www.czasopisma.pan.pl PAN www.journals.pan.pl

POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN), Committee on Agronomic Sciences
Section of Land Reclamation and Environmental Engineering in Agriculture
Institute of Technology and Life Sciences (ITP)

JOURNAL OF WATER AND LAND DEVELOPMENT
2020, No. 46 (VII–IX): 10–19
https://doi.org/10.24425/jwld.2020.134097

Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://journals.pan.pl/jwld

Received 06.01.2020
Reviewed 04.03.2020
Accepted 25.03.2020

Evaluation of water treatment plants quality in Basrah Province, by factor and cluster analysis

Zainb A.A. AL SAAD ✉, **Ahmed N.A. HAMDAN**

The University of Basrah, Engineering College, Civil Engineering Department, Basrah 61004, Iraq

For citation: Al Saad Z.A.A., Hamdan A.N. 2020. Evaluation of water treatment plants quality in Basrah Province, by factor and cluster analysis. Journal of Water and Land Development. No. 46 (VII–IX) p. 10–19. DOI: 10.24425/jwld.2020.134097.

Abstract

The Shatt Al Arab River (SAAR) is a major source of raw water for most water treatment plants (WTP's) located along with it in Basrah province. This study aims to determine the effects of different variables on water quality of the SAAR, using multivariate statistical analysis. Seventeen variables were measured in nine WTP's during 2017, these sites are Al Hussain (1), Awaissan (2), Al Abass (3), Al Garma (4), Mhaigran (5), Al Asmaee (6), Al Jubaila (7), Al Baradia (8), Al Lebani (9). The dataset is treated using principal component analysis (PCA) / factor analysis (FA), cluster analysis (CA) to the most important factors affecting water quality, sources of contamination and the suitability of water for drinking and irrigation. Three factors are responsible for the data structure representing 88.86% of the total variance in the dataset. CA shows three different groups of similarity between the sampling stations, in which station 5 (Mhaigran) is more contaminated than others, while station 3 (Al Abass) and 6 (Al Asmaee) are less contaminated. Electrical conductivity (*EC*) and sodium adsorption ratio (*SAR*) are plotted on Richard diagram. It is shown that the samples of water of Mhaigran are located in the class of C4-S3 of very high salinity and sodium, water samples of Al Abass station, are located in the class of C3-S1 of high salinity and low sodium, and others are located in the class of C4-S2 of high salinity and medium sodium. Generally, the results of most water quality parameters reveal that SAAR is not within the permissible levels of drinking and irrigation.

Key words: *cluster analysis (CA), factor analysis (FA), multivariate statistics, the Shatt Al Arab River, water quality, water treatment plant*

INTRODUCTION

The shortage and deterioration of water are increasing, as well as the uses of the existing water resources are increasing due to the exceeding demands in several sectors such as agriculture, domestic, hydropower generation, and industrial, etc. Therefore, the water quality evaluated in various countries has become a topic of critical research in the last years [ONGLEY 1998].

The quality of water is defined in the expression of its biological, physical, and chemical parameters. The quality is important before use for various intended purposes such as potable, recreational, agricultural and industrial water usages [SARGAONKAR, DESHPANDE 2003]. It is evaluated with the help of different parameters to indicate their pollution level. Any sample of the water will exhibit different levels of pollution concerning the various parameters tested [ABBASI 1999].

The classification and interpretations of the data are the most important steps in the evaluation of water quality. The application of multivariate statistical techniques, such as principal component analysis (PCA) and cluster analysis (CA) for the interpretation of the data offers a better understanding of water quality and the ecological status of the studied systems. As well as it allows the consistency of possible factors/sources that influence the water system and offers a precious tool for the credible management of water resources as well as quick solutions to pollution problems [MOYEL 2014].

Factor analysis (FA) is designed to find and interpret the hidden and complex relationships among data attributes. So, it is one way for investigation if a number of variables of interest y_1, y_2, y_3, … y_t, are linearly related to a smaller number of unobservable factors f_1, f_2, f_3, … f_k. This way is used to assemble the variables, the variables that have significant relations will be toppled together in the same factor. Their relations can be negative or positive. FA with PCA is utilized to identify important factors that explain most of the variance of a system. They are designed to decrease the number of variables to a small number of indices (i.e., factors) whereas attempting to preserve the relationships extant in the original data. The problems of import monitoring station identification or indicator parameter, data reduction and interpretation, and characteristics change in water quality parameters, can be approached persuading the PCA and principal factor analysis methods (PFA) [OUYANG 2005].

The purpose of cluster analysis (CA) is to identify groups or clusters of similar stations or similar parameters based on similarities within a class and dissimilarities between different classes. Hierarchical agglomerative clustering is the most popular method, that provides similarity relationships between any sample and the whole dataset, which is typically illustrated by a dendrogram. The dendrogram gives an idea of the groups and their proximity to one another, with a dramatic reduction in the dimensionality of the original data.

In the last years, some researchers have used applications of multivariate statistical techniques (FA and CA) in many environmental subjective in Iraq, such as surface water quality, groundwater quality, and wastewater.

DAWOOD *et al*. [2018], used the method of multivariate statistical analysis to assess the quality of the groundwater in Basrah province in Iraq, where 41 groundwater samples were collected and tested from selected areas in Basrah province in 2014 to assess its suitability for irrigation uses. PCA and CA were used to arranging and explicate the chemical analysis, water was categorized into three classes. The classes I and II have classified the water to be of good quality and suitable for irrigation. Whereas, the class III regards the water is unsuitable for irrigation. All samples of the groundwater in the study location falls in classes I and II; therefore, considering Doneen's chart, the groundwater in the study area tends to be suitable for irrigation.

ISSA ALRWAI [2018], were studied, an evaluation for three drinking water treatment plants (DWTPs) called, Efraz 1, Efraz 2, and Efraz 3 which supply drinking water to Erbil City (North of Iraq), the assessment was made by testing thirteen physicochemical and two bacteriological parameters during a period extended from 2003 to 2017. It has been found that turbidity, electrical conductivity, total alkalinity, total hardness, total coliform, and faecal coliform have the most influence on drinking water quality. The applied hierarchical clustering analysis classifies the drinking water dataset into three major clusters, reflecting diverse sources of the physicochemical and bacteriological parameters: natural, agriculture, and urban discharges.

DAWOOD [2017], used PCA and CA to the surface water quality data set of the SAAR (South of Iraq), for a period over four year, for five different monitoring sites through the river for seven water quality parameters. Water samples were analyzed for dissolved oxygen (DO), phosphate (PO_4), calcium (Ca), magnesium (Mg), nitrate (NO_3), chloride (Cl), and sulphate (SO_4). The results of his research were exposed to PCA and FA with three potential factors which were extracted with 98.9% of the total variance contained in the data-set, where the first factor explains the largest proportion (67.9%) of the total variance and it has positive loadings for calcium, magnesium, chloride, and sulphate, while it has negative loading for dissolved oxygen, phosphate, and nitrate. This factor is considered to be major cations and anions, factor and depends mainly on Ca, Mg, Cl and SO_4, and that is caused by several processes such as the exchange between the cations, The second factor explained 20.1% of the total variance and had high positive loadings for dissolved oxygen, phosphate, calcium, magnesium, chloride, and sulphate, while it had a negative loading for nitrate, the third factor explained 10.9% of the total variance and has negative loadings for all the studied water parameters.

