

Long-term Drinking Water Quality Assessment Using Index and Multivariate Statistical Analysis for Three Water Treatment Plants of Erbil City, Iraq

Hayder Mohammed Issa¹ and Reem A. Ahmed Alrawi²

¹College of Human Sciences, University of Garmian, Kurdistan Region – F.R. Iraq

²Department of Dams and Water Resources, College of Engineering, Salahaddin University, Kurdistan Region - F.R., Iraq

*Corresponding author's email: hayder.mohammed@garmian.edu.krd

Received: 14 October 2018

Accepted: 13 December 2018

Available online: 26 December 2018

ABSTRACT

Safe source of drinking water is always considered as an essential factor in water supply for cities and urban areas. As a part of this issue, drinking water quality is monitored through a useful scheme: Developing drinking water quality index (DWQI). DWQI is preferably used as it summarizes the whole physicochemical and bacteriological properties of a drinking water sample into a single and simple term. In this study, an evaluation was made for three drinking water treatment plants (DWTPs) named: Efrac 1, Efrac 2, and Efrac 3 which supply drinking water to Erbil City. The assessment was made by testing 13 physicochemical and two bacteriological parameters during a long period of 2003–2017. It has been found that turbidity, electrical conductivity, total alkalinity, total hardness, total coliform, and fecal coliform have more influence on drinking water quality. Except for various occasional periods where the quality was varying from good to fair, DWQI results showed that the quality of drinking water supplied by the three DWTPs in Erbil City fallen within the good level. The quality of the drinking water supply never reached the level of marginal or poor over the time investigated. The applied hierarchical clustering analysis classifies the drinking water dataset into three major clusters, reflecting diverse sources of the physicochemical and bacteriological parameter: Natural, agriculture, and urban discharges.

Keywords: Physicochemical Parameters, Bacteriological Parameters, Drinking Water Quality Index, Water Treatment Plant, Erbil City

1. INTRODUCTION

Water is an important natural resource in the world, and it is the most essential element on the earth to maintain human life (Issa, 2017). Water physicochemical property is always a key factor for the assessment and evaluation of drinking water quality (Bhuiyan, *et al.*, 2011). There are numerous chemical and physical parameters that can be included within the water

quality assessment. Many guidelines have been proposed to evaluate the chemical and physical parameters of drinking water quality individually (World Health Organization, 2004).

Many attempts have been made to reduce the timescale for making decisions on the quality of drinking water and to have more general assessment processes which involve all concerned parameters. Water quality index (WQI) was developed to contain whole comparisons and evaluation procedures for a specific drinking water in one standard that represents the accurate status of the drinking water that is under investigation (Berisha and Goessler, 2013). First attempt to build such standard that called the WQI was done by Horton, 1965. Various water quality indices have been developed within a particular area which is used to evaluate different water systems: The US National Sanitation

Access this article online

DOI: 10.25079/ukhjse.v2n2y2018.pp39-48

E-ISSN: 2520-7792

Copyright © 2018 Issa and Alrawi. Open Access journal with Creative Commons Attribution Non-Commercial No Derivatives License 4.0 (CC BY-NC-ND 4.0).

Foundation WQI (NSFWQI) (Hoseinzadeh, *et al.*, 2015), Canadian Council of Ministers of the Environment WQI (Goher, *et al.*, 2014; Hurley, *et al.*, 2012; Magesh, *et al.*, 2013), British Columbia WQI (Poonam, *et al.*, 2013), and Universal WQI (Bharti and Katyal, 2011; Boyacioglu, 2007).

WQI represents a certain level of water quality while eliminating the subjective assessments of such quality, where it turns complex water quality data into information that is understandable and usable by the public (Simões, *et al.*, 2008). Water quality for drinking water is a complex subject with multiple physical and chemical parameters and their interactions. Drinking WQI (DWQI) is a mathematical and statistical method to integrate and facilitate the complex water quality collected data into a numerical illustration for the general water quality status (Wang, *et al.*, 2017). Significant progress has been done based on this principle of DWQI using slightly modified concepts (Ramesh, *et al.*, 2010). DWQIs usually have ten or more water quality of physicochemical variables. The problem is that these variables have non-continuous data, therefore developing DWQI depending on fewer input data, and that can be used to compare sites that have water quality expectations (Said, *et al.*, 2004). WQI is then used as a communication tool by environmental agencies to monitor specific water (Sadiq, *et al.*, 2010). Numerous studies have been conducted to build DWQI for various regions in the world depending on the local physicochemical quality of drinking water of those regions (Krishan, *et al.*, 2016; Oke, *et al.*, 2017; Tiwari, *et al.*, 2015; Wanda, *et al.*, 2016).

Besides WQI, diverse statistical analysis techniques were performed on water quality data also either to interpret temporal and spatial variances or to determine the significance of tested parameters. Correlation matrix (CM) analysis is applied to determine the significant interrelations between the investigated water quality parameters, where these parameters may have a low or high effect on the quality (Abhishek and Khambete, 2013). A regression equation can be easily developed with the help of statistical analysis software depending on CM analysis (Heydari, *et al.*, 2013). Multivariate statistical analysis is widely used in the analysis of water physicochemical data, and this technique is an effective tool for water quality evaluation (Aris, *et al.*, 2015; Pejman, *et al.*, 2009; Shrestha and Kazama, 2007; Tahri, *et al.*, 2005).

Drinking water in Erbil City comes mainly from three drinking water treatment plants (DWTPs), namely, respectively: Efrac 1, Efrac 2, and Efrac 3. In addition to that, groundwater wells are used in some areas of the city.

