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Assessment of the Effluents of Basra City Main Water Treatment Plants for Drinking and Irrigation Purposes

Suhad Almuktar [1,2,3], Ahmed Naseh Ahmed Hamdan [4] and Miklas Scholz [2,3,5,*]

1. Department of Architectural Engineering, Faculty of Engineering, The University of Basra, Al Basra 61004, Iraq; suhad.suhad81@yahoo.com
2. Division of Water Resources Engineering, Department of Building and Environmental Technology, Faculty of Engineering, Lund University, P.O. Box 118, 221 00 Lund, Sweden
3. Civil Engineering Research Group, School of Science, Engineering and Environment, The University of Salford, Newton Building, Salford M5 4WT, UK
4. Department of Civil Engineering, College of Engineering, The University of Basra, Al Basra 61004, Iraq; ahmed.hamdan@uobasrah.edu.iq
5. Department of Civil Engineering Science, School of Civil Engineering and the Built Environment, University of Johannesburg, Kingsway Campus, PO Box 524, Aukland Park, Johannesburg 2006, South Africa

* Correspondence: miklas.scholz@tvrl.lth.se; Tel.: +46-(0)462228920; Fax: +46-(0)462224435

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Abstract: A severe water scarcity challenge is facing Iraq, which is predominantly due to the absence of water management policies, negatively impacting the water quantity and quality provision from the Tigris and Euphrates Rivers. Moreover, these practices have led to the intrusion of the Arabian Gulf salinity wedge into the Shatt Al-Arab River (SAR), which is the main water source for most water treatment plants (WTPs) in Basra city. In addition, the inadequate management and operation for most WTPs is another reason for the deterioration of water quality provided to Basra province. Accordingly, the aim of this study is to evaluate the performance of the main WTP within Basra province and to subsequently make recommendations for decision-makers to come up with new management strategies and policies. The effluents from eight WTPs were selected to study the quality of water supply for Basra city during the period between January 2018 and December 2018. The results showed that all WTPs were inadequate to treat raw water for drinking or irrigation purposes mainly due to the very bad raw water quality provided by the SAR as well as the lack of maintenance for such plants, resulting in very low removal efficiencies for various water contaminants.

Keywords: Irrigation water quality; potable water quality; public health; salinity; water supply challenges; water treatment efficiency

1. Introduction

Water is a vital natural resource for life to continue on earth. Therefore, the provision of safe water is essential for community life [1,2], since more than 80% of human health issues relate to insufficient sanitation and low-quality drinking water [3,4]. Raw water treatment and purification by removing chemical and microbial contaminants as well as the undesirable physical constituents such as taste and odour are essential to provide water fit for human consumption [5]. Raw water can be treated using various treatment processes such as flocculation, sedimentation, filtration and disinfection, which should be undertaken in treatment plants to produce safe water for communities [6]. Regular evaluation of the water treatment plant (WTP) performance by monitoring the treated water quality is essential to ensure that the produced water is within legal thresholds. Treated water is mainly dependent on the raw water source properties as well as on the technical and operation conditions in treatment plants units [6,7]. Normally, physicochemical properties are used to evaluate the quality for both raw and treated water, while in some other studies biological characteristics may be considered as well [8].

Water treatment in the Basra governorate uses the conventional coagulation-filtration process, which is suited for most surface waters, but will not lower total dissolved solids (TDS) levels. Hence, the population started to use the water supplied from the plants for purposes other than drinking and cooking. Drinking water is usually purchased (reverse osmosis water) from private suppliers in containers or delivered in bulk by tank truckers. Almost all WTP use aluminum sulphate (alum) as a coagulant. However, this treatment method is rarely fully effective, because of dosing equipment commonly malfunctioning. Universal disinfection using chlorine (Cl) gas is common, but very few dosing equipment items function as designed [9]. While the deterioration of Basra's water sources has been a persistent problem for decades, it became a full-blown crisis in the summer of 2018, when at least 118,000 people were hospitalized due to poor water quality. That year, the water flowing to the Shatt Al-Arab River (SAR) from rivers upstream decreased, resulting in elevated levels of sewage, agricultural and industrial pollution, as well as high salinity due to the intrusion of saline water from the Arabian Gulf, which connects to the SAR. The main reason for the poisoning is officially unknown. However, some researchers claim chemical or biological pollutants as the main reason [10].

In Iraq, most of the conventional WTPs are supposed to supply safe potable water for all communities. Investigation of those treatment plant performances was carried out by several studies either by assessing the quality of treated water produced by those plants or by evaluating the efficiency of each treatment unit in these plants [5,9–14].

Hamdan [9] investigated the water samples of effluents from 11 WTP in Basra province in the year 2013 and tested 12 physiochemical parameters for the benefits of water for irrigation purposes. The study concluded that all the considered WTPs had bad water quality except for R-Zero station and the Al-Ma'aqil station. This was because both WTPs were fed raw water from the Sweet Water Canal (SWC). A study by Mohammed [15], in 2011, highlighted that the quality of raw water taken from the SAR in the Basra WTP was poor due to high amounts of contaminants, which were discharged into the SAR. Another reason was the effect of salinity intrusion from the Arabian Gulf. Most WTPs in Basra city are of the conventional type that have not been designed to treat soluble elements. In 2012, Al-Anbar et al. [14] calculated the water quality index for most WTPs in Basra province, and concluded that most of the WTPs in Basra province had either poor or marginally acceptable water quality, except for the Al-Abass and Al Shauaiba WTPs, which were classified as good. These findings agreed with a study conducted by Mohammed [15].

Al Chalabi [16] studied some physical and chemical parameters in the Al-bradiah WTP in Basra city during the period from December 2017 to March 2018, and compared them with the World Health Organization (WHO) and Iraqi standard thresholds. They found that the treated water parameters such as electric conductivity (EC), TDS, turbidity and total suspended solids (TSS) were higher than the WHO and Iraqi standard thresholds except for the pH value, which was 6.9 and within the permissible limits.

Hamdan [17] used a multivariate statistical analysis (principal component analysis, factor analysis and cluster analysis) to determine the effects of different variables on water quality of the SAR. They studied nine WTPs in Basra city during the year 2017. The purpose was to assess the quality of water for drinking and irrigation purposes. They concluded that the results of most water quality parameters reveal that SAR water is not within the permissible levels for both drinking and irrigation purposes. Al-Badran [18] assessed the suitability of the SAR as a source for domestic water for the main water treatment plants in Basra city. The study included the calculation of the water quality index (WQI) for both raw and treated water for 10 water treatment plants. During the period from March 2011 to March 2012, the measured parameters were pH, turbidity, EC, alkalinity, total hardness (TH), calcium (Ca), magnesium (Mg), Cl, sulphate (SO_4), TDS, sodium (Na) and potassium (K). The results indicate that SAR water is very poor for domestic, industrial and irrigation purposes during all seasons. These earlier studies indicate the importance of this study to assess if the water quality situation has changed in the meantime.

In 2018, the shortage of water sources and the poor water quality in Basra province highlighted the necessity for decision-makers to invest more into WTPs [19]. Basra is the second largest city in Iraq and is positioned downstream of the Euphrates-Tigris River system, with a population of more than two million inhabitants [20,21]. In this governorate, the SAR serves as the main source for water supply. Most WTPs are located alongside this river. There are several treatment plants in Basra city. Most of them are conventional and old treatment plants, which are relying on the coagulation-filtration treatment process [20].

The key aim of this study is to evaluate the performance of the main WTP of Basra city, since there are insufficient previous studies covering this important issue relating to the public health and the environment of Basra governorate. The main corresponding objectives are to: (a) assess the quality of raw water supplied by various sources to the treatment plants; (b) evaluate the treated water quality for various application purposes, such as portable drinking water and agricultural irrigation water; (c) calculate the water quality index for raw and treated water to evaluate the efficiency of the WTP; and (d) make recommendations of interest to international water managers. Findings will contribute to the understanding of generic compliance challenges with national and international guidelines and standards.

2. Materials and Methods

2.1. Study Area

A steady increase in the population to more than four million people living in Basra city, coupled with a deterioration of water quality, has led to the most serious urban water supply problem in Iraq. The Shatt Al-Arab River (SAR) is the main water source, which is a natural river that passes through Basra governorate with a flow rate ranging between 25 and 75 m^3/s. Municipal, industrial and agricultural sources discharge into the river. As a result, the total dissolved solids (TDS) levels in the river were almost three times the maximum acceptable standards for potable water. The Sweet Water Canal (SWC) was constructed as a temporary measure in the late 1990s to provide an improved water supply. However, it is now the only significant source of low TDS water, because the SWC was originally designed as a fully lined concrete channel to minimize losses and guarantee the delivery of the designed capacity to Basra.

The untreated water, coming from the SWC, flows to a specific point of the reservoir called R-Zero, which is located just west of Basra city. Some of the water is treated near R-Zero, but the majority is pumped to the intakes of existing WTPs in Basra. The Governorate of Basra has several WTPs; the majority is located near the SAR. Most of these plants are either old conventional plants or use multiple package units made up of many compact units installed in the 1990s. They require major rehabilitation to bring them up to a suitable standard of performance [9].