ISMAIL *et al*. [2014] was used in their study the FA and CA to evaluate spatial variations and to explicate measured water quality data set in the Tigris River in Baghdad (capital of Iraq). The water quality was measured at seven WTP's, along the waterway, over the year (2011) using fourteen water quality parameters. When the factor analysis was applied, three factors were identified, which were responsible for 86.75% of the total variance of the water quality in the Tigris River. The first factor called the anthropogenic factor explained 49.83% of the total variance and the second factor called the rainfall and erosion factor that explained 24.97% of the total variance, while, the third factor called the pH factor explained 11.95% of the total variance. CA was used to classify seven stations with similar properties that distinguished three groups of stations, their results showed that water quality in the Tigris River was strongly affected by anthropogenic influences. They concluded that the methods used are important to help water resources managers to understand the complex nature of water quality issues and determine the priorities to improve water quality.

MOYEL [2014], used statistical analysis of a set of physicochemical parameters, that monthly collected from December 2012 to November 2013 at seven sampling stations distributed along with the SAAR. 17 parameters were treated using PCA and CA for the evaluation and explain water quality data set for the SAAR. The results of PCA identified four latent factors, which are responsible for the data structure explaining 78.64% of the total variance of the data set these factors were water mineralization, the seasonal effect of temperature and organic pollution, nutrients content and water visibility. CA showed four different groups of similarity between the sampling stations reflecting the different physicochemical characteristic features and natural background source types.

SHEKHA [2008], studied the variable that effects on the quality of water in Greater Zab River in Erbil province (North of Iraq), using multivariate statistical analysis (PCA/FA), CA to the most important factors affecting water quality, where seventeen variables were tested in four sites during the period that extended from May 2012 until April 2013, results of most water quality parameters revealed that the Greater Zab River was within permissible levels for drinking water consumption. This study, it focuses on the water quality of WTPs, hence there is no previous study interest to use the methods of multivariate statistical analysis in WTPs of Basrah province, except the study of MOYEL [2014], but he studied on samples taken from stations spread along SAAR, not from WTP's, as well as he didn't study the CA for the water quality parameters for raw and treated water. He concluded from his study at four extracted factors representing four different processes responsible for water quality variations in SAAR which were, water mineralization, the seasonal effect of temperature and organic pollution, nutrients content and water visibility. In this study, there is some compatibility with MOYEL [2014] studies such as the sources of pollution and salinity. This study was therefore guided by the following objectives: (1) evaluate the levels of physico-chemical parameters to determine the quality of water and sources of pollutants in SAAR by using multivariate statistical methods; (2) evaluate the performance of nine water treatment plants in Basrah in terms of their efficiency of turbidity removal; (3) evaluate their suitability for irrigation and drinking purposes according to Iraqi and world's standards of drinking [FAO 1994; IQS417ICS:13.06.20; WHO 2011].

MATERIALS AND METHODS

STUDY AREA

One of the most important rivers in Iraq is the Shatt Al Arab River (SAAR). It is formed by the meeting of the Tigris and Euphrates Rivers in Al-Qurnah district in the North of Basrah province. Basrah province is situated in the southern part of Iraq and lies between 29°50′ and 31°20′ latitudes in the North and 47°40′ and 48°30′ longitudes in the East (Fig. 1). Basrah province containing an area extending the land of about 181 km^2. The climate of Basrah is classed as a semi-arid climate which is dry and warm with summer temperatures frequently exceeding 50°C and high humidity that sometimes exceeding 90%.

Fig. 1. Basrah (Iraq) location; source: own elaboration

DATA COLLECTION

The water samples were collected two times per month from nine WTPs influent and effluent, the samples were measured directly by the lab team of the Basrah Water Directorate in the year of 2017 (Fig. 2). Seventeen water quality parameters have been chosen to evaluate the water quality for nine WTPs based on both the availability of data and the importance of the parameters. The seventeen parameters were pH, alkalinity (Alk.), turbidity (Turb.), total dissolved solids (*TDS*), total hardness (*TH*), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), sulphate (SO_4^{2-}), aluminum (Al^{3+}), potassium (K^{+}), sodium (Na^{+}), total suspended solids (*TSS*), temperature (Temp.), electrical conductivity (*EC*), as well as calculating the following (Na%) and sodium adsorption ratio (*SAR*) according to the Equations (1) and (2):

$$Na\% = \frac{100\,Na}{(\mathrm{Na+K+Mg+Ca})} \quad (1)$$

$$SAR = \frac{\sqrt{\mathrm{Ca+Mg}}}{2} \quad (2)$$

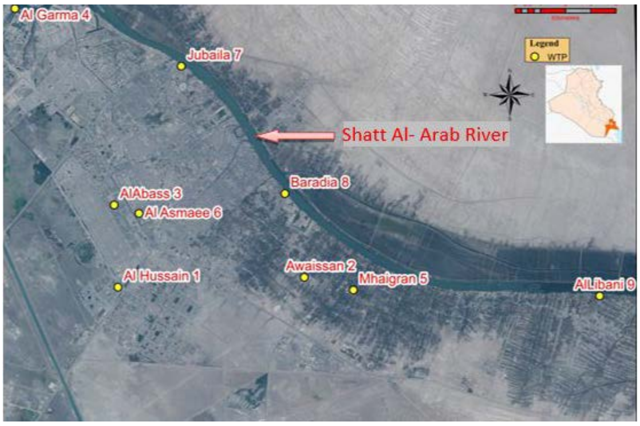

Fig. 2. Water treatment plants locations in the area under study; source: own elaboration

The determination of the *SAR* value can be used to characterize the problems caused by sodium [RUMP 1999]. HANNA and SHEKHA [2015] and SHEKHA [2013] have reviewed that high *SAR* is attributed to a considerable load of cations from untreated sewage from nearby regions.

MULTIVARIATE STATISTICAL METHODS

All mathematical and statistical computation was made using Microsoft Office Excel 2010 and SPSS 24.

Principal component analysis/ Factor analysis

Principal component analysis is designed to convert the original variables into new, not connected variables, called the principal components, which are linear assemblages of the original variables. The new axes lie along with the directions of maximum variance. Principal component analysis provides an objective way of finding indices of this type so that the variation in the data can be accounted for as concisely as possible [SÂRBU *et al.* 2005]. PCA provides data on the most meaningful parameters, which depict a whole data set that gives data reduction with minimum wastage of original information [HELENA *et al*. 2000]. This technique is utilized to assemblage the variables. The variables that have strong relations will be pieced together in the same factor. Their relationships can be positive or negative. There are no relations or weak between variables in disagreed factors. The computation steps are shown as follows, the first step is to compute the KMO (Kaiser–Meger–Olkin) Equation (3) as shown below to calculate the degree of relationships amongst parameters.

$$KMO = \frac{\sum ri^2}{\sum ri^2 + \sum(\text{partial correlation})^2} \quad (3)$$

Where r_i = the correlation matrix.

If KMO is greater than 0.5 then the factor analysis technique can be used, the second step is to analyze the factors using principal component analysis method, wherein this step factor loading (I_{ij}) will be getting, consider the absolute value of the factor loading (I_{ij}) when a variable has the factor loading value close to 1 then this variable is strong relation with that factor, while the variable that has factor loading value between 0.4 and 0.6 then the factor rotation technique will be used, herein orthogonal rotation will be applied using Varimax method, and in the last step (step 4), consider the value of I_{ij} that got from step 2–3, multi factors will be formed. The factor loading was classified as per [LIU *et al*. 2003] and LIU *et al*. [2011] who categorized the factor loading values of 0.4–0.5 as “weak”, 0.5–0.75 as “moderate” and >0.75 as “strong”.