The source of raw water for the treatment of plants is the Greater Zab River. Various studies were performed to investigate the drinking water quality of Erbil City (Goran, 2010; Shareef and Muhamad, 2008). Bapeer, *et al.* (2006) studied, for the 1st time, some physicochemical variables and trace metal concentrations in treated water samples from two water treatment plants Efrac 1 and Efrac 2, and they found that water samples were fluctuated from safe and unsafe for drinking purposes. Ahmed and Ali, 2009, examined the chemical and radioactive levels of drinking water resources in Erbil City, and they concluded that no unusual concentrations were observed in the collected water samples all around the city. The seasonal variation in physicochemical properties in the Greater Zab River has been examined by Ali, 2010. He reported that dissolved and particulate trace metals in the Greater Zab River were fair and medium when compared to the adjacent Canadian and European standard for surface water quality, respectively. Kafia, *et al.* (2009) and Toma (2013) investigated various physicochemical parameters and traces of heavy metals such as Fe, Pb, Hg, Zn, Cd, Ni, and Cu, from the three water treatment plants on the Greater Zab River that provides drinking water to Erbil City, and they reached the same results of Bapeer, *et al.*, 2006. Toma (2013) has also calculated the WQI for the three water treatment plants and found that the index was between good to excellent for the period 2009–2012. The physicochemical property of the groundwater used for drinking in Erbil City was assessed by Toma, *et al.* (2013), and they found that the quality for wells at different places at Erbil City was varying between good to excellent for a time period 2004, 2005, and 2012.

The purpose of this study is developing a DWQI for Erbil City to assess the water physicochemical quality depending on a database collected over a long time period of time from 2003 to 2017 for the three water treatment plants. However, several studies as mentioned above were made about this subject, but they all were preliminary and did not cover long-term time period. This selected time period is important as there was a significant and large growth in population numbers and residential neighborhoods in the city at that time. Hence, this study can be considered as the first attempt that applied to cover this long time duration. This paper highlights also the variation in physicochemical major parameters of drinking water in Erbil City that comes from the three treatment plants to evaluate the acceptability and to give a historical determination of the treated water for drinking purposes and for other human needs within Erbil City from 2003 to 2017. Different statistical analysis methods have been applied: Analysis of variance (ANOVA), Pearson's CM, and multivariate analysis to the collected

data to determine the spatial and temporal variance of physicochemical parameters examined during the period 2003–2017. It is worth to mention that this period does not cover the water treatment plant Efrac 3 as it started to work since 2006.

2. MATERIALS AND METHODS

2.1. Study Area

Erbil City is situated at the North of Iraq and it is the capital of Erbil Province and the Kurdistan Region of a population of more than two million people. Erbil City lies at a latitude of $36^{\circ}19' N$ and longitude of $44^{\circ}00' E$ and about 380 km North of Baghdad. The climate is semi-arid continental, similar to other parts of Iraq that characterized by hot dry summer and cold wet winter more rainfall in the north (Aziz, 2011).

The Greater Zab River originates in Turkey and is partly regulated by the Bekhme Dam, and its length is 392 km from the source to the end, where it merges with the Tigris River. The Greater Zab River is the only source of surface water in Erbil City for drinking and other purposes (Shareef and Muhamad, 2008). Three water treatment plants (Efrac 1, Efrac 2, and Efrac 3) were constructed on this river at three different positions [Figure 1]. These plants are the main source for drinking water and other purposes in Erbil City (Aziz, 2009). The water treatment plants are Efrac 1

(conventional WTP) constructed in 1968 with a design capacity of $38400 \text{ m}^3/\text{day}$, Efrac 2 constructed in 1985, which supplies about $44000 \text{ m}^3/\text{day}$, and Efrac 3 constructed in 2006 with a design capacity of $144,000 \text{ m}^3/\text{day}$ (Toma, 2013). The treatment processes in these plants include four main steps: Screens, sedimentation (coagulation and flocculation), filtration, and chlorination (Goran, 2010).

2.2. DWQI Structure for Erbil City

In this study, water samples were provided by Erbil City Municipality Directorate Center for the years 2003–2017. The characteristics of water samples were analyzed in the laboratory of the Erbil City Municipality Directorate Center, where they use highly pure chemicals and double distilled water for preparing solutions for analysis. Procedures for selected groundwater constituents followed for analysis have been in accordance with the standard methods for the examination of water and wastewater (Apha, *et al.*, 1998). The validity and quality of data resulting from water sampling are dependent on many factors such as collecting representative water samples, practicing quality assurance in the field, and properly analyzing the parameters in the water samples (Tebbutt, 1997).

WQI was determined in this study on the basis of various physicochemical parameters such as pH, electrical conductivity (EC), turbidity, total alkalinity, total hardness, sulfate, chloride, nitrate, calcium, sodium, and potassium and other different parameters of water samples. The bacteriological parameters of drinking water samples were not included as all tests showed zero results of MPN of coliform, thermotolerant coliform, and MPN of *Escherichia coli* during the investigation period. Depending on the collective expert opinions taken from different previous studies on the perceived effect of each parameter on the primary health and various human uses (Srinivasamoorthy, *et al.*, 2008; Vasanthavigar, *et al.*, 2010), the relative weight assigned to each parameter was ranged from 1 to 5 according to the importance of the parameter for drinking purposes. The relative weight assigned to each parameter was ranged from 1 to 5, based on the importance of the parameter for drinking purposes. Water quality parameters were studied in respect to their suitability for human consumption. The used “standards” (permissible values of various pollutants) for the drinking water have been recommended by the World Health Organization (World Health Organization, 2004). High assigned weights were given to TDS and Cl, while Na and SO_4 have a moderate assigned weight each. Ca, Mg, and pH each have assigned weights of low-moderate each. The maximum weight of 5 has been assigned to MPN of total