The intake of the SWC is at Bada'a near Ash Shatra on the Gharraf River, which is a branch of the Tigris north of Al Nasiriyah in the Governorate of Dhi Qar. Most of the plants are constructed close to the SAR, and can also draw raw water from it, if required [20]. The SAR was Basra's original raw water source, and hence, all main WTPs were constructed on its banks. However, the reduction of freshwater flow from the Tigris and Euphrates Rivers over time resulted in seawater intrusion advancing inland. This led to an increase of the salinity within the SAR water. Moreover, the Iraqi river systems have been used as a point of discharge for agricultural drainage water and sewage, which has further aggravated the problem of insufficient water quality in the SAR. For example, TDS levels in SAR increased from an average of 1792 mg/l in 1997 to an average exceeding 3000 mg/l in the year of 2001. This has been followed by a significant increase to about 10,000 and 20,000 mg/l in the years of 2009 and 2018, respectively [20].

The SWC was designed to deliver 8.5 m^3/s, but it is currently operating at approximately 6.0 m^3/s, which is equivalent to 518,400 m^3/d [20]. Two open rectangular reservoirs were constructed 8.0 km north of R-Zero and have a total capacity of 75,000 m^3, which is equivalent to a two-day supply for Basra centre and nearby districts. These reservoirs are used just for storage of the water that comes from the SWC and used in times of water shortage. No active treatment of the waters in the reservoirs that might improve the water quality has been undertaken [20], as shown in Figure 1.

Figure 1. Rectangular reservoirs in Basra [20].

2.2. Main water Treatment Plants of Basra City

The main WTP of Basra city are shown in Table 1. Most of these plants are either conventional old plants or ones that use multiple package units (MPU) constructed in the mid-1980s to early 2000s [20]. All the WTPs were designed to satisfy the requirement of drinking water where the source of water was fully welled up at the start of the 1980s. As a result, the WTPs were functioning to a high standard. Figure 2 indicates the locations of the WTP under study.

Table 1. Main water treatment plant (WTP) details for Basra city.

Water Treatment Plant name	Water Treatment Plant Type	Location		Water Source	Water Volume (m^3/day)	Year of Construction
		Longitude	Latitude			
Al-bradiah 1	Conventional	47.855	30.503	SWC * and SAR	20,000	1958
Al Jubila 1	Conventional	47.813	30.550	SWC * and SAR	20,000	1936
Shatt Al Arab	Multiple package units	47.857	30.537	SWC * and SAR	20,000	1976
Al-Garmma 1	Multiple package units	47.746	30.571	SWC * and GAR	32,000	1986
Al-Ribat	Multiple package units	47.831	30.536	SWC * and SAR	12,000	1986
Al Basra Unified	Conventional	47.748	30.649	SWC * and SAR	80,000	1978
Al Shauaiba Old	Conventional	47.670	30.420	SWC *	16,000	1938
Abu Al Khaseeb	Conventional	47.979	30.460	SWC * and SAR	12,000	1960

Note: SWC, Sweet Water Canal; SAR, Shatt Al-Arab River; GAR, Garmat Ali River.; * Raw water from the SWC can be provided when possible.

R-Zero is a reservoir located at the end of the SWC near the Basra International Airport, and provides the raw water for most WTPs. The intake of the SWC is at Bada'a near Ash Shatra on the Gharraf River, which is a branch of the Tigris north of Al Nasiriyah in the Governorate of Dhi Qar. Most of the plants are constructed close to the SAR (Figure 2), and can also draw raw water from it, if required [20].

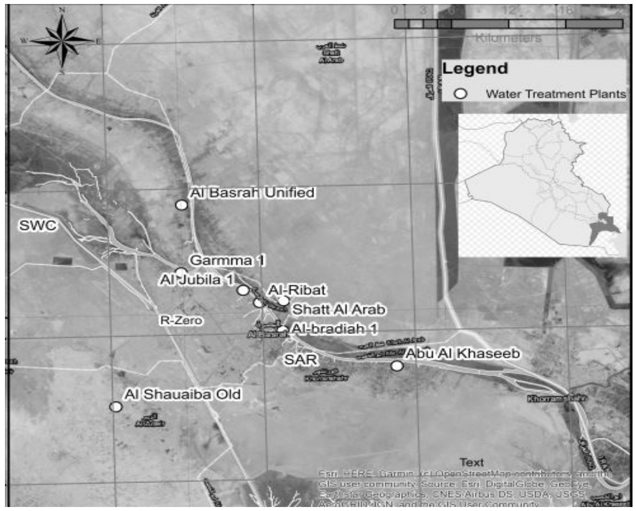


Figure 2. Locations of the assessed key water treatment plants.

2.3. Analysis of Water Quality

Standard methods for the examination of water and wastewater (American Public Health Association (APHA)) [22] were considered for water quality sampling and testing, unless stated otherwise. Eight WTP outflows were selected to evaluate the quality of water supplied to Basra city during the period from January 2018 to December 2018. All sampling bottles were washed with distilled water and a non-ionic detergent, soaked overnight in 10% nitric acid (HNO_3) solution and then rinsed with deionized water before use. The samples were collected monthly from each plant during the studied period. They were taken from the influent and effluent taps of each WTP, collected in plastic bottles of one litre and kept within a cooled box during transportation to the laboratory. Within two hours of collection, the required physical and chemical analyses were performed. All samples were encoded by sample number, time and date of collection, name of location, geographical coordinates and any other measurements taken in situ. Three replicates for each sample location were analysed for various parameters such as aluminum (Al), K, Na, Cl, Mg, Ca, SO_4, TSS, TDS, TH, alkalinity, electrical conductivity (EC), turbidity (TUR), pH and water temperature, using common procedures to assess the suitability of treated water for drinking and irrigation purposes according to national and international standards.

In situ tests were performed for several water parameters such as temperature using a digital thermometer. Electrical conductivity (mS/cm) and TDS (mg/l) were measured by using a portable digital device (METTLER TOLEDO FIVE GOTM conductivity meter (Mettler Toledo, Columbus, OH, USA)). The pH of the water samples was measured directly in the field by using the portable pH meter model SD300. Turbidity was determined with the Turbidity Meter Lovibond TB 300 IR (The Tintometer Limited, Amesbury, UK). The measurement unit was Nephelometric Turbidity Unit (NTU). All portable equipment items were calibrated in the laboratory before traveling to the sample stations.

In the laboratory, TSS measurements were carried out using the Gravimetric Method; 100-mL water samples were evaporated to dryness at 105 °C within a drying oven using a pre-weighed 100-mL beaker. After evaporation, the beakers were placed in desiccators before weighing [22]. Total hardness, Ca^{+2} (mg/l) and Mg^{+2} (mg/l) were measured by the (EDTA) complex metric titration method, as described by the APHA [22]. Sodium (Na^+; mg/l) and potassium (K^+; mg/l) concentrations were measured by the flame photometer model M410. Chloride (Cl^-; mg/l) concentrations were determined by the silver nitrate titration procedure. Sulfate (SO_4; mg/l) concentrations were estimated spectrophotometrically using the barium sulfate turbidity method according to APHA [22]. Alkalinity (mg/l) and aluminum (Al; mg/l) in the water samples were measured by the Atomic Absorption Spectrophotometer model SpectroDirect LoviBond (The Tintometer Limited, Amesbury, UK). The detection limit for aluminum was 0.01 mg/l.

2.4. Data Analysis

Microsoft Excel has been applied for basic statistical analyses such as mathematical mean, standard deviation as well as the minimum and maximum values of the measured water characteristics. The IBM–SPSS Statistics Version 23.0 software (IBM, Endicott, NY,USA) was operated for more advanced statistical analyses of the results at a 5% significance level. The normality of the data was assessed using the Shapiro-Wilk test. The one-way analysis of variance and the Kruskal-Wallis H-test were applied for data that were normally and non-normally distributed, respectively. The Spearman's test was applied to assess the correlations among variables.

2.5. Water Quality Index

The WQI is an arithmetical tool used to transform large quantities of water quality parameters into a single cumulatively derived number. The WQI is an indicator of the quality of drinking water for different uses [23]. In order to compute the WQI for the proposed case study, 12 physicochemical parameters (pH, EC, TDS, K^+, Na^+, Mg^{+2}, Ca^{+2}, alkalinity, TH, Cl^-, TUR and SO_4^{-2}) were considered in a three-stage process. Firstly, weights were assigned to parameters according to their perceived effects on primary health (Table 2). A maximum weight of 4 has been assigned to parameters such as TDS, pH, SO_4^{-2} and EC due to their major importance in water quality assessment. Ca^{+2}, Mg^{+2}, TH, K^+ and Na^+ were given the minimum weight of 2 due to their minor effect on water quality. Other parameters, such as TUR, Cl^- and alkalinity, were assigned a weight between 2 and 4 depending on their importance in the overall quality of water for drinking purposes [24].

In the second step, the relative weight (Wi) of each parameter is computed using Equation (1):

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \quad (1)$$

where wi is the weight of each physicochemical parameter, n is the number of parameters and Wi is the relative weight.

