abbawi & Hassen 1990).

Table 2 | Paired samples T-test

T	Df	Sig. (*p*-Value)	Property
8.848	11	0.002	Turbidity
0.84	11	0.406	pH
1.189	11	0.249	Alkalinity
8.619	11	0.012	Hardness
0.548	11	0.589	Calcium
2.982	11	0.011	Magnesium
0.969	11	0.349	Sulfates
2.618	11	0.035	Dissolved Solids

Non-significant differences were found for average pH values of raw water and treated water, where it was found that the *P*-value is greater than the level of significance (0.05), as shown in Table 2. The average pH of raw and treated water were 7.7 and 7.63, respectively. These values meet WHO and Iraqi limits (6.5–8.5) (Abbawi & Hassen 1990).

In Terms of alkalinity, non-significant differences for this characteristic between the average of raw and treated water where it was found that *P*-value is greater than the level of significance (0.05) as shown in Table 2 thus does not reject the null hypothesis. The removal of alkalinity reached 84%, i.e. a very good average alkalinity of raw water was noticed (130.7 mg/L). In contrast, the average alkalinity of treated water was 125.6 mg/L. These values do not meet the WHO (125–150 mg/L) and Iraqi (125–200 mg/L) requirements for drinking water (Abbawi & Hassen 1990).

Significant differences were noticed between the average hardness of raw and treated water, where the *p*-value is less than 0.05, as shown in Table 2. Thus the null hypothesis was rejected. The degree of hardness removal was 35%, i.e. the hardness level in raw water was 479 mg/L. At the same time, the average hardness of treated water was 466 mg/L. These values are less than the maximum permissible hardness level by WHO and Iraqi standards (500 mg/L) (Abbawi and Muhammad 1990; WHO 2011). The same trend was noticed in the removal of sulphate, where the average sulphate for raw water and treated water was 250 and 248 mg/L, respectively, which are less than the maximum permissible concentration (400) mg/L by WHO and Iraqi standards (Abbawi & Hassen 1990).

Finally, the results of the dissolved solids indicated significant differences between the average concentrations in raw and treated water, where the *p*-value was less than 0.05, as shown in Table 2. Thus the null hypothesis was rejected. The best removal of the dissolved solids was 9.4%, and the average concentrations of dissolved solids in raw and treated water were 580 and 578 mg/L, respectively. According to the WHO and Iraqi standards, the maximum permissible concentration of dissolved solids in treated water is 1,000 mg/L (Abbawi & Hassen 1990).

Finally, the obtained results agree with the general trends, with some differences, in other studies in the literature, such as the results of (Alobaidy *et al.* 2010).

4. CONCLUSIONS

The current study investigated the performance of the Al-Mussaib drinking water treatment plant at Babylon city, Iraq, in terms of quality of produced water and compared it with international (WHO) and national standards (Iraqi standards). The experimental and statistical analyses focused on the concentrations/levels of key parameters, including turbidity, hardness, magnesium, dissolved solids alkalinity, pH, calcium and sulphates in both raw and treated water. The baited results indicated significant differences between the water quality of raw and treated water (P-value <0.05) in terms of turbidity, hardness, magnesium and dissolved solids concentrations, but there was no significant (P-value >0.05) difference in terms of alkalinity, pH, calcium and sulphates concentrations.

Generally, although most of the measured parameters had concentrations less than the maximum permissible limits, they were higher than the favourable limits. For example, the favourable sulphate concentration in drinking water is 200 mg/L (WHO), but the measured sulphate concentration in the produced water from the studied treatment plant was 248 mg/L.

Therefore, it is recommended to enhance the performance of the Al-Mussaib drinking water treatment plant by adding pre-treatment units to remove the extra load of the unwanted pollutants or by adopting alternatives for the traditional treatment methods that are currently used in this plant.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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