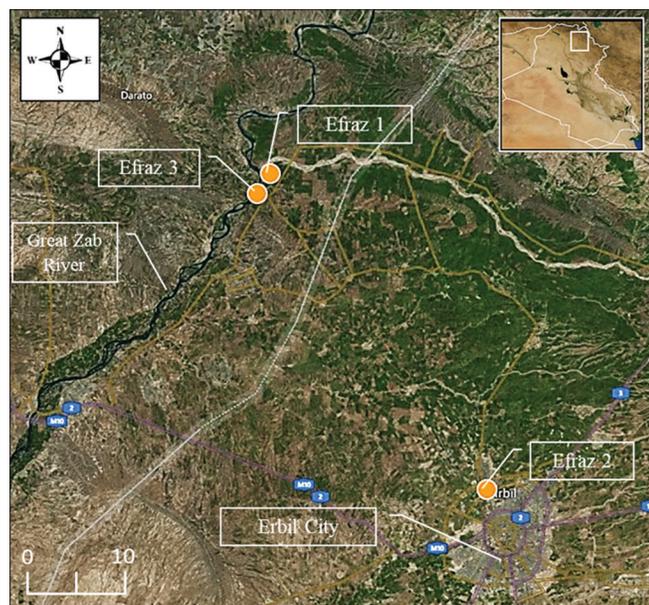


Figure 1. Locations of Erbil City, Greater Zab River, and sites of drinking water treatment plants: Efrac 1, Efrac 2, and Efrac 3

coliform and MPN of *E. coli* for their main importance in drinking water quality assessment. These two parameters are considered as key indicators of any pollution happened due to mixing with sewage or other sources that generated from anthropogenic activities. The subindices were first calculated for each parameter and then used to determine the DWQI.

DWQI, in this work, was developed according to the US NSFQI (Baghapour and Shoostarian, 2018; Gharibi, *et al.*, 2012; Sharda and Sharma, 2013; Tyagi, *et al.*, 2013). This index can be used to assess the quality of any water body and is mathematically expressed in Equation 1:

$$DWQI = \sum_{i=1}^N W_i \cdot Q_i \quad (1)$$

Where Q_i is sub-index water quality of i-parameter, W_i is relative weight of i-parameter, and N is the total number of water quality parameters (Issa, 2014). Many other ways to calculate WQI are existed for particular regions and conditions such as WQI for surface water resources or for drinking water (Poonam, *et al.*, 2013). For calculating WQI, the relative weight W_i is usually inversely proportional to the standard value $V_{standard}$ for each i-parameter (Tiwari and Mishra, 1985)

$$w_i = K[1/V_{standard}]_i \quad (2)$$

Where K is a constant and $V_{standard}$ is a water quality standard value for each parameter that adopted by the World Health Organization, 2011. The relative weight is then determined as follows.

$$W_i = w_i / \sum w_i \quad (3)$$

Where w_i is the assigned weight of each i-parameter. The rating sub-index water quality (Q_i) is calculated according to the following Equation 4:

$$Q_i = 100 \cdot [V_{actual} / V_{standard}]_i \quad (4)$$

While the sub-index water quality for pH (Q_{pH}) was calculated on the basis of the following relation.

$$Q_{pH} = 100 \cdot [V_{actual} - V_{ideal}] / [V_{standard} - V_{ideal}] \quad (5)$$

Where V_{actual} is the value of the water quality parameter obtained from the water sample, V_{ideal} is the ideal value of pH which is considered to be 7.00, and $V_{standard}$ is the value of quality parameter recommended by the WHO. Q_i equals 0 when a pollutant is totally absent in the water sample, and

Q_i equals 100 when the value reaches its maximum allowable limit (MAL). Accordingly, a higher value of Q_i represents more polluted sample (Alobaidy, *et al.*, 2010). MAL values are used in this study as per the standards established by the WHO, 2011. DWQI values are classified into five categories: Excellent water (DWQI < 50), good (DWQI 50–100), fair (DWQI 100–200), marginal (DWQI 200–300), and poor (DWQI > 300) (Abtahi, *et al.*, 2015; Monjerezi and Ngongondo 2012). $V_{standard}$ for total coliform and total fecal coliform are set to be zero in drinking water (World Health Organization, 2011). In this case, to get rid of the problem of the denominator is zero in Equation 4, Q_i value is considered to be equal to V_{actual}

2.3. Statistical Analysis

Analysis results of water samples from Erbil City water treatment plants: Efrac 1, Efrac 2, and Efrac 3, were subjected to statistical analysis methods such as ANOVA, Pearson's CM, and a multivariate analysis of agglomerative hierarchical clustering (AHC) analysis. The advantages of statistical analysis are obtaining a useful method to establish a comprehensive understanding for both the spatial and temporal differences of physicochemical and bacteriological qualities over the years 2003–2017 for the drinking water in Erbil City. ANOVA was first employed to determine the differences in the mean values of drinking water samples parameters among the three plants. Pearson CM was used to discover the strength of relationships between each two or more of the studied parameters. AHC was applied in this work to classify groundwater samples according to their temporal variation of physicochemical parameters in water samples. Ward-algorithmic linkage method and Euclidean distance are the basis to conduct statistical cluster analysis. AHC was applied in this work to classify samples according to their content variation of physicochemical parameters. Ward-algorithmic linkage method and Euclidean distance are the basis to conduct statistical cluster analysis. Cluster analysis was performed in this work using XLSTAT software (version 2014 for Excel 2013 software).

3. RESULTS AND DISCUSSION

3.1. Descriptive Statistics

The descriptive statistics for the obtained dataset of drinking water quality of 17 quality parameters from 2003 to 2017 is shown in Table 1 which includes the mean, median, standard deviation, maximum, and minimum values for each monitoring period. The mean values of the investigated parameters in drinking water samples have been arranged according to their quality rating.