The weight (wi), the calculated relative weight (Wi) values and the WHO standards for each parameter are given in Table 2. In the third step, the quality rating scale (qi) was calculated for each parameter using Equation (2):

$$qi = \frac{Ci}{Si} * 100 \quad (2)$$

where qi is the quality rating, Ci is the concentration of each parameter in each water sample in mg/l and Si is the WHO standard for each chemical parameter in mg/l (Table 2).

For computing the WQI, the Sli is first determined for each parameter using Equation (3), which is then used to determine the WQI as per Equation (4):

$$Sli = Wi * qi \quad (3)$$

$$WQI = \sum_{i=1}^{n} Sli \quad (4)$$

where Sli is the sub-index of the ith parameter, qi is the rating based on the concentration of the ith parameter and n is the number of parameters. Calculated WQI values are commonly classified into five categories, as shown in Table 3; excellent, good, poor, very poor and unsuitable for human consumption [25].

Table 2. WHO standards and the calculation of relative weight (Wi).

Relative Weight (Wi)	Weight (wi)	WHO Standard [3]	Chemical Parameters
pH	8.5	4	0.1143
Turbidity	5	3	0.0857
Ca^{+2}	50	2	0.0571
Mg^{+2}	50	2	0.0571
Total hardness	500	2	0.0571
K^+	12	2	0.0571

Na^+	200	2	0.0571
SO_4^{+2}	250	4	0.1143
Cl^-	250	3	0.0857
TDS	1000	4	0.1143
EC	2000	4	0.1143
Alkalinity	120	3	0.0857
		$\sum$ w i=35	$\sum$ W i=1

Table 3. Categories of the water quality index (WQI).

Type of Water	WQI Range
Excellent water	<50
Good water	≥50–<100
Poor water	≥100–<200
Very poor water	≥200–≤300
Unsuitable water quality	> 300

2.6. Efficiency of the Water Treatment Plants

In order to evaluate the effectiveness of a WTP, the efficiency of the WTP has to be calculated by using Equation (5) [6]:

$$E\ \% = \frac{\Delta \text{WQI}}{\text{WQI of raw water}} * 100 \quad (5)$$

where ΔWQI is the difference in WQI between raw and treated water.

2.7. Cluster Analysis

Cluster Analysis (CA) includes a progression of multivariate strategies that are utilized to assemble similar objects into homogeneous groups with respect to the same properties and different from or unrelated to the objects in the other groups [26]. In this study, hierarchical agglomerative cluster analysis was performed. By this method, the levels of similarity at which observations are combined are used to build a dendrogram. The agglomerative hierarchical clustering was used with Ward's linkage method and squared Euclidean distances as a measure of similarity [27].

2.8. Irrigation Water Quality Evaluation

The excess of salt content is one of the main concerns with water used for irrigation. A high salinity content in the water will negatively affect the crop yield and degrade the soil. The quantity of water transpired through a crop is directly related to yield. Therefore, high EC in irrigation water reduces the yield potential and can result in physiological drought. Table 4 shows the criteria that are used to assess the irrigation water quality concerning salinity hazard [9].

Table 4. Salinity hazard guidelines for the determination of water quality for irrigation [28].

Electrical Conductivity (µS/cm)	Salinity Class	Hazard
<250	C1	Excellent or low
250–750	C2	Good or medium
720–2250	C3	Permissible or high
2250–5000	C4	Unsuitable or very high

Sodium hazard is expressed as the sodium adsorption ratio (SAR). This index measures the rate of sodium (Na) to calcium (Ca) and magnesium (Mg) ions in the water; the SAR is considered a good measure of the sodium hazard in irrigation water [9]. The continued use of water with a high SAR value leads to a degradation of the physical structure of the soil caused by excessive amounts of adsorbed sodium. SAR is calculated using the Equation (6):

$$\text{SAR} = \frac{\text{Na}}{\sqrt{(\text{Ca} + \text{Mg})/2}} \tag{6}$$

where Na, Ca and Mg are expressed in milli equivalent per liter (meq/l). Table 5 represents a classification of irrigation water based on the SAR values.

Table 5. Irrigation water classification based on SAR values [9].

Level	SAR	Hazard
S1	<10	No harmful effects from sodium.
S2	10–18	Appreciable sodium hazard in fine–textured soils, but could be used on sandy soils with good permeability.
S3	18–26	Harmful effects could be anticipated in most soils and amendments such as gypsum would be necessary to exchange sodium ions.
S4	>26	Generally unsatisfactory for irrigation.

Note: SAR; sodium adsorption ratio.

The Wilcox diagram [9] was used to evaluate the suitability of water for irrigation, which is based on the combined effect of EC and the SAR. Table 6 shows the classification of irrigation water based on the effect of EC and the SAR [9].

Table 6. Classification of water according to the Wilcox Diagram [9].

Index	Water Class	Index	Water Class
C1S1	Excellent	C3S1	Admissible
C1S2	Good	C3S2	Marginal
C1S3	Admissible	C3S3	Marginal
C1S4	Poor	C3S4	Poor
C2S1	Good	C4S1	Poor
C2S2	Good	C5S2	Poor
C2S3	Marginal	C4S3	Very Poor
C2S4	Admissible	C4S4	Very Poor

3. Results and Discussion

3.1. Raw Water Quality Analysis

An overview of the raw water quality provided to the main WTP assessed in this study can be seen in Tables 7 and 8. Findings showed that no Al was detected in all water sources supplied to the WTP. Water supplied to the Abu Al Khaseeb treatment plant has the highest values for K, Na, Mg, Ca, Cl and SO_4, resulting in elevated EC, TDS and TH values followed by those for Al-bradiah 1 and Shatt Al Arab plants, while the lowest values were observed for the raw water supplied to the Al Shauaiba old and Al-Ribat plants followed by the Al Basra Unified plant. Slight differences in these parameter values were observed in the raw water supplied to the Shatt AlArab and Al-Garmma 1 plants (Tables 7 and 8). These findings indicated that the Abu Al Khaseeb, Al-bradiah 1 and Shatt AlArab plants were provided with raw water having the worst water quality. This is because of the agricultural industry dominant in these areas. Irrigation drainage water flows into the SAR, which is the main raw water source for most WTPs (Table 1). Moreover, the locations of the Abu Al Khaseeb, Al-bradiah 1 and Shatt AlArab plants, which are geographically situated close to the Arabian Gulf, make them the most vulnerable to saline intrusion, mainly when there is a severe water scarcity in the Basra governorate during the hot season as shown in Figure 2. In comparison, the Al Shauaiba Old WTP showed the best overall water quality, because it received raw water only from the SWC (Table 1).

Moreover, TSS and TUR values for the raw water showed a similar trend of maximum values for the Al Basra Unified plant followed by the Al-Ribat WTP, while no considerable differences in TSS and TUR were observed among other plants (Table 7). Furthermore, the alkalinity of the raw water was the lowest for the Al Shauaiba Old WTP, while no significant differences were observed among the other plants. The raw water pH was alkaline for all supplied waters (Table 7). Regarding the seasonal variation of the raw water quality (Figure 3), findings showed that for all supplied waters, there is a significant deterioration in water quality mainly during the hot season starting from June and ending in October. This is possibly due to the elevated outside temperature resulting in high water demand especially for potable and agricultural consumptions, leading to considerable reductions in the SWC waters. If supply provisions of the SWC are low, then most WTP depend on the SAR as the only raw water supply source. Additionally, during hot months, the quantity of supplied water provided to the Governorate of Basra is considerably reduced, resulting in low water levels in the SAR and subsequent intrusion of saline Arabian Gulf water to the SAR [20].

Table 7. Raw and treated water (effluent) quality parameters for the Basra city main water treatment plants during the period between January 2018 and December 2018.