Cluster analysis

Cluster analysis is a set of multivariate techniques; the main purpose of cluster analysis is to gather objects based on the characteristics they possess [SHRESTHA, KAZAMA 2007]. The Euclidean distance normally gives the sameness between two samples and a distance can be performed by the variance between analytical values from the samples [OUYANG *et al*. 2006]. In this study, hierarchical agglomerative cluster analysis was performed on the normalized data set using Ward’s method, utilizing squared Euclidean distances as a measure of the sameness [PEJMAN *et al*. 2009]. Cluster analysis can be utilized as a strong tool for analysing data set of water quality to explain the relationship between sites and variables [YANG *et al*. 2009].

Analysis of variance (ANOVA)

ANOVA was used to finding whether sets of variables have the same means of data that are normally or continuously distributed and with homogenous variance.

Correlation analysis

Pearson correlations were used to analyse the relationship between the physicochemical characteristics of the water.

RESULTS AND DISCUSSION

PHYSICOCHEMICAL PARAMETERS

The statistical results of physicochemical parameters for raw water of the nine stations are shown in Table 1. The results showed that the average values of Na^+, TDS, Cl^-, Ca^{2+}, *TH*, Alk., and *EC* were not within the standards limit of WHO and IQS that have shown in Table 2 except station 3, Turb. values were out of limits of standards except stations 3 and 6, SO_4^{2-} and Mg^{2+} were out the limits of standards for all stations, K^+ was within the standards for all stations except stations 2 and 5, and pH values were within the standard limits for all stations.

Table 1. Statistics parameters of the Shatt Al Arab River of raw water represented as a minimum and maximum with mean standard deviation values

Parameter	Value for station								
	Al Hussain (1)	Awaissan (2)	Al Abass (3)	Al Garma (4)	Mhaigran (5)	Al Asmaee (6)	Al Jubaila (7)	Al Baradia (8)	Al Lebani (9)
1	2	3	4	5	6	7	8	9	10
Al^{3+} (mg·dm^{-3})	0–0 0±0	0–0 0±0	0–0 0±0	0–0 0±0	0–0 0±0	0–0 0±0	0–0 0±0	0–0 0±0	0–0 0±0
K^+ (mg·dm^{-3})	5.8–13.5 10.9±2.3	10.0–15.1 12.1±1.7	3.7–5.6 4.4±0.5	6.6–13.3 10.2±2.1	11.6–18.8 14.1±1.9	4.6–8.7 6.9±1.2	9.0–13.0 11.1±1.3	9.3–16.3 11.5±2.2	6.4–15.6 10.6±2.9
Na^+ (mg·dm^{-3})	263.0–1059 658.7±257.4	503.0–1059 727.7±204.7	67.0–111.3 85.6±13.3	299.7–969.25 624.2±228.2	621.0–1142.8 919.6±165.8	149.7–458.0 320.2±102.9	419.5–1088.5 668.8±212.6	477.0–1036.7 684.4±218.4	431.5–1040.0 624.1±214.1
Na%	58.4–73.3 67.5±4.8	64.8–74.2 69.3±3.5	33.5–47.1 37.6±3.9	60.1–72.7 67.4±4.2	67.0–73.7 70.5±2.2	51.8–65.2 59.6±5.3	62.5–74.1 68.1±3.6	64.1–73.9 68.6±3.3	64.5–73.3 67.8±2.7
SAR (meq·dm^{-3})	6.7–9.7 8.4±0.9	8.1–9.5 8.6±0.5	5.0–6.3 5.8±0.4	6.9–9.4 8.3±0.8	8.6–10.7 9.6±0.6	5.8–7.7 7.1±0.6	7.8–9.6 8.5±0.6	7.7–9.6 8.5±0.7	7.5–9.8 8.3±0.82
TSS (mg·dm^{-3})	77.3–107.2 90.2±10.8	64.0.0–118.0 93.9±16.7	19.0–120.0 50.9±33.5	78.0–122.0 94.0±13.6	51.3–111.5 88.6±17.2	33.3–110.0 72.8±21.0	76.0–124.0 93.9±14.6	72.0–116.0 91.6±13.2	80.0–107.0 93.1±8.97
TDS (mg·dm^{-3})	1364.0–4191.0 2817.2±918.8	2297.0–4086.0 3015.5±659.6	598.0–871.3 731.4±99.7	1480.7–3831.5 2664.7±783.8	3133.0–4718.0 3812.9±522.8	869.3–2070.7 1578±373.9	2002.0–4214.0 2828.6±711.3	2190.0–4066.7 2864.9±731.9	1964.0–4010.0 2648.4±764.1
SO_4^{2-} (mg·dm^{-3})	403.7–1001.5 719.0±191.2	617.5–955.0 761.2±117.3	150.0–325.0 260.6±59.9	422.3–928.7 691.3±165.7	717.8–1269.0 969.5±159.9	254.3–564.7 452.6±97.5	581.0–987.0 730.4±140.6	572.0–984.7 733.7±146.2	532.0–972.0 683.4±154.7
Cl^- (mg·dm^{-3})	387.3–1592.0 994.3±385.7	760.0–1595.7 1095.7±303.8	130.0–192.7 161.3±18.3	449.7–1450.0 939.6±340.6	941.0–1701.3 1376.1±241.0	242.7–691.0 503.5±148.3	625.0–1632.0 1005.9±316.7	719.5–1555.0 1033.5±325.3	654.0–1565.0 941.4±327.9
Mg^{2+} (mg·dm^{-3})	67.3–138.0 106.1±23.6	97.0–133.0 110.8±12.8	37.0–57.7 50.1±6.9	68.3–130.8 102.3±20.9	108.8–170.0 136.6±17.8	49.7–86.0 73.6±11.5	88.5–136.5 107.4±15.9	88.0–136.0 108.2±16.7	82.5–144.0 102.1±21.0
Ca^{2+} (mg·dm^{-3})	114.0–235.5 181.4±37.9	163.0–226.0 189.1±22.8	64.0–101.0 87.4±11.9	123.7–220.8 174.3±31.8	185.3–291.8 230.9±30.6	85.0–150.3 127.2±20.9	153.5–232.0 182.7±26.6	150.7–232.0 182.4±28.7	141.5–238.0 174.6±35.2
TH (mg·dm^{-3})	560.0–1156.0 888.2±191.7	804.0–1112.0 926.9±109.6	312.0–488.0 423.4±57.3	589.3–1088.0 855.2±164.7	908.0–1426.0 1137.4±149.3	416.0–725.3 619.8±99.2	748.0–1140.5 896.9±131.6	736.7–1138.7 899.3±140.2	692.0–1184.0 854.8±173.5

continue Tab. 1

1	2	3	4	5	6	7	8	9	10
Alkalinity (mg·dm^{-3})	151.3–182.0 165.4±9.4	147.3–181.3 166.2±10.8	96.0–120.0 108.6±9.6	152.0–184.0 164.7±11.0	160.0–198.0 183.6±11.6	116.0–154.7 130.5±11.9	160.0–177.0 167.5±5.9	149.3–170.7 162.2±7.3	146.5–181.0 164.3±12.7
EC (µS·cm^{-1})	2214.3–6600.5 4450.5±1400.0	3693.5–6496.0 4819.6±1000.0	980.0–1434.3 1201.5±159.1	2389.0–6107.8 4266.9±1200.0	4311.0–7406.5 5975.4±902.3	1416.0–3319.0 2580.1±593	3231.0–6680.5 4513.0±1100.0	3510.5–6463.0 4572.9±1200.0	3170.0–6379.0 4242.3±1200.0
pH	7.3–7.8 7.5±0.1	7.4–7.8 7.5±0.14	7.7–8.0 7.9±0.1	7.4–7.9 7.5±0.16	7.3–7.6 7.4±0.11	7.5–7.8 7.6±0.12	7.3–7.8 7.5±0.13	7.4–7.9 7.5±0.15	7.4–7.8 7.6±0.12
Turbidity (NTU)	9.5–24.6 14.7±4.2	6.9–21.4 14.3±4.7	2.2–21.4 7.6±6.8	8.5–17.9 13.6±2.8	6.7–22.7 13.6±4.4	3.5–14.5 9.6±3.8	8.4–19.9 14.3±3.1	10.4–16.1 13.2±2.2	9.3–33.1 16.6±7.3
Temperature (°C)	23.5–28.8 25.5±1.8	23.5–30.7 25.8±2.3	22.8–30.0 25.8±2.2	22.6–30.7 25.7±2.5	21.8–28.6 25.4±1.8	22.9–30.0 25.6±2.3	23.5–30.0 25.5±1.9	23.7–28.9 25.6±1.65	22.6–30.1 25.3±2.2

Explanations: *SAR* = sodium adsorption ratio, *TDS* = total dissolved solids, *TSS* = total suspended solids, *TH* = total hardness, *EC* = electrical conductivity; values with ± mean standard deviation.
Source: own study.