Table 1. Descriptive statistics and assigned weights of physicochemical and bacteriological parameters of drinking water samples produced from the three DWTPs in Erbil City during 2003–2017

Parameters	Mean	Maximum	Minimum	Standard deviation	MAL* ($V_{standard}$)	Wt. ** (w_i)
pH (pH unit)	7.58	8.02	7.20	0.21	8.0	3.0
Electrical conductivity ($\mu\text{S}/\text{cm}$)	436.27	584.58	305.88	61.11	250	4.0
Total dissolved solid (mg/l)	246.95	374.13	152.94	51.70	500	5.0
Total alkalinity (mg/l)	174.93	220.00	145.00	17.38	100	3.0
Total hardness (mg/l)	229.88	329.00	188.06	29.73	100	2.0
Calcium (mg/l)	52.71	82.50	23.50	13.56	75	3.0
Sodium (mg/l)	9.67	47.00	3.48	9.31	50	4.0
Potassium (mg/l)	1.52	5.10	0.70	1.03	100	2.0
Magnesium (mg/l)	22.86	49.95	8.60	10.07	30	3.0
Chloride (mg/l)	11.90	19.00	2.84	3.90	250	5.0
Nitrate (mg/l)	6.10	25.08	2.25	3.80	50	4.0
Sulfate (mg/l)	71.22	157.94	8.08	36.04	250	4.0
Turbidity (NTU)	4.07	13.66	0.90	2.79	5.0	5.0
Fecal coli (MPN/100 ml)	0.34	3.43	0.00	0.81	0.0	5.0
Total coli (MPN/100 ml)	0.13	2.64	0.00	0.44	0.0	5.0

*MAL: Maximum allowable limit of drinking water as proposed by the World Health Organization; **Wt.: Assigned weights of investigated parameters, DWTPs: Drinking water treatment plants

Table 1 illustrates the mean values of physicochemical and bacteriological parameters obtained from a dataset of 4389 water samples. The samples are collected over the period of 2003–2017 from the main three DWTPs in Erbil City: Efrac 1, Efrac 2, and Efrac 3. As presented in Table 1, the mean values for some of the parameters in water samples are higher than MAL proposed by the World Health Organization (2011). EC has to mean value of 436.27 ($\mu\text{S}/\text{cm}$), and this value is higher than the MAL of 250 $\mu\text{S}/\text{cm}$. Similar condition exists for many parameters such as total hardness and total alkalinity. Their mean values are approximately the double of the MAL of 100 mg/L for each. This fact reveals the significance of these parameters on the chemistry of drinking water quality in Erbil City. Mean values of Mg in water samples are 22.86 mg/L, which is close to the MAL for Mg of 30 mg/L. Hence, this level discloses the significant role of Mg in the drop of drinking water quality. Noticeable mean values of bacteriological parameters are compared with standard MAL. The rest of the parameters display low levels in examined drinking water samples.

3.2. DWQI of Erbil City's DWTPs

The annual WQI values for DWTPs at Erbil City during the period of 2003–2017 have been calculated and presented in Figure 2. However, the annual WQI values for the three DWTPs build a clear and general vision for the physicochemical and bacteriological quality of drinking water produced from these plants in the study area during the observation time. All the annual DWQI fall in good quality of DWQI is <100. Nevertheless, it can be observed that a considerable higher DWQI value of 133 was recorded for

DWTP Efrac 1 in the year 2004. From 2003 to 2007, the annual DWQI values are significantly higher than those for the rest of the investigation period.

The effect of dryness in the area, specifically in the year 2008 (Nanekely, *et al.*, 2016), does not show an evidence that increasing of WQI value is related to rainfall decline throughout that period. The elevation of DWQI values at the duration 2003–2007, especially in the upstream plant Efrac 1, is most probably due to the direct discharge of wastewater and effluents to Greater Zab River (Bapeer, *et al.*, 2006; Shareef and Muhamad, 2008). The reason for that, at that period, environmental limits and legislation seem to be poorly applied. In general, results showed DWQI <100 in all DWTPs, with one exception, meaning that, for temporal variation, the drinking water quality was generally safe throughout the study period. The peak year of registered DWQI value was 2004 in Efrac 1. The poor performance of old DWTP Efrac 1 at that period was might be behind the clearly observed depletion of DWQI, and this seems to be overcome gradually by later maintenance works.

3.3. Analysis of DWQI Rating Sensitivity to Water Quality Parameters

To understand the importance of each parameter in establishing DWQI, the average value of the DWQI was calculated with removing one parameter each time to determine the sensitivity of the DWQI to these physicochemical and bacteriological parameters (Rickwood and Carr, 2008). Figure 3 presents the range of removing each parameter, and the highest positive weight on DWQI