Parameter	Al-bradiah 1	Al Jubila 1	Shatt Al Arab	Al-Garmma 1	Al-Ribat	Al Basra Unified	Al Shauaiba Old	Abu Al Khaseeb
				Raw Water				
Aluminum (mg/l)	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
Potassium (mg/l)	17.2 ± 7.6	12.9 ± 5.4	16.4 ± 5.4	15.7 ± 6.5	10.5 ± 5.4	12.1 ± 3.6	4.9 ± 0.8	19.9 ± 9.3
Sodium (mg/l)	2790 ± 2230	1570 ± 1500	2310 ± 1850	2150 ± 1550	1010 ± 1360	1160 ± 726	112 ± 33	2940 ± 2170
Magnesium (mg/l)	260 ± 161	172 ± 117	237 ± 147	215 ± 117	129 ± 101	140 ± 51	53 ± 7	270 ± 144
Calcium (mg/l)	438 ± 270	291 ± 194	395 ± 240	362 ± 192	214 ± 165	235 ± 88	92 ± 11	461 ± 245
Chlorine (mg/l)	4240 ± 3400	2380 ± 2280	3500 ± 2810	3270 ± 2370	1530 ± 2070	1770 ± 1120	199 ± 51	4470 ± 3310
Sulphate (mg/l)	1640 ± 1220	990 ± 750	1790 ± 1190	1310 ± 840	900 ± 830	986 ± 406	281 ± 54	2080 ± 1190
Total hardness (mg/l)	2170 ± 1320	1430 ± 965	1960 ± 1200	1780 ± 960	1060± 830	1160 ± 430	446 ± 54	2260 ± 1210
Turbidity (NTU)	11.0 ± 5.4	10.7 ± 5.7	11.1 ± 7.1	11.0 ± 4.4	17.1 ± 10.7	18.1 ± 14.9	14.6 ± 24.3	13.7 ± 8.0
TSS (mg/l)	86 ± 25	87 ± 41	81 ± 38	88 ± 25	124 ± 59	130 ± 41	84 ± 64	94 ± 28
EC (mS/cm)	14,900 ± 10800	8890 ± 7420	12,700 ± 9150	11800 ± 7700	6150 ± 6840	6890 ± 3580	1350 ± 23	15,700 ± 10,500
TDS (mg/l)	9850 ± 7350	5800 ± 5050	8370 ± 6220	7750 ± 5190	3919 ± 4530	4420 ± 2400	825 ± 141	10,400 ± 7100
pH (–)	7.38 ± 0.15	7.42 ± 0.14	7.40 ± 0.20	7.39 ± 0.14	0.47 ± 0.18	7.60 ± 0.15	7.72 ± 0.14	7.48 ± 0.17
Alkalinity (mg/l)	165 ± 9	163 ± 14	172 ± 10	165 ± 17	156 ± 16	158 ± 16	114 ± 16	174 ± 16
Temp (°C)	25.6 ± 2.4	26.0 ± 2.7	25.5 ± 2.1	26.0 ± 2.4	25.8 ± 2.3	26.9 ± 2.1	25.4 ± 3.6	25.4 ± 1.6
				Treated Water				
Aluminum (mg/l)	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Potassium (mg/l)	17.0 ± 7.6	12.7 ± 5.3	16.8 ± 5.9	14.7 ± 6.8	10.3 ± 5.4	11.8 ± 3.8	4.6 ± 0.9	19.5 ± 9.4
Sodium (mg/l)	2760 ± 2200	1550 ± 1440	2330 ± 1890	1870 ± 1460	1010 ± 1350	1150 ± 740	109 ± 31	2860 ± 2200
Magnesium (mg/l)	261 ± 161	172 ± 113	239 ± 147	193 ± 113	128 ± 101	140 ± 52	52 ± 7	261 ± 148
Calcium (mg/l)	434 ± 264	287 ± 187	397 ± 241	326 ± 185	213 ± 165	235 ± 90	91 ± 11	446 ± 247
Chlorine (mg/l)	4190 ± 3360	2360 ± 2190	3530 ± 2860	2840 ± 2220	1530 ± 2050	1740 ± 1130	195 ± 50	4350 ± 3360

Sulphate (mg/l)	1630 ± 1210	1000 ± 789	1800 ± 1200	1130 ± 707	892 ± 825	983 ± 418	276 ± 55	2010 ± 1210
Total hardness (mg/l)	2160 ± 1320	1420 ± 930	1970 ± 1210	1610 ± 930	1060 ± 830	1160 ± 440	441 ± 55	2190 ± 1240
Turbidity (NTU)	5.0 ± 3.2	5.6 ± 3.2	4.3 ± 2.1	4.2 ± 1.1	7.1 ± 4.5	5.9 ± 2.9	9.0 ± 11.4	4.0 ± 0.9
TSS (mg/l)	48 ± 34	53 ± 29	41 ± 21	37 ± 12	65 ± 40	56 ± 28	62 ± 51	37 ± 9
EC (mS/cm)	14,800 ± 10,700	8860 ± 7230	12,900 ± 9300	10,500 ± 7300	6110 ± 6830	6830 ± 3630	1340 ± 230	15,300 ± 10600
TDS (mg/l)	9740 ± 7270	5750 ± 4870	8450 ± 6310	6790 ± 4880	3880 ± 4500	4370 ± 2430	813 ± 144	10,100 ± 7200
pH (–)	7.24 ± 0.17	7.29 ± 0.14	7.29 ± 0.16	7.26 ± 0.18	7.30 ± 0.18	7.42 ± 0.22	7.56 ± 0.24	7.19 ± 0.18
Alkalinity (mg/l)	162 ± 11	157 ± 14	170 ± 10	161 ± 16	151 ± 18	154 ± 13	113 ± 15	167 ± 14
Temp (°C)	25.4 ± 2.4	25.9 ± 2.6	25.5 ± 2.3	26.1 ± 1.9	25.9 ± 2.4	26.4 ± 1.9	25.5 ± 3.8	25.4 ± 25.4

Note: Value in table (mean ± standard deviation); TSS, total suspended solids; TDS, Total dissolved solid; EC, electrical conductivity; NTU, nephelometric turbidity unit; and Temp, temperature.

Table 8. Raw and treated water (effluent) quality parameters for the Basra city main water treatment plants during the period between January 2018 and December 2018.

Parameter *	Al-bradiah 1	Al Jubila 1	Shatt Al Arab	Al-Garmma 1	Al-Ribat	Al Basra Unified	Al Shauaiba Old	Abu Al Khaseeb
				Raw Water				
Aluminum	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
Potassium	10.0–37	5.7–26	10.5–24	9.6–31	4.2–23	6.0–19	4.0–6.3	11.6–42
Sodium	500–6400	124–4900	488–5120	556–4890	89–5020	321–2580	78–179	614–6780
Magnesium	92–530	52–430	82–520	102–450	49–420	80–234	45–65	104–500
Calcium	162–875	90–723	148–856	179–744	80–688	128–400	79–117	182–896
Chlorine	750–9750	188–7400	720–7750	850–7450	148–7650	475–3950	146–308	925–10,300
Sulphate	0–3750	0–2610	544–4090	0–2580	235–3260	488–1780	226–398	706–4120
Total hardness	784–4360	440–3600	706–4270	870–3700	400–3440	648–1960	392–560	880–4300
Turbidity (NTU)	4.1–24	6.0–21	2.9–27	3.3–20	6.6–40	3.6–57	2.7–90	5.0–30
TSS	40–120	54–170	26–140	30–130	58–270	34–170	22–230	50–130
EC (mS/cm)	3590–32,400	1440–25,000	3490–28,000	4010–26,000	1150–26,100	2620–13,800	1110–1840	4440–33,800
TDS	2260–21,900	900–17,000	2150–18,500	2520–17,200	715–17,200	1640–9120	675–1120	2770–22,400

pH (–)	7.16–7.73	7.29–7.77	7.19–7.95	7.22–7.70	7.30–7.88	7.43–7.88	7.37–7.89	7.22–7.84
Alkalinity (mg/l)	148–180	144–188	160–186	136–188	126–180	140–190	92–146	150–210
Temp (°C)	21.3–31.0	22.4–30.3	20.7–29.2	22.7–29.7	22.3–30.8	24.4–30.0	18.8–33.0	23.3–29.0
Treated water								
Aluminum	0.0–0.1	0.0–0.2	0.0–0.2	0.0–0.1	0.0–0.2	0.0–0.1	0.0–0.1	0.0–0.2
Potassium	9.8–37	5.0–25	10.6–26	8.0–31	4.0–23	5.8–18	3.0–6.0	11.2–41
Sodium	496–6430	114–4270	490–5050	548–4960	85–5000	315–2600	77–169	610–6920
Magnesium	92–530	45–400	82–510	93–460	47–420	78–240	45–65	102–510
Calcium	162–880	80–660	148–850	166–760	80–690	128–400	77–117	181–880
Chlorine	745–9800	180–6500	725–7700	840–7600	144–7600	470–4000	146–299	920–10,600
Sulphate	0–3700	0.0–2600	543–4030	0–2160	232–3260	481–1790	223–396	698–4110
Total hardness	784–4380	384–3280	706–4220	798–3760	400–3440	646–2000	388–560	872–4280
Turbidity (NTU)	2.0–14	1.0–14	2.0–9	2.0–6	2.5–16	3.6–14	1.5–42	2.4–5.0
TSS	16–150	8–130	18–80	18–54	22–130	32–130	12–150	22–48
EC (mS/cm)	3580–32,600	1410–22,700	3500–28,000	4020–26,300	1140–26,000	2600–14,000	1100–1800	443–34,700
TDS	2250–22,000	860–15,100	216–18,200	2300– 17,000	700–17,000	1610–9150	670–1120	2730–23,100
pH (–)	6.98–7.65	7.14–7.67	7.06–7.63	7.00–7.60	7.05–7.66	7.03–7.87	7.02–7.83	7.00–7.49
Alkalinity (mg/l)	148–180	140–180	152–184	140–180	120–190	140–180	92–142	150–200
Temp (°C)	20.9–31.0	22.4–31.1	21.5–30.7	23.4–28.8	22.2–31.4	24.0–30.0	18.8–33.8	23.3–29.0

Note: Value in the table (Minimum–Maximum), TSS, total suspended solids; TDS, Total dissolved solid; EC, electrical conductivity; NTU, nephelometric turbidity unit; and Temp, temperature.;* Parameter unit in (mg/l), unless otherwise mentioned.