Table 2. Guidelines used for water quality computations

Water quality parameters	Measurement unit	Standard value	
		IQS [2001]	WHO [2011]
pH	–	6.5–8.5	7–8.5
Turbidity (Turb.)	NTU	10	10
Total dissolved solids (*TDS*)	mg·dm^{-3}	1000	1000
Electrical conductivity (*EC*)	µS·cm^{-1}	1000	1000
Alkalinity (Alk.)	mg·dm^{-3}	120	120
Total hardness (*TH*)	mg·dm^{-3}	500	300
Chlorides (Cl^-) ()	mg·dm^{-3}	250	250
Sulphate (SO_4^{2-})	mg·dm^{-3}	400	250
Calcium (Ca^{2+})	mg·dm^{-3}	125	200
Magnesium (Mg^{2+})	mg·dm^{-3}	50	50
Sodium (Na^+)	mg·dm^{-3}	200	200
Potassium (K^+)	mg·dm^{-3}	12	12

Source: own study.

The statistical results of physicochemical parameters for treating water of the nine stations are shown in Table 3. It shows that the average values of Turb., were within the standard limits of WHO and IQS for all stations and the average values of pH for testing samples were within the standard limit of WHO and IQS, whereas the average value of SO_4^{2-}, Mg^{2+}, *EC*, and *TH* are not within standard limits of WHO and IQS. Na^+, *TDS*, Cl^-, and Alk. were out of the limit of standards except station 3. People who drink from these WTP's are exposed to health hazards due to polluted and high salinity water, hence, effective measures are needed to enhance the drinking water quality by circumscribing an effective management plan for water quality and inboard a new technology for water treatment such as reverse osmosis technique (RO).

Table 3. Statistics parameters of the Shatt Al Arab River of treated water represented as minimum and maximum with mean standard deviation values

Parameter	Value for station								
	Al Hussain (1)	Awaissan (2)	Al Abass (3)	Al Garma (4)	Mhaigran (5)	Al Aasmaee (6)	Al Jubaila (7)	Al Baradia (8)	Al Lebani (9)
Al^{3+} (mg·dm^{-3})	0.04–0.11 0.06±0.02	0.04–0.06 0.04±0.006	0.06–0.14 0.08±0.02	0.05–0.07 0.06±0.006	0.06–0.14 0.09±0.02	0.02–0.028 0.021±0.003	0.04–0.08 0.06±0.01	0.03–0.07 0.05±0.013	0.04–0.14 0.08±0.03
K^+ (mg·dm^{-3})	5.5–13.8 10.8±2.4	9.7–14.9 11.9±1.7	3.6–5.0 4.2±0.5	6.4–13.4 10.2±2.1	10.8–18.5 13.7±1.9	4.4–8.5 6.8±1.3	9.0–12.8 10.7±1.2	9.7–15.9 11.5±2.1	6.6–15.0 10.4±2.8
Na^+ (mg·dm^{-3})	253.3–1073.0 654.9±257.8	492.5–1053.5 722.9±206.7	65.0–108.3 83.7±13.6	295.0–979.0 623.7±227.0	611.8–1129.0 906.7±169.0	145.7–454.0 318.3±104.1	410.5–1085.0 641.4±190.0	449.0–1035.3 674.0±225.9	424.0–981.0 616.8±201.9
Na%	57.7–73.4 67.4±4.9	64.7–74.1 69.2±3.5	32.9–46.7 37.3±4.0	59.7–72.8 67.3±4.3	66.8–73.6 70.4±2.2	51.7–65.1 59.4±5.3	62.3–74.1 67.9±3.4	64.4–73.9 68.4±3.4	64.6–72.1 67.6±2.5
SAR meq·dm^{-3l})	6.7–9.7 8.4±0.9	8.0–9.5 8.6±0.5	5.0–6.3 5.8±0.4	6.9–9.4 8.3±0.8	8.6–10.7 9.5±0.6	5.7–7.7 7.1±0.6	7.7–9.6 8.4±0.6	7.5–9.6 8.5±0.7	7.5–9.8 8.3±0.81
TSS (mg·dm^{-3})	24.0–68.0 45.8±10.4	42.0–98.0 51.8±15.6	9.0–44.0 19.0±10.0	21.0–50.7 43.1±9.9	8.0–30.7 20.2±6.3	28.0–76.7 45.6±12.5	26.7–50.0 41.4±8.9	12.0–50.0 33.0±15.2	12.0–36.0 19.5±7.7
TDS (mg·dm^{-3})	1321.3–4221.0 2807.6±923.7	2274.0–4079.0 3006.8±667.4	594.0–860.0 720.4±100.2	1472.7–3860.5 2663.7±784.7	2694.0–4661.5 3732±596.1	860.0–2064.0 1576.7±380.7	1968.0–4195.0 2738.9±635.8	2004.0–4068.7 2827.7±763.1	1945.0–4024.0 2637.4±731.7
SO_4^{2-} (mg·dm^{-3})	399.0–1003.5 716.6±189.8	617.5–960.0 758.1±119.2	148.0–330.0 257.4±60.6	424.3–933.8 691.5±162.4	718.3–1254.8 958.4±156.0	248.3–563.0 452.0±101.3	574.0–981.5 708.8±129.1	525.5–980.3 729.2±152.4	530.5–970.0 683.2±152.5
Cl^- (mg·dm^{-3})	377.3–1616.5 992.6±386.9	750.0–1593.0 1091.5±307.2	128.0–188.7 159.0±18.3	447.0–1458.8 938.6±337.9	929.0–1681.3 1359.6±246.3	240.0–686.7 502.9±150.0	616.0–1630.0 968.0±282.8	673.0–1553.3 1016.1±338.0	646.0–1513.0 932.1±309.7
Mg^{2+} (mg·dm^{-3})	67.3–138.0 106.1±23.3	96.5–133.0 110.3±13.0	37.0–59.0 50.3±7.2	68.0–131.8 102.6±20.4	108.0–169.3 135.2±17.5	48.3–86.0 73.5±12.2	89.0–135.5 104.9±14.1	82.5–136.3 107.0±17.8	83.3–144.0 102.3±20.7
Ca^{2+} (mg·dm^{-3})	113.0–237.0 181.0±38.0	161.5–230.0 188.8±23.8	64.0–99.0 86.1±11.6	124.3–221.5 174.3±31.4	184.8–285.3 228.4±29.2	83.3–149.3 127.2±21.5	150.5–232.0 178.5±24.8	141.5–232.0 181.4±30.1	140.5–238.0 174.8±35.1
TH (mg·dm^{-3})	557.3–1160.0 886.6±191.0	800.0–1120.0 924.4±112.5	312.0–488.0 421.2±58.0	589.3–1094.0 855.9±162.0	904.0–1408.0 1125.3±145.2	408.0–725.3 619.9±103.8	740.0–1136.0 876.1±120.1	692.0–1133.3 891.9±147.9	696.0–1184.0 856.0±171.9
Alkalinity (mg·dm^{-3}	148.0–176.0 160.1±9.3	140.7–174.7 161.4±11.2	91.3–116.0 104.3±9.9	145.0–180.0 160.6±10.9	158.6–185.0 175.5±8.7	114.7–151.3 127.6±12.1	140.0–174.0 159.3±9.5	142.0–169.3 158.4±9.4	143.5–176.0 160.4±11.3
EC (µS·cm^{-1})	2175.3–6647.0 4444.3±1400.0	3664.0–6492.5 4805.0±1000.0	973.0–1414.3 1189.1±154.2	2390.0–6152.0 4266.6±1200.0	4320.3–7343.3 5917.3±902.7	1401.3–3309.3 2583.7±607.8	3200.5–6632.0 4380.0±991.3	3240.5–6477.7 4568.7±1200.0	3145.5–6384.0 4223.8±1136.8
pH	7.2–7.5 7.4±0.07	7.1–7.6 7.3±0.1	7.5–7.9 7.7±0.12	7.1–7.7 7.4±0.2	7.0–7.3 7.1±0.09	7.4–7.7 7.5±0.09	7.1–7.6 7.3±0.11	7.2–7.4 7.3±0.08	7.2–7.8 7.4±0.16
Turbidity (NTU)	3.7–7.7 5.0±1.0	4.2–19.9 6.2±4.5	1.7–5.0 2.6±1.0	3.3–6.6 4.8±0.8	1.2–4.1 2.5±0.8	3.0–11.1 5.2±2.1	3.0–5.0 4.5±0.8	1.7–5.0 3.7±1.3	1.8–3.8 2.6±0.7
Temperature (°C)	23.9–28.9 25.6±1.7	23.6–31.0 25.9±2.4	22.8–30.0 25.7±2.3	21.9–30.7 25.7±2.8	21.9–28.9 25.4±1.8	22.9–30.1 25.7±2.3	23.0–29.9 25.5±1.8	23.1–28.3 25.7±1.6	22.6–30.3 25.4±2.2