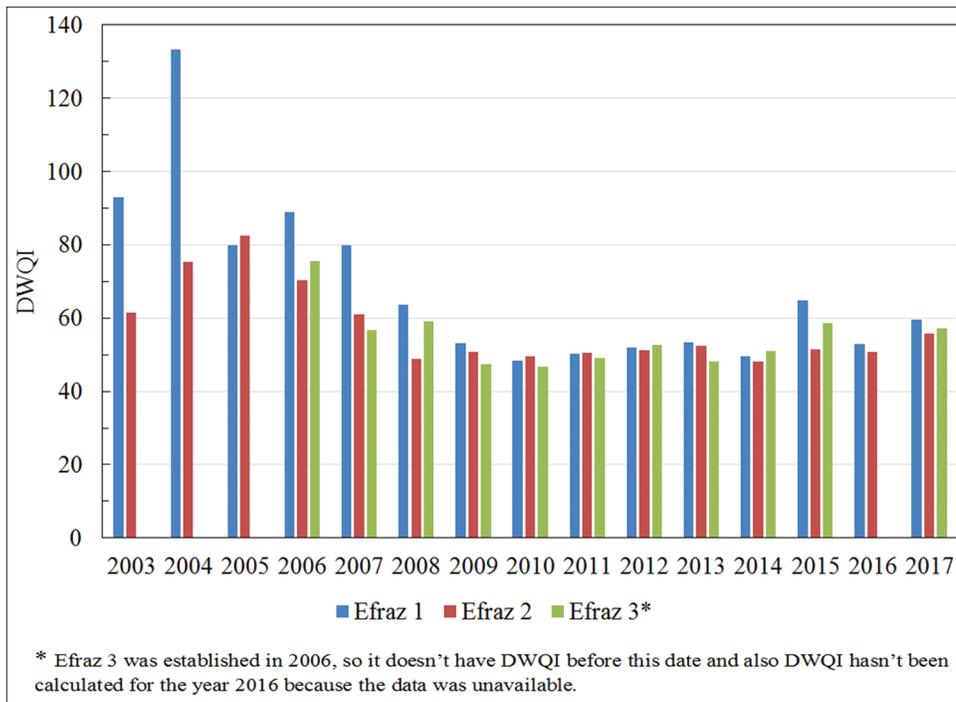


Figure 2. Annual drinking water quality index in Erbil City of treated water produced from three Water treatment plants: Efrac 1, Efrac 2, and Efrac 3 over the period (2003–2017)

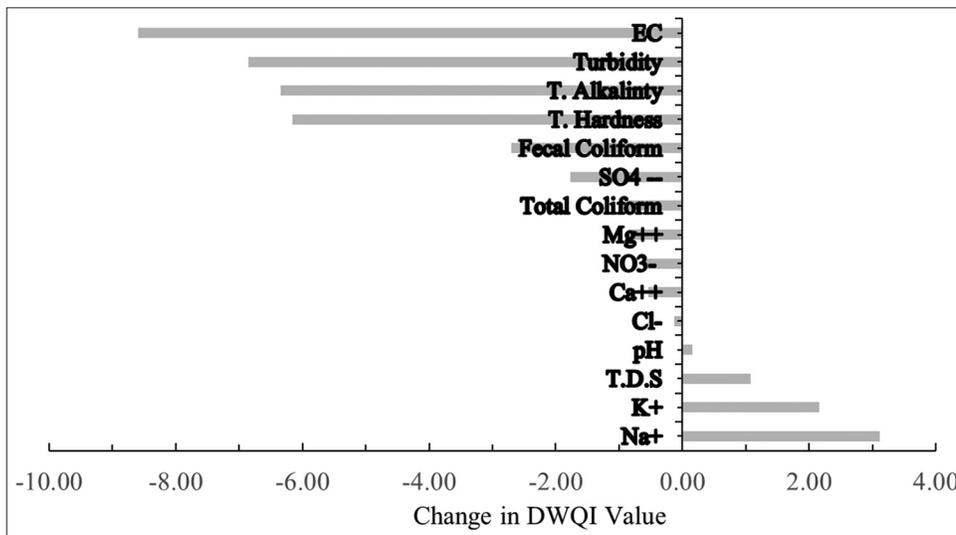


Figure 3. Changes in average drinking water quality index value caused by eliminating each water quality parameter

value was +3.11 with eliminating Na. The lowest negative weight of -8.6 was happened with eliminating EC nitrate. The reduced DWQI, when EC was eliminated, was not considerably correlated to the original DQWI ($R^2 = 0.55$), and this means that the established DWQI for the three DWTPs is strongly sensitive to the EC parameter. Nevertheless, none

of the other parameters did not show a strong effect on the DWQI value ($R^2 > 0.90$). The sensitivity analysis also showed the eliminated parameters with a positive effect on DWQI such as Na, K, TDS, and pH which are the higher compliant parameters. On the other hand, parameters with a negative effect on DWQI such as EC and turbidity mare

the higher violent parameters causing deterioration of treated water quality produced from the three DWTPs working at Erbil City.

3.4. ANOVA Analysis of DWTP-Treated Water

The ANOVA was conducted to search any significant variation among the treated water samples examined in this study for the three SWTPs: Efrac 1, Efrac 2, and Efrac 3. This ANOVA analysis was implemented for variation of average physicochemical and bacteriological parameter levels in water samples and with replications using 95% confidence level. The ANOVA results disclosed that statistically there are no significant variances among treated water samples at a confidence level of 95 % ($P > 0.05$). Efrac 3 was included in analysis starting from 2006 the year it was constructed. The resulted P -value was 0.149, F value was 1.911, and F_{crit} was 3.0157.

3.5. AHC Analysis

The hierarchical cluster analysis (HCA) can identify any similarity that may exist among clustered results regarding their locations or the physicochemical and bacteriological parameters over the time investigated of 2003–2017. This was done by showing considerable internal clusters homogeneity and significant external heterogeneity concerning clusters.

Figure 4 displays the results of the dendrogram of HCA of three generated distinct clusters. Nonetheless, the ANOVA showed no significant difference among DTWP-treated water samples. The dissimilarity of treated water samples in terms of sampling treatment sites was classified into three clusters. Groups of sample locations are Cluster 1, Cluster 2, and Cluster 3 which are corresponding to the three DWTPs: Efrac 3, Efrac 2, and Efrac 1, respectively.

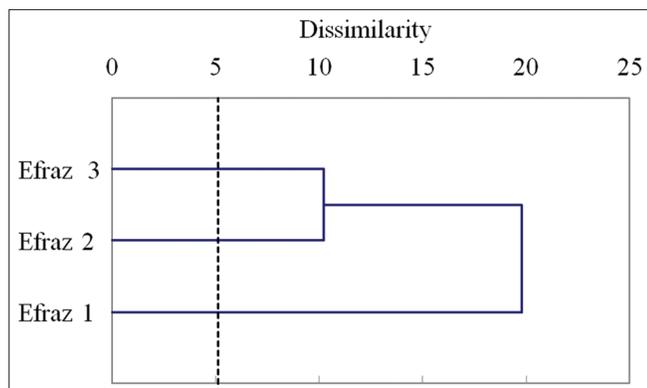


Figure 4. Dendrogram using Ward's method for treated water quality of three drinking water treatment plants in Erbil City during the period 2003–2017 (except Efrac 3 starting from 2006 as it was constructed in this year)

On this basis, it can be realized that spatial dissection of water samples appears among treatment plants regarding the investigated parameters. As the Efrac 1 defined in cluster 3 is the older water treatment plant constructed at downstream of the Greater Zab River, the sample showed higher levels of water quality parameters than from other plants, more specifically between the years 2003 and 2007. Therefore, Efrac 1 showed more dissimilarity from the two plants Efrac 2 and Efrac 3 as illustrated in Figure 3. However, the deterioration of water quality to river water quality has not shown a significant effect on plants distinction.