3.2. Treated Water Quality Analysis

3.2.1. Ions

Although Al was not detected in all raw water supplied to the treatment plants, the treated water of the WTP contained some Al (Tables 7 and 8). This is possibly due to the use of aluminum as a coagulant in the traditional treatment process of the considered plants [20]. Findings showed that the maximum Al values were detected for the Abu Al Khaseeb plant, showing an average value of 0.06 mg/l, while the minimum values were recorded for the Al Shauaiba Old plant (0.03 mg/l). The Al-bradiah 1, Al-Garmma1 and Al Basra Unified WTP showed similar Al values of 0.04 mg/l, while the Al-Ribat, Shatt Al Arab and Al Jubila 1 WTP had similar Al values of 0.05 mg/l. The measured Al levels for the treated water did not exceed the standards for potable use of 0.2 mg/l [29,30] and irrigation standards of 5 mg/l [30,31], according to Table 9.

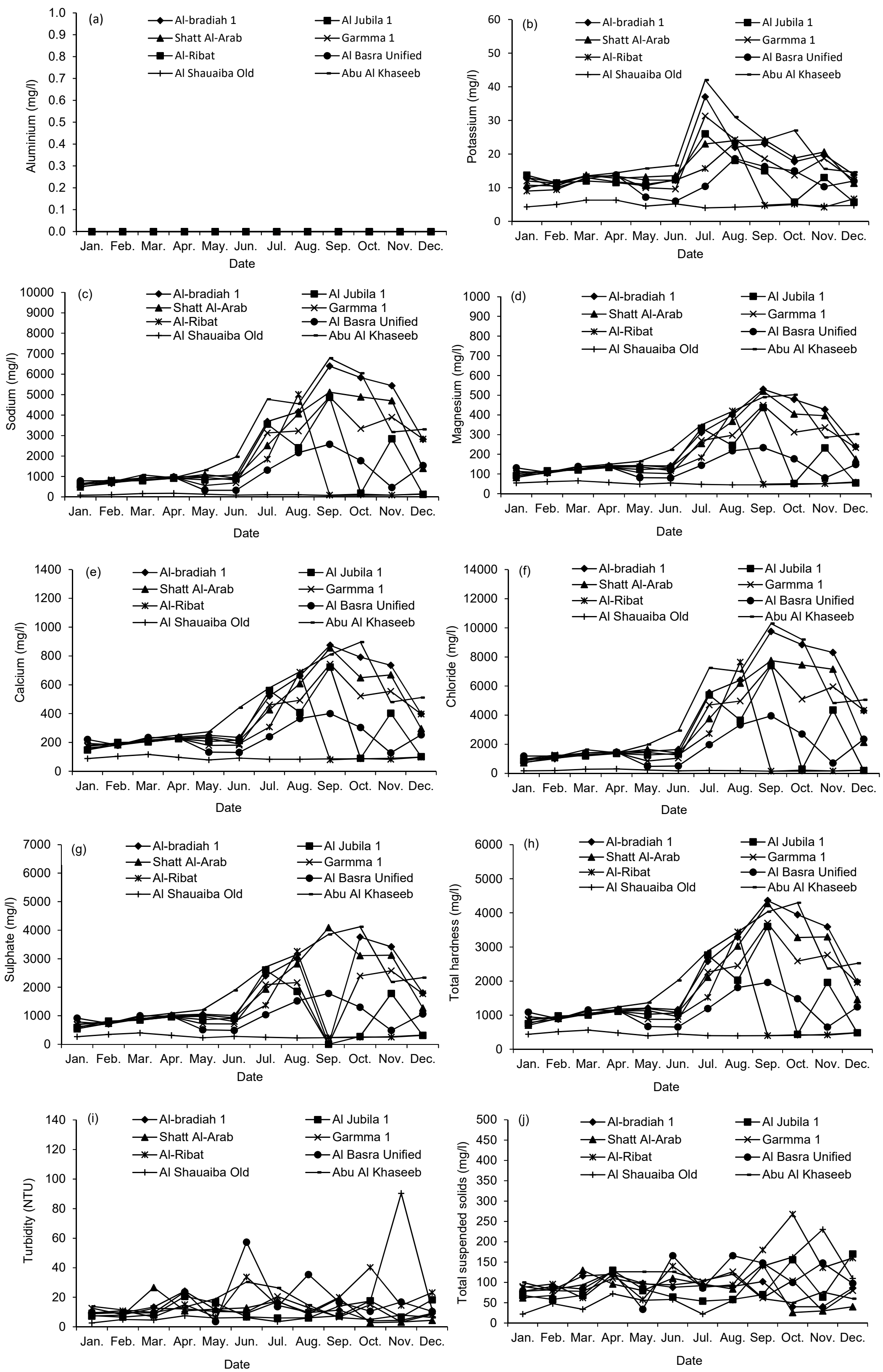
The study indicated that the K values are at their maximum for treated water obtained from Abu Al Khaseeb WTP, followed by concentrations for the Al-bradiah 1 and Shatt Al Arab plants (Table 7). The water treated by the Al-Garmma 1 plant had K values higher than those for the waters obtained from the Al Jubila 1 and Al Basra Unified plants. The Al Shauaiba Old plant has treated raw water values for K, which are significantly ($p < 0.05$) lower than the ones for other WTP (Table 7). Compared to the raw waters, no considerable K removal was observed in any of the treatment plants.

Findings show that K concentrations significantly exceed the standards for potable and agricultural use of 8 mg/l and 12 mg/l, as indicated by WHO [3] and the Food and Agriculture Organization (FAO) [29] of the United Nations, respectively. Considering public health concerns, there are no considerable health challenges linked to the consumption of high K dosages from drinking water as reported by Sebastian et al. [31]. From an agricultural point of view, elevated K values may prevent stem damage of plants at predominantly low temperature as reported by Hakerlerler et al. [32] and Cakmak [33].

Sodium concentrations for treated waters were at their maximum for water obtained from the Abu al Khaseeb plant followed by those for the Al-bradiah 1 and Shatt Al Arab plants. The Al-Garmma 1 plant treated water leading to Na concentrations slightly higher than those for the Al-Jubila plant. Statistically, no significant difference ($p > 0.05$) in Na concentrations were observed for the water treated by A-Ribat and Al Basra Unified plants, while the Al Shauaiba Old plant produced water with Na concentrations, which were significantly ($p < 0.05$) lower than the ones for the other WTP (Table 7).

Table 9. Standard thresholds of ions and other parameters for drinking water and irrigation.

Parameter	Unit	Iraqi Standard ICS [26]	WHO Standard WHO [3]	Irrigation Standard FAO [29]
pH	–	6.5–8.5	6.5–8.5	6.5–8.4
Turbidity	NTU	5	–	–
Aluminum (Al)	mg/l	0.2	0.2	5
Calcium (Ca)	mg/l	125	200	400
Magnesium	mg/l	50	50	60
Total hardness	mg/l	500	300	–
Potassium (K)	mg/l	12	12	2
Sodium (Na)	mg/l	200	200	920
Chloride (Cl	mg/l	250	250	1063
Sulfate (SO_4)	mg/l	400	250	690
Total dissolved solids	mg/l	1000	1000	2000
Electrical conductivity	µS/cm	2000	1500	3000
Alkalinity	mg/l	120	50-150	100


(a)
Aluminium (mg/l)
(b)
Potassium (mg/l)
(c)
Sodium (mg/l)
(d)
Magnesium (mg/l)
(e)
Calcium (mg/l)
(f)
Chloride (mg/l)
(g)
Sulphate (mg/l)
(h)
Total hardness (mg/l)
(i)
Turbidity (NTU)
(j)
Total suspended solids (mg/l)
Al-bradiah 1
Al Jubila 1
Shatt Al-Arab
Garmma 1
Al-Ribat
Al Basra Unified
Al Shauaiba Old
Abu Al Khaseeb
Jan. Feb. Mar. Apr. May. Jun. Jul. Aug. Sep. Oct. Nov. Dec.
Date