Explanations as in Tab. 1. Source: own study.

CORRELATION ANALYSIS

Correlation analysis of water quality parameters shows that pH has a significant correlation ($P \leq 0.01$) with *TSS* and negative correlation with TDS, SO_4^{2-}, *SAR*, Na%, Al^{3+}, Ca^{2+}, Na^+, Mg^{2+}, K^+ and *EC*, has a significant correlation ($P \leq 0.01$) with *TH*, Na^+, K^+, Ca^{2+}, Mg^{2+}, and SO_4^{2-}. This represents the main constituents of water conductance.

Total hardness (*TH*) has a highly significant correlation with Ca^{2+}, Mg^{2+}, and SO_4^{2-}, for example, see Figure 3a and b, which related to temporary hardness in water. Na^+ has a highly significant correlation ($P \leq 0.01$) with K^+, Ca^{2+}, Cl^-, Na%, *SAR* and SO_4^{2-}, for example, see Figure 3c and d. K^+ has a highly significant correlation ($P \leq 0.01$) with *SAR*, Na^+, Na%, SO_4^{2-}, Ca^{2+} and weak significant correlation with *TSS* and Turb. On the other hand, Ca^{2+} has a significant correlation with SO_4^{2-}. Also, Cl^- has a highly significant correlation to Na% and *SAR*.

SAR is an index of the potential of water to induce sodic soil conditions and is calculated for Na^+, Ca^{2+} and Mg^{2+} concentrations in the water. *SAR* values of SAAR were ranging from 5.8 to 9.5 meq·dm^{-3}, hence higher *SAR* values were recorded in Mhaigran (station 5) which may be caused by domestic effluent that discharged to SAAR or due to effect of salinity intrusion from the Arabian Gulf. Most values of *SAR* and *EC* of the nine stations were projected in the salinity laboratory diagram of irrigation water (USSL diagram) it located in C4-S2 zone that considered as very high salinity and medium sodium type, except Al-abbas (3) and Mhaigran (5) which were located in C3-S1 and C4-S3 respectively as shown in Figure 4, hence Al Abass (3) is considered high salinity with low sodium type, and Mhaigran 5 is considered very high salinity and high sodium type.

EVALUATING THE PERFORMANCE OF WATER TREATMENT PLANTS (WTP)

The performance of WTPs in Basrah province was evaluated based on the collected data regarding the quality parameters of raw and treated water (Tab. 1 and 2). Since the major function of the treatment units in all WTPs of Basrah province is turbidity removal, then, the performance of WTPs (plant efficiency) is defined in terms of percent of turbidity removal. This percent was determined using Equation 4. The obtained values of WTP's efficiency are as given in Table 4.

$$\%\ \text{of turbidity removal} = \frac{Turb.r - Turb.t}{turb.r} 100 \qquad (4)$$

Where: *Turb.r* = turbidity of raw water, *Turb.t* = turbidity of treated water.