Figure 5 presents a hierarchical clustering analysis performed on the tested quality parameters in treated water samples. The results display three main clusters for the annual water samples. Cluster 1 includes NO_3 and Ca, cluster 2 includes K and Na, whereas cluster 3 includes the remaining of tested physicochemical and bacteriological parameters. As for cluster 3, it is reasonable to see some parameters such as turbidity with bacteriological parameters in one cluster as any increase of turbidity enriches the bacteria growth and microorganisms, leading to an increase in the total and fecal coliform bacteria. From obtained clusters, it can be identified that cluster 1 is most possibly come from soil erosion and agriculture fields at the upstream areas, while cluster 2 is most likely represents one source of soil erosion from the river basin area. However, cluster 3 shows the combined effects of industrial agricultural and urban sources. Consequently, the treated water quality parameters are dominated mainly by natural, agricultural and urban sources.

Taking into account the treatment and disinfection efficiency in the three DWTPs, the majority of treated water quality samples are suitable for drinking purposes. However, the authorities should pay more attention to control the ongoing activities at the river upstream by activating water management programs including construction of wastewater treatment systems.

4. CONCLUSIONS

Drinking water quality assessment has been performed for three DWTPs: Efrac 1, Efrac 2, and Efrac 3, which supply Erbil City with treated water over the period of 2003–2017. Thirteen physicochemical and two bacteriological were analyzed. Mostly, EC, total alkalinity, and total hardness among the tested parameters exceed the MAL according

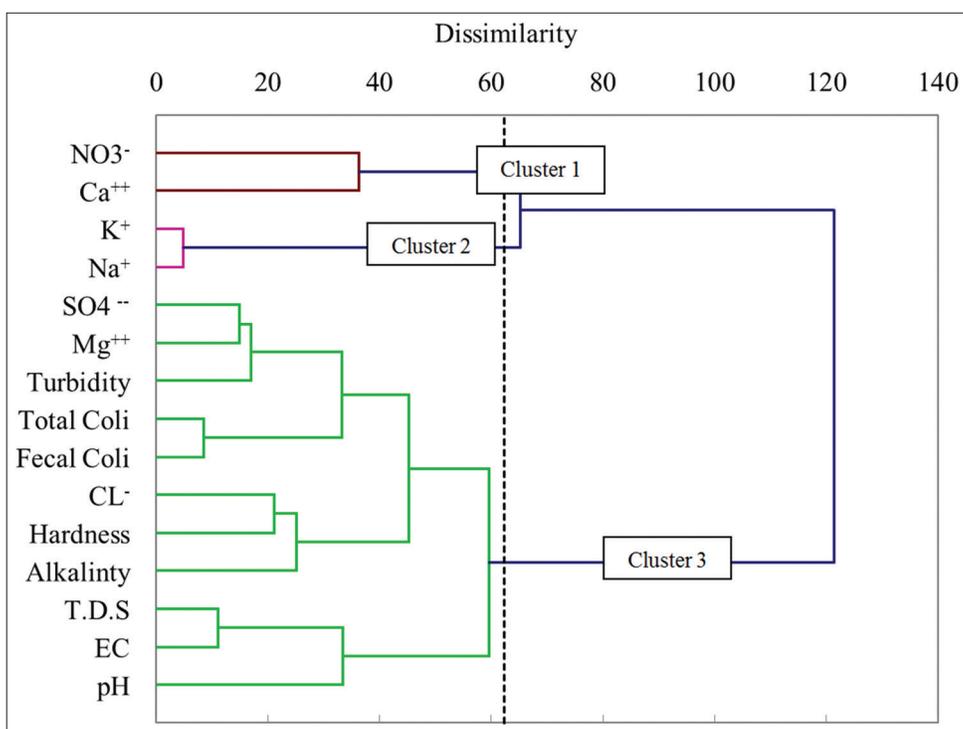


Figure 5. Dendrogram using Ward's method for physicochemical and bacteriological parameters of treated water samples from three drinking water treatment plants in Erbil City during the period 2003–2017 (except Efrac 3 starting from 2006 as it was constructed in this year)

to World Health Organization (2011) standard. DWQI was then established for the three DWTPs based on the US NSFQI to assess the drinking source water quality of Erbil City for the investigation time 2003–2017. DWQI results showed that drinking water quality falls within the excellent to good quality. A fair quality was observed in the year 2004 for the station Efrac 1. Marginal or poor quality was not found during the study period. Sensitivity analysis revealed that is strongly sensitive to EC. The multivariate statistical technique (AHC analysis) explored the similarities between examined sites and parameters in order to categorize drinking water samples into similar classes. The first HCA application has allocated each DWTP in a separate cluster. HCA application has then identified three groups among the drinking water quality parameters. The classification has recognized that sources affecting drinking water quality in Erbil City are mainly: Natural, agricultural, and rural wastewater. The study described here leads to better understanding the DWTP overall situation and the treated drinking water quality supplied by them to Erbil City. The study showed the usefulness of DWQI and hierarchical clustering analysis for evaluating and monitoring the drinking water quality.

5. ACKNOWLEDGMENTS

The authors wish to express their gratitude to the General Directorate of Water and Sewerage Quality Assurance/ Erbil City, Drinking Water Quality Control Department, Laboratory Division, for their help in providing the historical drinking water dataset.