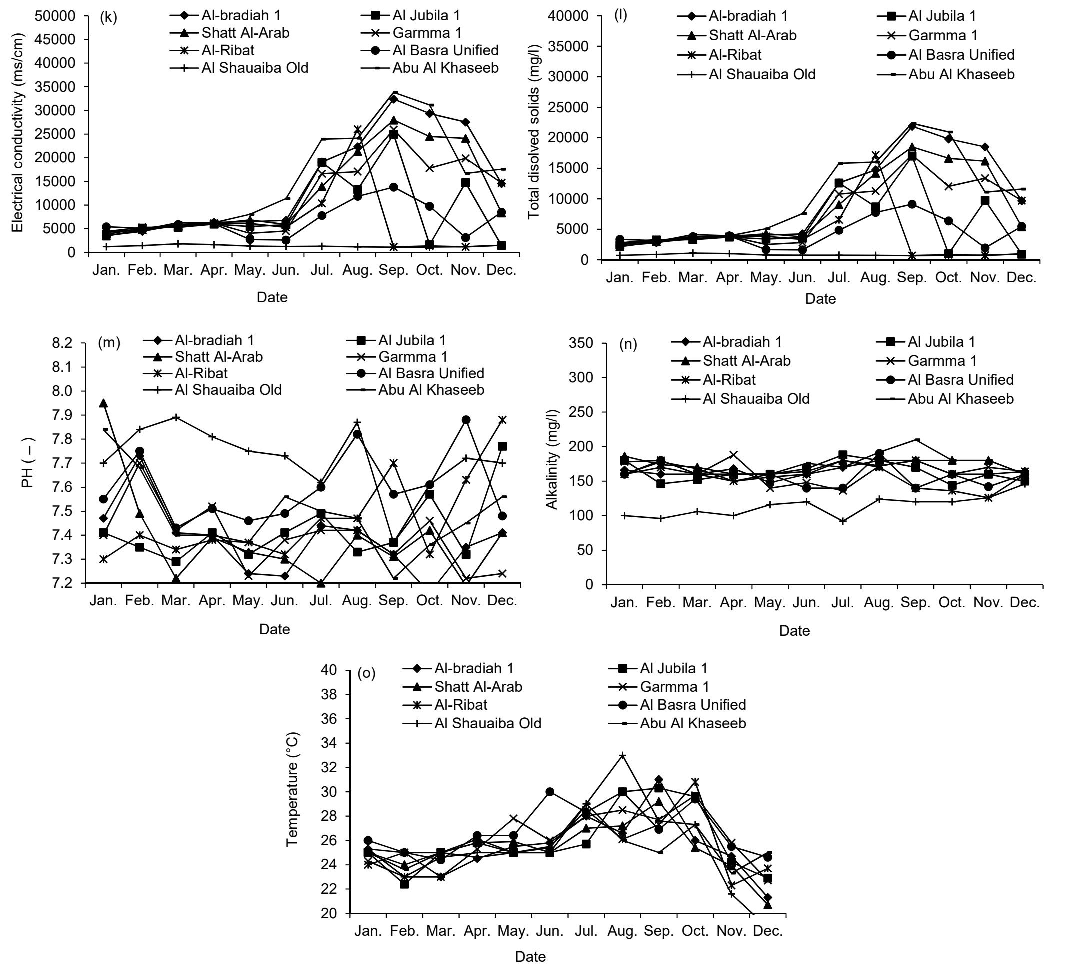


Figure 3. Monthly variations of raw water quality parameters during the period between January 2018 and December 2018: (**a**) aluminum; (**b**) potassium; (**c**) sodium; (**d**); magnesium; (**e**) calcium; (**f**) chloride; (**g**) sulphate; (**h**) total hardness; (**i**) turbidity; (**j**) total suspended solids; (**k**) electrical conductivity; (**l**) total dissolved solids; (**m**) pH; (**n**) alkalinity; and (**o**) temperature.

Findings showed that all treated water had Na levels that significantly exceeded the standards for drinking water, which are 200 mg/l, as recommended by ICS [26] and USEPA [30]. For people requiring a restricted Na intake, a threshold of 500 mg/day is recommended. Moreover, a value of 200 mg Na/l for drinking water has been suggested to allow for a good taste of the water (Table 9) [3]. Vomiting, nausea, thirst, convulsions, muscular twitching and possible death due to hypertension may result from orally overdosing with sodium chloride [30]. Furthermore, the treated water showed elevated Na levels that significantly exceeded the threshold for agricultural, which is 920 mg/l [30]. Only the Al Shauaiba Old plant had treated water with Na concentrations (109 mg/l) that would allow for water use in irrigation. Saline soil may be obtained when irrigated with water containing elevated Na concentrations, which will impact negatively on soil structure and permeability as well as on plant growth and productivity [34].

The Abu Al Khaseeb plant had treated water of the highest Mg concentration, which is similar to those of the Al-bradiah 1 plant followed by those for the Shatt Al Arab plant (Table 7). Statistically, there is no significant difference ($p > 0.05$) in Mg values for treated waters obtained from the Al-Ribat and Al Basra Unified plants. The Al-Garmma 1 WTP produced water with Mg levels higher than water from the Al Jubila 1 plant. Moreover, the Al Shauaiba Old plant produced the best effluent in terms of Mg concentrations, which were significantly ($p < 0.05$) lower than the ones for the other plants (Table 7). No exceedances were noted for treated water Mg values compared to the standards for drinking water, which are 50 mg/l, as indicated by ICS [26] and WHO [3], respectively. The World Health Organization indicated that drinking water portability may be impaired when concentrations of Mg plus Na sulphate exceeded 1000 mg/l [3]. In comparison, all treated waters (except for those obtained from the Al Shauaiba Old plant) had Mg values that considerably exceeded the irrigation threshold of 60 mg/l [30]. Irrigation water with high Mg concentrations may cause infiltration problems and subsequent drainage challenges for soil. The sodium impact on soil may increase when the Ca to Mg ratio (Ca/Mg) is less than one (Mg dominant water), which would reduce the yield of some crops such as sugar beets, wheat, maize and barley [29].

Regarding Ca concentrations, Table 7 shows that the maximum values were recorded for the water treated by the Abu Al Khaseeb plant followed by those for the Al-bradiah 1 and Shatt Al Arab plants. Slight differences were observed for Ca concentrations when compare to values of the Al Jubila 1 and Al-Garmma 1 plants. Statistically, the results indicated that there are no significant differences ($p > 0.05$) in Ca concentrations when comparing Al-Ribat and Al Basra Unified treated waters with each other, while the Al Shauaiba Old plant treated water had Ca values, which were significantly ($p < 0.05$) lower than the ones for the other plants (Table 7). Compared to the standard thresholds of 125 mg/l and 200 mg/l as indicated by ICS [26] and WHO [3], respectively, recommended for drinking purposes, Ca concentrations in the treated water were considerably elevated with the exception of those linked to the Al Shauaiba Old plant.

Regarding public health, Ca is important for the human body; mainly for strong teeth and bone building, activation of oocytes, contraction of muscles, clotting of blood, transmission processes, heart beat regulations and cells fluid balances. Sufficient Ca is also required during pregnancy, breast feeding and for the main growth periods of children. Calcium deficiency may result in the deterioration of bones, leading to increases in fractures (osteoporosis) as stated by Pravina et al. [35].

Compared to the irrigation standard threshold of 400 mg/l for Ca [29], results showed that all treated waters had Ca concentrations that were lower than this threshold, with the exception of the Abu Al Khaseeb and Al-bradiah 1 plants, which had treated waters of Ca concentrations slightly exceeding the threshold (Table 7). Calcium is a critical secondary nutrient for yield development as it is required in relatively large amounts for plant cell wall and temperance formations. Moreover, Ca is vital for the soil structure, as it displaces Na in the soil, resulting in soil quality improvements [29].

The Abu Al Khaseeb plant followed by the Al-bradiah 1 and Shatt Al Arab plants had waters with the highest Cl concentrations (Table 7). Statistically, no significant differences ($p > 0.05$) for Cl were observed in the treated waters obtained from the Al-Garmma 1 and Al Basra Unified plants when compared with the Al Jubila 1 and Al-Ribat plants, respectively, while the Al Shauaiba Old plant treated water resulting in Cl values, which were significantly ($p < 0.05$) the lowest. Treated water from all plants had Cl values that were considerably exceeding standard thresholds, which are 250 mg/l for drinking water, as indicated by ICS [26] and WHO [3], and 1063 mg/l for irrigation [30]. In treatment plants, Cl was added as a disinfectant to purify the water in terms of pathogens. Chlorine is available as an abundant ion in nature mainly in the form of salts. Exposure to Cl gas or liquid could be harmful even in small amounts. Highly contaminated drinking water with Cl may cause respiratory issues such as asthma and cell damage, mainly in children, as well as increasing the risk of bladder cancer [3]. Using Cl as a disinfectant is useful in managing and maintaining a drip irrigation system. However, highly chlorinated irrigation water may be toxic for plants, resulting in the slow-down of plant growth or even their death [29].

The highest sulphate concentrations were noted for the Abu Al Khaseeb plant followed by those for the Shatt Al Arab and Al-bradiah 1 plants (Table 7), while the lowest values were recorded for those waters from the Al Shauaiba Old plant followed by ones for the Al-Ribat plant. Statistically, the results showed that there is no significant ($p > 0.05$) difference in sulphate values when comparing treated waters of the Al-Ribat plant with those of the Al-Jubila1, Al Basra Unified and Al-Garmma 1 plants, while the Al Shauaiba Old one showed treated waters with sulphate values, which were significantly ($p < 0.05$) the lowest.

Compared to drinking water standards, treated waters from all plants had sulphate concentrations that considerably exceeded the thresholds of 400 and 250 mg/l for drinking water as indicated by the ICS [26] and WHO [3], respectively. According to the World Health Organization, drinking water with high sulphate concentrations may cause laxative effects mainly when the two hardness constituents (both Ca and Mg) are available [3]. Moreover, the sulphate levels for all treated waters considerably exceeded the irrigation standard of 960 mg/l [29]. High sulphate availability in the irrigation water may increase the salt levels in the soil, resulting in the reduced availability of phosphorus for plants, as reported by the FAO [29].