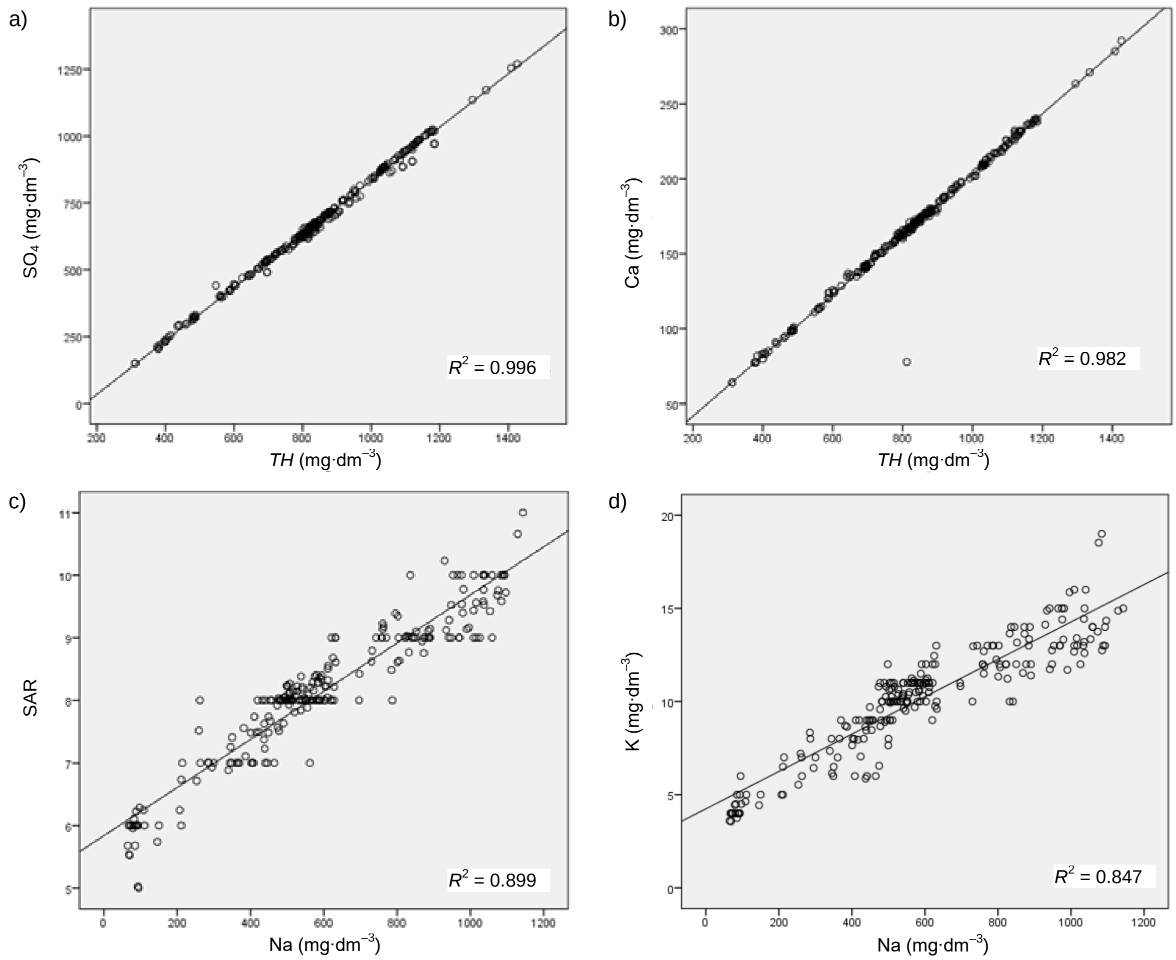

Fig. 3. The relationship between variables in the nine stations; a) *TH* vs. SO_4^{2-}, b) *TH* vs. Ca^{2+}, c) Na^+ vs. *SAR*, d) Na^+ vs. K^+; *TH* = total hardness, *SAR* = sodium adsorption ratio, R^2 = correlation coefficient; source: own study

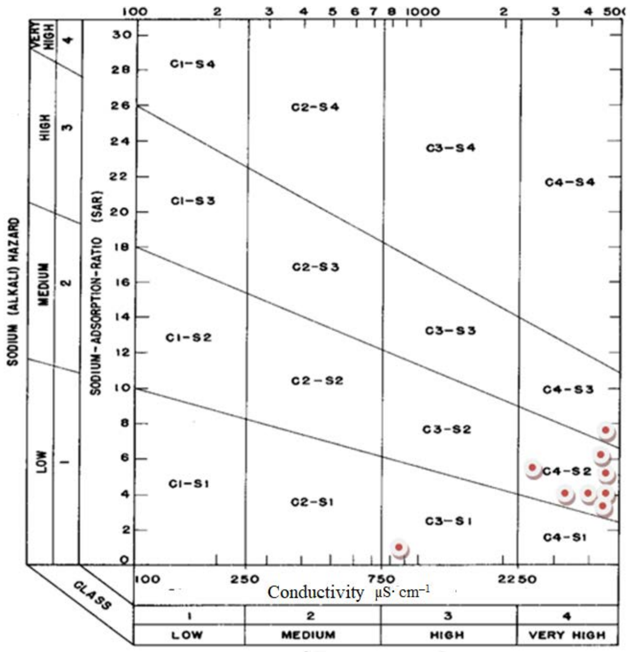

Fig. 4. Classification of water for irrigation; the mean values of the chemical data denoted as circles for water sampling sites; source: own study

Table 4. Efficiencies of wastewater treatment plants (WTP) of Basrah

WTP	Plant efficiency (%)
Al Hussain (1)	66
Awaissan (2)	56
Al Abass (3)	66
Al Garma (4)	65
Mhaigran(5)	82
Al Asmaee (6)	46
Al Jubaila (7)	68
Al Baradia (8)	72
Al Lebani (9)	84

Source: own study.

From Table 4, it can be noticed that the efficiencies of WTPs in Basrah province vary from 46 to 84 %. The low values of WTPs efficiency (percent of turbidity removal) can be referred to:

– the low dosage of applied alum;
– do not check the reasonable quantity of alum by using the jar test;
– high-velocity gradient in flocculation units;
– low detention time of sedimentation tanks due to hydraulic overload and lake of maintenance;
– high filtration rate.

FACTOR ANALYSIS (FA)

All data for the 17 physicochemical parameters collected during 2017 utilized as variable inputs for PCA/FA, preceded to analysis the data were standardized to produce a normal distribution of all variables since all the parameters of water quality had different scales of measurements and magnitudes. The factor loading was classified as values of >0.75 as "strong", of 0.5–0.75 as "moderate" and of 0.4–0.5 as "weak".

The factor loadings calculated from this data group are shown in Table 5. Table 5, can arrange variables into three-factor with eigenvalues >1 were extracted that account for more than 88.855% of the total variance in the data group. The first factor accounts for 66.698% of the total variance and contains *EC*, *TDS*, SO_4^{2-}, *TH*, Mg^{2+}, *SAR*, Na^+, Cl^-, Ca^{2+}, K^+, Na% and Alk. all with strong positive loading. This indicated temporary hardness ions. Also, it contains hydrochemical variables originating from the weathering process and an agricultural source of SO_4 in surrounding farmlands are possible. The Na^+, Na%, and *SAR* this salinity type represented influences from mineral salts and domestic wastes. The second factor explains 15.901% of the total variance is strong positive loading with *TSS* and Turb., and strong negative loading with Al. This indicated the strong relation between Turb. and *TSS* and the negative effect of alum on suspended solids. The third factor explains 6.257% of total variance with strong positive loading for temperature, and weak positive loading for pH. This indicated the effect of the temperature of the water on pH. Hence, as an abridgment, three factors were extracted and about 89% of the total variance was explained, and from the analysed results it can be shown that PCA/FA can be used as an important method to find out the main factor affecting water quality.

Table 5. Percentage of variance and eigenvalue of the three-factor loading values for water quality variables (parameters)

Specification	Factor-1	Factor-2	Factor-3
Eigenvalue	11.339	2.703	1.064
% total variance explained	66.698	15.901	6.257
% cumulative variance	66.698	82.598	88.855
Rotated factor correlation coefficients			
EC	0.993		
TDS	0.992		
SO_4^{2-}	0.988		
TH	0.987		
Mg^{2+}	0.986		
SAR	0.985		
Na^+	0.985		
Cl^-	0.983		
Ca^{+2}	0.981		
K^+	0.944		
Na%	0.871		
Alkalinity	0.838		
TSS		0.949	
Turbidity		0.913	
Al^{3+}		–0.887	
Temperature			0.910
pH	–0.398	0.368	0.429

Explanations: *EC*, *TDS*, *TH* = total hardness *SAR*, *TSS* as in Tab. 1.
Source: own study.

CLUSTER ANALYSIS (CA)

Cluster analysis can be utilized as a significant tool for analysing data set of water quality to explain the relationship between sites and variables (parameters) the results of