REFERENCES

- Abhishek, S. & Khambete, A. (2013). Statistical analysis to identify the main parameters to the wastewater quality index of CETP: A case study at VAPI, Gujarat, India. *Journal of Environmental Research And Development*, 7(3), 1294-1299.
- Abtahi, M., Golchinpour, N., Yaghmaeian, K., Rafiee, M., Jahangiri-rad, M., Keyani, A. & Saeedi, R. (2015). A modified drinking water quality index (DWQI) for assessing drinking source water quality in rural communities of Khuzestan Province, Iran. *Ecological Indicators*, 53, 283-291.
- Ahmed, A. H., & Ali, D. S. (2009). Investigation of chemical and radioactive contamination level of the drinking water resources in Erbil City. *Journal of Environmental Studies*, 1, 9-18.
- Ali, L. A. (2010). Seasonal variation in physico-chemical propertice and zooplankton biomass in greater zab river-Iraq. *Jordan Journal of Biological Sciences*, 3(3), 115-120.

- Alobaidy, A. H. M. J., Abid, H. S. & Maulood, B. K. (2010). Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraq. *Journal of Water Resource and Protection*, 2(9), 792-798.
- Apha, L., Clesceri, A. & Greenberg, A. (1998). *Standard Methods for the Examination of Water and Wastewater*. 20th ed. Washington, DC: American Public Health Association.
- Aris, A. Z., Tengku-Ismail, A. E. T. H., Harun, R., Firuz-Ramli, M., Abdullah, R., Azhar, S. C. & Juahir, H. (2015). Environmental forensics 2015 classification of river water quality using multivariate analysis. *Procedia Environmental Sciences*, 30, 79-84.
- Aziz, F. H. (2011). Checklist of the algal flora survey in Iraqi Kurdistan region Iraq with particular reference to habitats. *Zanco Journal of Pure and Applied Science*, 23(3):30-72.
- Aziz, S. Q. (2009). *Treatment of Greater-Zab Water by Direct Filtration*. Paper Presented at the Thirteenth International Water Technology Conference.
- Baghapour, M. A. & Shooshtarian, M. R. (2018). Assessment of groundwater quality for drinking purposes using water quality index (WQI) in Shiraz, Iran (2011 to 2015). *Iranian Journal of Health Safety and Environment*, 5(1), 888-893.
- Bapeer, U. H., Al-Naqishabandi, L. A., Toma, J. J. & Ismail, H. A. (2006). Study some physico-chemical and bacteriological variables of both drinking water purification projects (Ifraz and Ainkawa) in Erbil, Iraq. *Zanco, Journal of Pure and Applied Sciences/Salahaddin University*, 18(3), 19-21.
- Berisha, F. & Goessler, W. (2013). Investigation of drinking water quality in Kosovo. *Journal of Environmental and Public Health*, 2013, 9.
- Bharti, N. & Katyal, D. (2011). Water quality indices used for surface water vulnerability assessment. *International Journal of Environmental Sciences*, 2(1), 154.
- Bhuiyan, M. A. H., Rakib, M. A., Dampare, S. B., Ganyaglo, S. & Suzuki, S. (2011). Surface water quality assessment in the central part of Bangladesh using multivariate analysis. *KSCE Journal of Civil Engineering*, 15(6), 995-1003.
- Boyacioglu, H. (2007). Development of a water quality index based on a European classification scheme. *Water Sa*, 33(1), 101-106.
- Gharibi, H., Sowlat, M. H., Mahvi, A. H., Mahmoudzadeh, H., Arabalibeik, H., Keshavarz, M. & Hassani, G. (2012). Development of a dairy cattle drinking water quality index (DCWQI) based on fuzzy inference systems. *Ecological Indicators*, 20, 228-237.
- Goher, M. E., Hassan, A. M., Abdel-Moniem, I. A., Fahmy, A. H. & El-sayed, S. M. (2014). Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. *The Egyptian Journal of Aquatic Research*, 40(3), 225-233.
- Goran, S. M. (2010). Evaluation of Ifraz water treatment plants in Erbil city-Iraq. *Journal of Science Education*, 23(4), 19-22.
- Heydari, M. M., Abbasi, A., Rohani, S. M. & Hosseini, S. M. A. (2013). Correlation study and regression analysis of drinking water quality in Kashan City, Iran. *Journal of Science Education*, 10(3), 10.
- Horton, R. K. (1965). An index number system for rating water quality. *Journal of Water Pollution Control Federation*, 37(3), 300-306.
- Hoseinzadeh, E., Khorsandi, H., Wei, C. & Alipour, M. (2015). Evaluation of aydughmush river water quality using the national sanitation foundation water quality index (NSFWQI), river pollution index (RPI), and forestry water quality index (FWQI). *Desalination and Water Treatment*, 54(11), 2994-3002.
- Hurley, T., Sadiq, R. & Mazumder, A. (2012). Adaptation and evaluation of the Canadian council of ministers of the environment water quality index (CCME WQI) for use as an effective tool to characterize drinking source water quality. *Water Research*, 46(11), 3544-3552.
- Issa, H. M. (2014). An initial environmental assessment for the potential risk of the developing industry impact on the surface water resources in the Kurdistan Region - Iraq. *Journal of Garmian University*, 1(Special Issue), 35-48.
- Issa, H. M. (2017). Evaluation of water quality and performance for a water treatment plant: Khanaqin city as a case study. *Journal of Garmian University*, 3(No.12 Special Issue), 802-821.
- Kafia, M. S., Slaiman, G. M. & Nazanin, M. S. (2009). Physical and chemical status of drinking water from water treatment plants on Greater Zab River. *Journal of Applied Sciences and Environmental Management*, 13(3), 144-216.
- Krishan, G., Singh, S., Kumar, C., Garg, P. & Suman, G. (2016). Assessment of groundwater quality for drinking purpose by using water quality index (WQI) in Muzaffarnagar and Shamli Districts, Uttar Pradesh, India. *Hydrol Current Research*, 7(227), 2.
- Magesh, N. S., Krishnakumar, S., Chandrasekar, N. & Soundranayagam, J. P. (2013). Groundwater quality assessment using WQI and GIS techniques, Dindigul district, Tamil Nadu, India. *Arabian Journal of Geosciences*, 6(11), 4179-4189.
- Monjerezi, M. & Ngongondo, C. (2012). Quality of groundwater resources in Chikhwawa, lower shire Valley, Malawi. *Water Quality, Exposure, and Health*, 4(1), 39-53.
- Nanekely, M., Scholz, M. & Al-Faraj, F. (2016). Strategic framework for sustainable management of drainage systems in semi-arid cities: An Iraqi case study. *Water*, 8(9), 406.
- Oke, A. O., Sangodoyin, A. Y. & Omodele, T. (2017). Classification of river water quality in Ogun and Ona River Basins, Nigeria using CCME framework: Implications for sustainable environmental management. *Cogent Environmental Science*, 3(1), 1295696.
- Pejman, A. H., Bidhendi, G. R. N., Karbassi, A. R., Mehrdadi, N. & Bidhendi, M. E. (2009). Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. *International Journal of Environmental Science and Technology*, 6(3), 467-476.
- Poonam, T., Tanushree, B. & Sukalyan, C. (2013). Water quality indices—important tools for water quality assessment: A review. *International Journal of Advances in Chemistry*, 1(1), 15-28.
- Ramesh, S., Sukumaran, N., Murrugesan, A. G. & Rajan, M. P. (2010). An innovative approach of drinking water quality index - A case study from Southern Tamil Nadu, India. *Ecological Indicators*, 10(4), 857-868.
- Rickwood, C. J. & Carr, G. M. (2008). Development and sensitivity analysis of a global drinking water quality index. *Environmental Monitoring and Assessment*, 156(1), 73.
- Sadiq, R., Haji, S. A., Cool, G. & Rodriguez, M. J. (2010). Using penalty functions to evaluate aggregation models for environmental indices. *Journal of Environmental Economics and Management*, 91(3), 706-716.
- Said, A., Stevens, K. D. & Sehlke, G. (2004). An innovative index for evaluating water quality in streams. *Environmental Management*, 34(3), 406-414.
- Sharda, A. & Sharma, M. (2013). Water quality assessment of Swan River in Himachal Pradesh, India. *International Journal of Environmental Sciences*, 4(3), 402-414.
- Shareef, K. M. & Muhamad, S. G. (2008). Natural and drinking water quality in Erbil, Kurdistan. *Current World Environment*, 3(2), 227-238.
- Shrestha, S. & Kazama, F. (2007). Assessment of surface water quality