Water hardness is the amount of dissolved Ca and Mg in the water [3]. Similarly, the Abu Al Khaseeb and Al-bradiah 1 plants produced water of the highest hardness values followed by those of the Shatt Al Arab plant (Table 7). No significant differences ($p > 0.05$) were observed when comparing treated water hardness concentrations from the Al Jubila 1 and A-Ribat plants with those of the Al-Garmma 1 and Al Basra Unified plants, while the water hardness values for the treated water of the Al Shauaiba Old plant were significantly ($p < 0.05$) the lowest. The total hardness of water is mostly expressed as milligrams of Ca carbonate per liter [3].

The TH for the treated water had the highest concentrations for the Abu Al Khaseeb, Al-bradiah 1 and Shatt Al Arab plants (Table 7), while the lowest values were observed for the water obtained from the Al Shauaiba Old plant. No considerable differences were found when comparing the TH values for waters from the Al Jubila 1 and Al-Garmma 1 plants with those from the Al-Ribat and Al Basra Unified plants.

Concerning drinking water standards, the World Health Organization classified water based on Ca carbonate concentrations to be soft if the concentration of Ca carbonate is < 60 mg/l, moderately hard for concentrations between 60 and 120 mg/l, hard for values between 120 and 180 mg/l and very hard for values > 180 mg/l [3]. Based on this classification, treated water obtained from all plants can be classified as “very hard” (TH > 180 mg/l). Moreover, treated water from all plants (except for Al Shauaiba Old) showed TH values that considerably exceeded the Iraqi and WHO standards for drinking water, which are 500 mg/l and 300 mg/l, respectively [3,29].

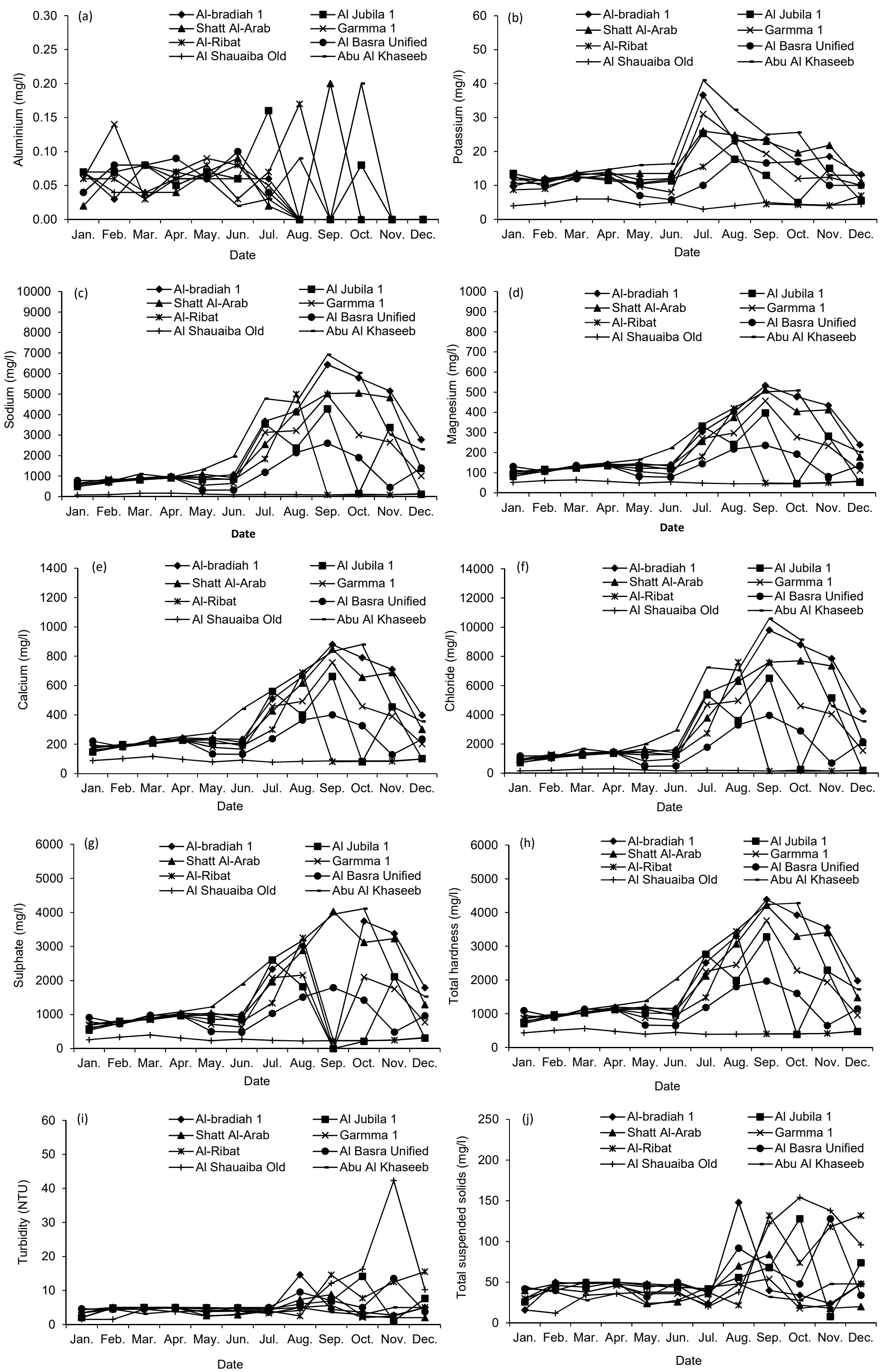
Generally, seasonal variations in concentrations were the highest during hot months (June to October) (Figure 4), possibly due to the high water demand caused by elevated temperatures. Moreover, the SAR, as the main raw water source, showed deteriorations in water quality parameters during hot months as well. No significant differences were observed when comparing the inflow and outflow water properties for all parameters, indicating that none of the treatment plants were fit-for-purpose.

3.2.2. Particles

The highest TSS concentrations were observed in the outflows of the Al-Ribat, Al Shauaiba Old and Al Basra Unified plants (Table 7), while the lowest values were recorded for the treated water of the Al-Garmma 1 plant followed by the Abu Al Khaseeb and Shatt Al Arab plants. Total suspended solids removal proportions were considerably better than those of other parameters, showing the highest value of 79% for the Al-bradiah 1 plant, followed by those for the Al-Garmma 1 (67%), Al-Ribat (66%) and Al Jubila 1 (62%) plants, while the lowest removals were recorded for the Al Shauaiba Old and Shatt Al Arab plants, showing values of 27% and 35%, respectively.

Furthermore, the results indicated that the maximum TUR values were measured for the treated water from the Al Shauaiba Old plant followed by those for the Al-Ribat one, while minimum values were observed for the Abu Al Khaseeb and Al-Garmma 1 plants (Table 7). Correlation analysis results show that TSS and TUR values were significantly positively ($R = 0.918$, $p < 0.001$) correlated with each other, confirming findings obtained by Hannouche et al. [36]. The results showed that some plants treated water with corresponding TUR effluent values, which exceed the permissible limit of 5 NTU for Iraqi standards for drinking water [29].

The Al Shauaiba Old plant usually showed the best water quality for treated water except for those related to suspended solids and TUR. The potential reasons for that are the high demand for water mainly at high temperature and bad weather leading plant operators to decrease the settling time in the sedimentation tanks resulting in elevated values for particles in treated water (Basra Water Directorate, personal communication on 30 July 2020).