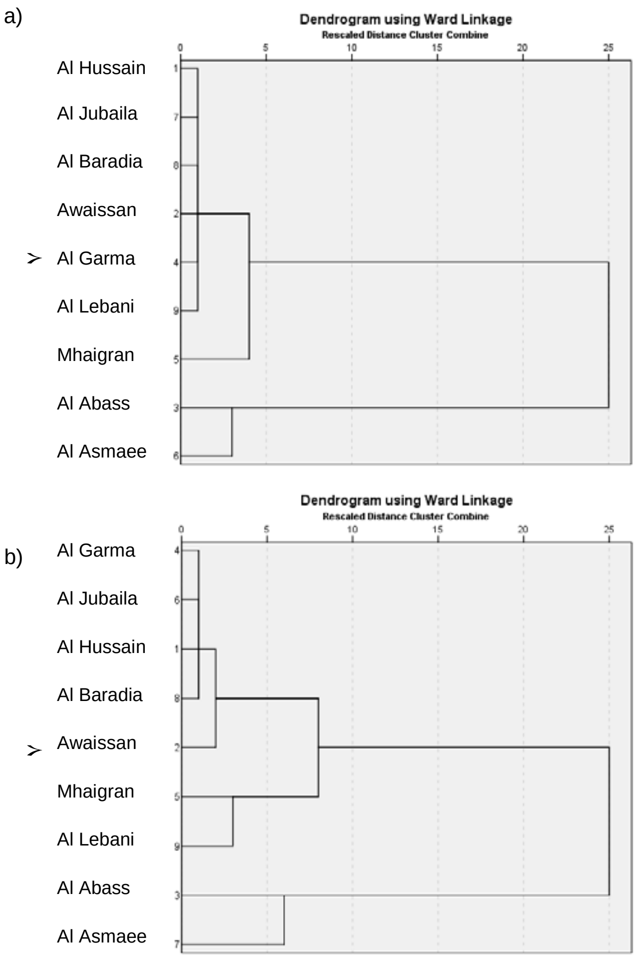

Fig. 5. Dendrogram obtained using Ward's method for water of the analyzed stations: a) raw water, b) treated water; source: own study

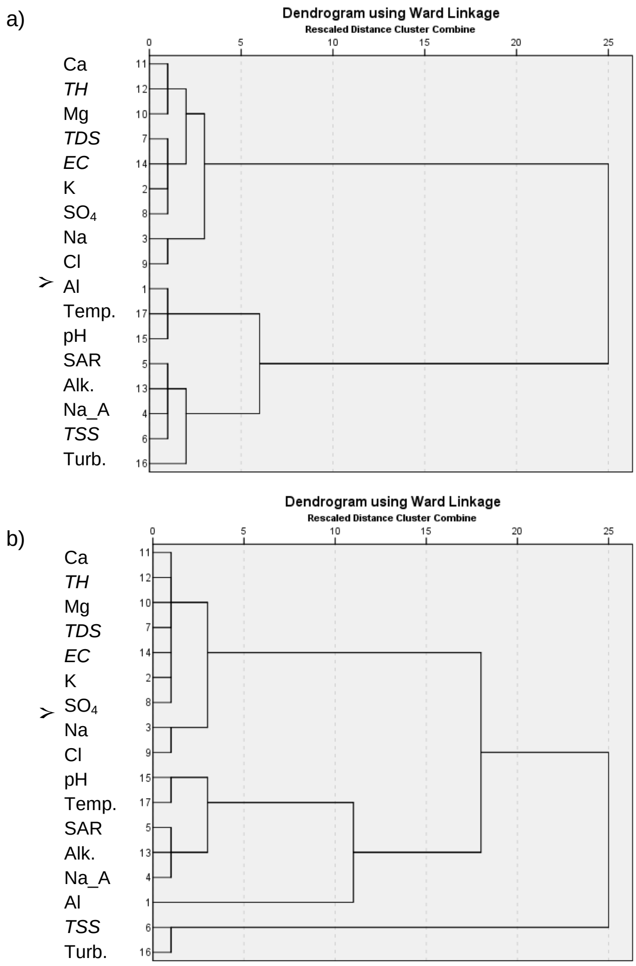

Fig. 6. Dendrogram obtained using Ward's method for water quality variables: a) raw water, b) treated water; Temp. = temperature, Turb. = turbidity, *TH*, *TDS*, *EC*, *TSS* as in Tab. 1; source: own study

CA shown in Figures 5 and 6 below, it was found the similarity groups between the variables and sites.

All raw data of the nine stations on the SAAR were grouped into three clusters, as shown in Figure 5a, the first cluster formed by Al Hussain (1), Awaissan (2), Al Garma (4), Al Baradia (8), Al Jubaila (7), and Al Lebani (9), which include relatively polluted water. The second cluster consists of Al Abass (3), and Al Asmaee (6) which include the stations that less polluted water than the first cluster, while the third cluster represents Mhaigran (5) which is the station that has the greatest pollution.

For treating water, all data of the nine stations on the SAAR were also grouped into three clusters as shown in Figure 5b. The first cluster formed by Al Hussain (1), Awaissan (2), Al Garma (4), Al Baradia (8), and Al Jubaila (7), which include relatively polluted water. The second cluster includes of Al Abass (3), and Al Asmaee (6), which contains the stations that less polluted water than the first cluster, while the third cluster represents Mhaigran (5) and Al Lebani (9) which are the stations that have high pollution.

Based on the results of CA and locations of the WTP's, it can be concluded that three major groups were formed by treating all data by clustering. First cluster showing that it has the high concentrations of most variables including the total dissolved solids, second cluster showing less effect of sewage from domestics and agricultural lands, as well as these, were take an additional source of raw water which is a Sweat canal that has a rather good water quality and most often mixed with the raw water that incoming from SAAR, therefore it has less polluted water, and the third cluster is located in the downstream of SAAR that is mainly affected by salinity that propagates from Arabian Gulf as well as the sewage effluent from domestics and agricultural lands.

From the results of CA, it can be shown that this method is useful to classify the WTP's with regards to the characteristics of water quality and it can be used to find out the sources of pollution and high salinity.

On the other hand, based on physicochemical variables in raw water three clusters were identified as shown in Figure 6a. CA showed the association of temperature, pH, and Al^{+3}) in the first cluster. The second cluster consists of Cl^{-}, *TDS*, SO_4^{2-}, Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, *TH*, and *EC*). While the third cluster contains (Na%, Alk., *SAR*, *TSS*, and Turb.). As for cluster 1 is reasonable to see some parameters such as temperature, and pH in one cluster as any increase in temperature, leads to the pH decreases hence, the temperature rises lead to molecular vibrations increase which results in the ability of water to ionise and form more hydrogen ions. As a result, the pH will drop. Cluster 2 is most likely represents one source of soil erosion from the river basin area. Cluster 3 is reasonable to see some parameters such as Turb., and *TSS* in one cluster as any increase of turbidity leads to the *TSS* increase and vice versa, where these components can be attributed to the water visibility.

Based on water quality variables for treated water CA showed the association of (Al^{3+}, Na%, *SAR*, Alk., pH, and Temp.) in the first cluster. The second cluster consists of (K^+, Na^+, *TDS*, SO_4^{2-}, Cl^-, Mg^{2+}, Ca^{2+}, *TH*, and *EC*). While the third cluster contains only *TSS* and Turb. as shown in Figure 6b. As for cluster 1 is reasonable to see some parameters such as Temp., and pH in one cluster as any increase in Temp., leads to the Ph drops and vice versa. Cluster 2 is most likely represents one source of soil erosion from the river basin area, cluster 3 is reasonable to see some parameters such as Turb., and *TSS* in one cluster as any increase of turbidity leads to the TSS increase and vice versa, where these components can be attributed to the water visibility.

The CA results showed that this method was very important in the classification of surface waters that supply WTP's for domestic water.

CONCLUSIONS

From the above results of this research, it can be shown that the average values of the raw water parameters of the nine wastewater treatment plants (WTPs) of Na^+, *TDS* Cl^-, Ca^{2+}, *TH*, Alk., and *EC* were not within the standards limit of WHO and IQS except station 3, Turb. values were out of limits of standards except stations 3 and 6, SO_4^{2-} and Mg^{2+} were out the limits of standards for all stations, K^+ was within the standards for all stations except stations 2 and 5, and pH values were within the standard limits for all stations.

And for treating water, it shows that the average values of Turb. were within the standard limits of WHO and IQS for all stations and the average values of pH for testing samples were within the standard limit, whereas the average value of SO_4^{2-}, Mg^{2+}, *EC*, and *TH* are not within standard limits, Na^+, *TDS*, Cl^-, and Alk. were out of the limit of standards except for station 3.