- using multivariate statistical techniques: A case study of the Fuji river basin, Japan. *Environmental Modelling and Software*, 22(4), 464-475.
- Simões, F. D. S., Moreira, A. B., Bisinoti, M. C., Gimenez, S. M. N. & Yabe, M. J. S. (2008). Water quality index as a simple indicator of aquaculture effects on aquatic bodies. *Ecological Indicators*, 8(5), 476-484.
- Srinivasamoorthy, K., Chidambaram, S., Prasanna, M. V., Vasanthavihar, M., Peter, J. & Anandhan, P. (2008). Identification of major sources controlling groundwater chemistry from a hard rock terrain — A case study from Mettur taluk, Salem district, Tamil Nadu, India. *Journal of Earth System Science*, 117(1), 49-58.
- Tahri, M., Benyaïch, F., Bounakhla, M., Bilal, E., Gruffat, J. J., Moutte, J. & Garcia, D. (2005). Multivariate analysis of heavy metal contents in soils, sediments, and water in the region of Meknes (central Morocco). *Environmental Monitoring and Assessment*, 102(1), 405-417.
- Tebbutt, T. H. Y. (1997). *Principles of Water Quality Control*. Oxford: Butterworth-Heinemann.
- Tiwari, A. K., De Maio, M., Singh, P. K., Amanzio, G. & Lavy, M. (2015). Surface water quality assessment for the suitability of drinking and domestic purposes in West Bokaro coalfield, India. *Rendiconti Online Della Società Geologica Italiana*, 35, 13-16.
- Tiwari, T. & Mishra, M. (1985). A preliminary assignment of water quality index of major Indian rivers. *Indian Journal of Environmental Protection*, 5(4), 276-279.
- Toma, J. J. (2013). Evaluating raw and treated water quality of greater Zab river within Erbil city by index analysis. *International Journal of Emerging Technologies in Computational and Applied Sciences*, 12, 147-154.
- Toma, J. J., Assad, Z. S. & Baez, D. R. (2013). Water quality assessment of some well water in Erbil city by quality index, Kurdistan REGION-Iraq. *Journal of Advanced Laboratory Research in Biology*, 4(4), 125-130.
- Tyagi, S., Sharma, B., Singh, P. & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American Journal of Water Resources*, 1(3), 34-38.
- Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragavan, K., Rajiv Ganthi, R., Chidambaram, S., Anandhan, P. & Vasudevan, S. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environmental Monitoring and Assessment*, 171(1), 595-609.
- Wanda, E. M. M., Mamba, B. B. & Msagati, T. A. M. (2016). Determination of the water quality index ratings of water in the Mpumalanga and North West Provinces, South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, 92, 70-78.
- Wang, X., Zhang, F. & Ding, J. (2017). Evaluation of water quality based on a machine learning algorithm and water quality index for the Ebinur Lake Watershed, China. *Scientific Reports*, 7, 12858.
- World Health Organization. (2004). *Guidelines for Drinking-water Quality: Recommendations*. Vol. 1. Geneva: World Health Organization.
- World Health Organization. (2011). *Guidelines for Drinking-water Quality*. Geneva: WHO Publications.