Also, it can be concluded that the US salinity diagram the water for all stations is considered as a C4-S2 zone that considered as very high salinity and medium sodium type, except Al Abbas and Mhaigran which were located in C3-S1 and C4-S3 respectively, hence Alabbas is considered high salinity with low sodium type, and Mhaigran is considered very high salinity and high sodium type for irrigation purposes.

It can be noticed that the efficiencies of WTPs in Basrah province vary from 46 to 84%. A significant correlation has pH ($P \leq 0.01$) with *TSS* and it has a negative correlation with *TDS*, SO_4^{2-}, *SAR*, Na%, Al^{3+}, Ca^{2+}, Na^+, Mg^{2+}, and K^+. *EC* has a significant correlation ($P \leq 0.01$) with *TH*, Na^+, K^+, Ca^{2+}, Mg^{2+} and SO_4^{2-}.

According to some of the selected parameters, the study indicates that the Shatt Al Arab River (SAAR) water cannot be used for drinking or irrigation, also the site Mhaigran station (5) has the greatest pollution. The results show that most of the WTPs' samples were not suitable for drinking and irrigation, but Alabbas station could be considered rather acceptable for irrigation.

SUGGESTIONS

1. Increasing the efficiency of WTPs, or more considerate treatment must be taken.
2. Improving water softening in water treatment plants for the removal of calcium, magnesium, and certain other metal cations in hard water.
3. Add activated carbon units to increase the efficiency of WTPs by removing contaminants and undesirable components as well as reducing components that result in undesirable tastes and odors.
4. If possible, it can add a reverse osmosis unit to connect it to the effluent of WTPs to improve the quality of water by decreasing the *TDS*.

REFERENCES

ABBASI S.A. 1999. Water quality indices. State of the Art Report. National Institute of Hydrology, Scientific Contribution No. INCOH/SAR-25/2002. Roorkee. INCOH pp. 73.

DAWOOD A.S. 2017. Using multivariate statistical methods for the assessment of the surface water quality for a river: A case study. International Journal of Civil Engineering and Technology (IJCIET). Vol. 8. Iss. 10 p. 588–597.

DAWOOD A.S., KHUDIER A.S., BASHARA A.N. 2018. Physico-chemical quality assessment and multivariate statistical analysis of groundwater quality in Basrah, Iraq. International Journal of Engineering and Technology. Vol. 7. Iss. 4.20 p. 245–250.

FAO 1994. Water quality for agriculture, irrigation and drainage. Paper No. 29. Rev. 1, M-56. Rome. Food and Agriculture Organization of United Nations. ISBN 92-5-102263-1 pp. 174.

HANNA N.S., SHEKHA Y.A. 2015. Using aquatic insects in water quality assessment of some branches of Greater Zab River within Erbil city, Iraqi Kurdistan Region. American International Journal of Research in Formal, Applied and Natural Sciences. Iss. 11 p. 18–22.

HELENA B., PARDO R., VEGA M., BARRADO E., FERNANDEZ J.M., FERNANDEZ L. 2000. Temporal evolution of groundwater composition an alluvial aquifer (Pisuerga River, Spain) by principal component analysis. Water Research. Vol. 34 p. 807–816. DOI 10.1016/S0043-1354(99)00225-0.

IQS417ICS:13.06.20. Iraq Quality Standard (IQS) 2001. First update. Baghdad, Iraq. Drinking Water Council of Minister – Central Agency for Metrology and Quality Control.

ISMAIL A.H., ABED B.S., ABDUL-QADER S. 2014. Application of multivariate statistical techniques in the surface water quality assessment of Tigris River at Baghdad stretch, Iraq. Journal of the University of Babylon. Vol. 22. Iss. 2 p. 450–462.

ISSA H.M., ALRWAI R.A. 2018. Long-term drinking water quality assessment using index and multivariate statistical analysis for three water treatment plants of Erbil City, Iraq. UKH Journal of Science and Engineering. Vol. 2. Iss. 2 p. 39–48. DOI 10.25079/ukhjse.v2n2y2018.pp39-48.

LIU C.W., LIN K.H., KUO Y.M. 2003. Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Science Total Environment. Vol. 313. Iss. 1–3 p. 77–89. DOI 10.1016/S0048-9697(02)00683-6.

LIU W., YU H., CHUNG C. 2011. Assessment of water quality in a subtropical Alpine lake using multivariate statistical techniques and geostatistical mapping: A case study. International Journal of Environmental Research and Public Health. Vol. 8 p. 1126–1140. DOI 10.3390/ijerph8041126

MOYEL M.S. 2014. Assessment of water quality of the Shatt Al Arab River, using multivariate statistical technique. Mesopotamia Environmental Journal. Vol. 1. Iss. 1 p. 39–46.

ONGLEY E.D. 1998. Modernization of water quality programs in developing countries issues of relevancy and cost efficiency. Water Quality International. September-October p. 37–42.

OUYANG Y. 2005. Evaluation of river water quality monitoring stations by principal component analysis. Water Research. Vol. 39 p. 2621–2635. DOI 10.1016/j.watres.2005.04.024.

OUYANG Y., NKEDI-KIZZA P., WU Q.T., SHINDE D., HUANG C.H. 2006. Assessment of seasonal variations in surface water quality. Water Research. Vol. 40 p. 3800–3810. DOI 10.1016/j.watres.2006.08.030.

PEJMAN A.H., NABI BIDHENDI G.R., KARBASSI A.R., MEHRDADI N., ESMAEILI BIDHENDI M. 2009. Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. International Journal of Environmental Science and Technology. Vol. 6. Iss. 3 p. 467–476. DOI 10.1007/BF03326086.

RUMP H.H. 1999. Laboratory manual for the examination of water, wastewater and soil. 3rd. ed. Wiley-VCH Verlag Publication. Germany pp. 225.

SÂRBU C., POP H.F. 2005. Principal component analysis versus fuzzy principal component analysis. A case study: the quality of Danube water, 1985–1996. Talanta. Vol. 65. Iss. 5 p. 1215–1220. DOI 10.1016/j.talanta.2004.08.047.

SARGAONKAR A., DESHPANDE V. 2003. Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. Environmental Monitoring and Assessment. Vol. 89. Iss. 1 p. 43–67. DOI 10.1023/A:1025886025137.

SHEKHA Y.A. 2008. The effect of Erbil city wastewater discharge on water quality of Greater Zab River, and the risks of irrigation. PhD Thesis. Baghdad University, Iraq pp. 121.

SHEKHA Y.A. 2009. Abiotic factors and their influences on phytoplankton density in Greater Zab River (Khabat subdistrict-Erbil, Iraq). Zanco Journal. Vol. 21. Iss. 2 p. 71–80.

SHEKHA Y.A. 2013. Multivariate statistical characterization of water quality analysis for Erbil wastewater channel. Journal of Environmental Science Toxicology and Food Technology. Vol. 5. Iss. 6 p. 18–26. DOI 10.21271/zjpas.v28i3.915.

SHRESTHA S., KAZAMA F. 2007. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji River basin, Japan. Environmental Modeling and Software. Vol. 22. Iss. 4 p. 464–475. DOI 10.1016/j.envsoft.2006.02.001.

WHO 2011. Guidelines for drinking water quality. 4th ed. Incorporating the 1st addendum. World Health Organization ISBN 978-92-4-154995-0 pp. 541.

YANG L., XU L., LI S. 2009. Water quality analysis of the Soughua River basin using multivariate. Journal of Water Resource and Protection. Vol. 2 p. 110–121. DOI 10.3390/su8020133.