(a)
Aluminium (mg/l)
(b)
Potassium (mg/l)
(c)
Sodium (mg/l)
(d)
Magnesium (mg/l)
(e)
Calcium (mg/l)
(f)
Chloride (mg/l)
(g)
Sulphate (mg/l)
(h)
Total hardness (mg/l)
(i)
Turbidity (NTU)
(j)
Total suspended solids (mg/l)
Al-bradiah 1
Al Jubila 1
Shatt Al-Arab
Garmma 1
Al-Ribat
Al Basra Unified
Al Shauaiba Old
Abu Al Khaseeb
Jan.
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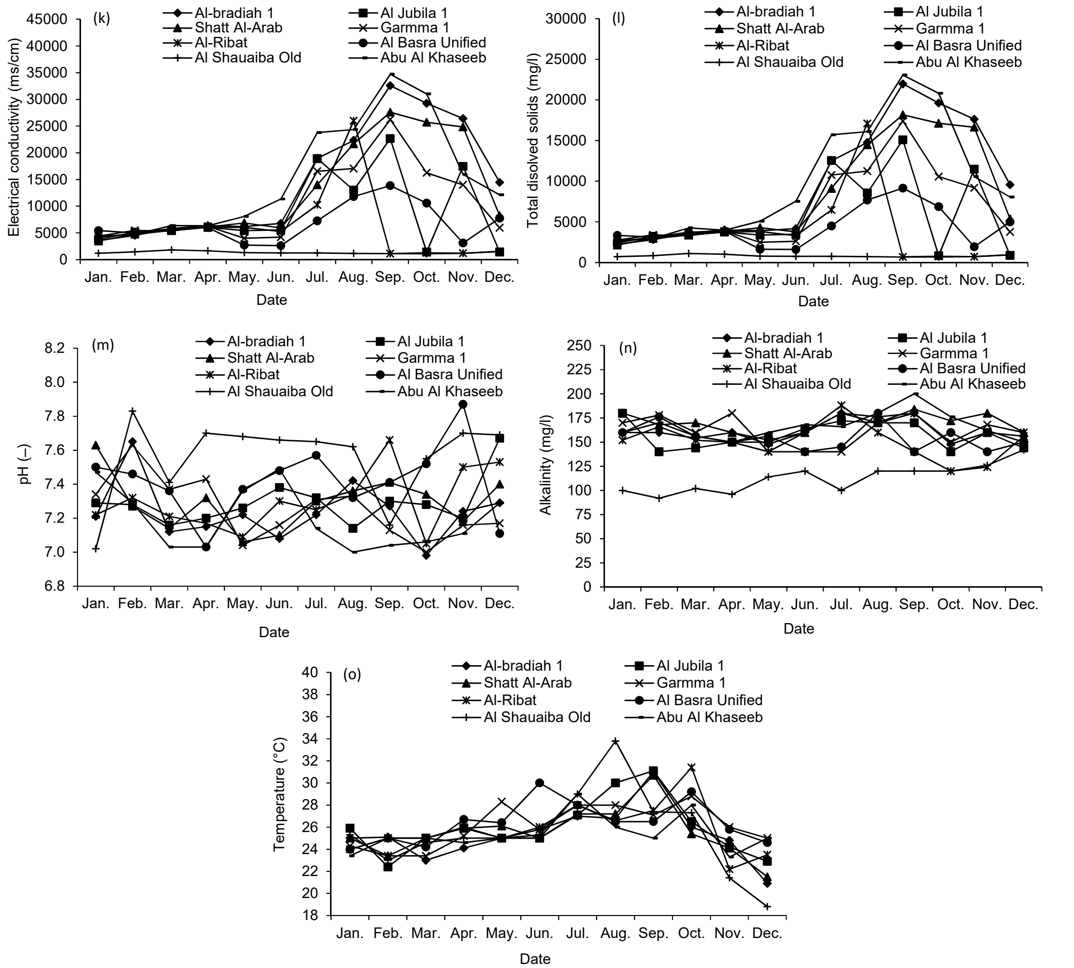

Figure 4. Monthly variations of effluent water quality parameters during the period between January 2018 and December 2018: (**a**) aluminum; (**b**) potassium; (**c**) sodium; (**d**); magnesium; (**e**) calcium; (**f**) chloride; (**g**) sulphate; (**h**) total hardness; (**i**) turbidity; (**j**) total suspended solids; (**k**) electrical conductivity; (**l**) total dissolved solids; (**m**) pH; (**n**) alkalinity; and (**o**) temperature.

3.2.3. Salinity

In this study, Table 7 shows the highest TDS and EC values for water obtained from the Abu Al Khaseeb treatment WTP followed by those for the Al-bradiah 1 and Shatt Al Arab plants, while the lowest values were observed for water treated by the Al Shauaiba Old plant, followed by the Al-Ribat and Al Basra Unified plants. A correlation analysis showed that TDS and EC were significantly positively ($R = 0.999$, $p < 0.001$) correlated with each other, confirming the results obtained by Rusydi [37]. However, all treated waters showed TDS concentrations that considerably exceeded the drinking water standard of 500 mg/l, as recommended by USEPA [30], resulting in very bad water quality, since the elevated TDS content in the drinking water may result in high hardness, bad taste and an elevated laxative effect.

Electrical conductivity is a parameter that is measured for an indirect indication of water salinity in the water and agricultural sectors [31]. Irrigation water standards recommend the EC to be 3 mS/cm. All treated waters had values that significantly exceeded this threshold. Irrigation with such amounts of saline water will lead to saline soils (Table 7), which are linked to reduced plant growth and associated yield quality as well as unfavorable soil permeability and structure [34]. The results showed that all plants (except the Al Shauaiba Old) provide water with TDS concentrations that are considerably higher than the drinking water standard of 1000 mg/l [29].

Generally, an increase in TDS results in elevated K and Mg (see section of treated water ions). The main reason for high TDS is the shortage of the water reaching the SAR, which leads to the intrusion of the salinity coming from the Arabian Gulf. Most WTPs in Basra are supplied by the SAR, except for plants that are far away from the river such as the Al Shauaiba Old plant. Therefore, the results showed a sudden increase in TDS and associated parameters for the months of June, July, August and September. This is due to the fact that existing WTP are conventional and lacking treatment units to reduce salinity, such as reverse osmose [9].

3.2.4. Alkalinity and pH

For treated water, Table 7 shows that the maximum alkalinity values were recorded for the Shatt Al Arab and Abu Al Khaseeb WTP, while the Al Shauaiba Old plant showed significantly ($p < 0.05$) low values. Alkalinity is an indication of the ability of waters to neutralize acids added to them. Therefore, this parameter indicates the buffering capacity of waters [3]. Dissolved hydroxides, carbonates and bicarbonates are the most important chemicals that may affect the water alkalinity [3]. According to drinking water standards [30], alkalinity with moderate levels is preferred in a water supply to control the effect of corrosively caused by acidity. The United States Environmental Protection Agency (USEPA) stated the regulation limits for drinking water alkalinity only in terms of TDS, which should be about 500 mg/l (subject to pH limitations) [30]. On the other hand, from an agricultural point of view, elevated alkalinity within irrigation water may result in increasing soil pH values, and subsequently, to a reduction in the availability of micro-nutrients and low pesticide efficiency for the protection of plants. The Food and Agriculture Organization recommended the maximum alkalinity value for irrigation water to be 100 mg/l [30].

All treated water was basic (alkaline) in character (pH > 7). However, all waters were within the recommended range by WHO [3] and ICS [26], which is between 6.5 and 8.5 for drinking water purposes. Generally, water treated by the Al Shauaiba Old plant showed the highest pH values (7.56), while the lowest ones (7.19) were observed for those waters treated by the Abu Al Khaseeb plant. This indicates the negative correlation between water alkalinity and pH values as shown statistically ($R = -0.156$, $p = 0.128$).

In water treatment system operation, the pH is considered to be one of the most important parameters. The water pH should be controlled in the different treatment stages and may not be less than 8 for satisfactory clarification and disinfection. Moreover, treated water pumped to the distribution system should be monitored and controlled at all times to avoid the risk of water mains and household pipe corrosion. Otherwise, the distributed water will be contaminated and there will be problems in water odor, taste and appearance [3]. All treated waters had pH values that did not exceed the irrigation limits, which are between 6.5 and 8.4 as recommended by FAO [29].

3.3. Water Quality Index

Figure 5 shows the spatial variation of annual WQI for the raw and treated water for all the stations. It can be seen that all stations were within the limits of unsuitable water quality except for Al-Ribat, which had treated water within the limits of very poor water quality, and the treated water of Al-Shauaiba was within the limits of good water quality. The reason behind the bad water quality of all stations except for the Al-Shauaiba plant is the effect of pollution and salinity intrusion of the Arabian Gulf into the Shatt Al Arab River, which is considered the second source of raw water for the stations that are located on its banks. In comparison, the Al-Shauaiba plant is located far away from the river and the raw water is only taken from R-Zero, which had good water quality. It can also be sees that the Abu Al Khaseeb, Al-bradiah 1 and Shatt Al Arab plants always had unsuitable water quality due to the effect of the Arabian Gulf. The locations of Al-Ribat and Al-Basra Unified were unaffected by salinity intrusion from the Arabian Gulf, but Al-Garmma 1 is located on the Al-Garmma river that is connected with the Euphrates river, which has a high level of salinity.

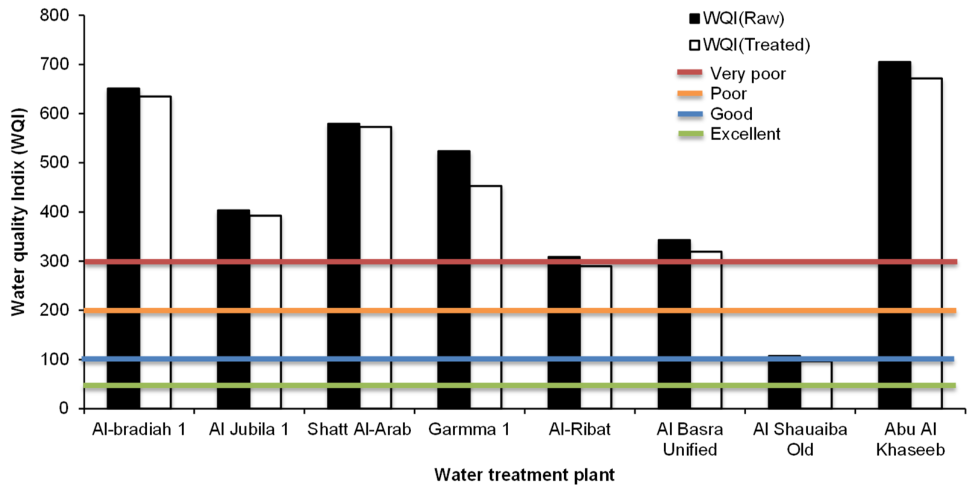

Figure 5. Variation of the annual water quality index (WQI) for the raw and treated water for all stations.

Figure 6 and Table 8 show the seasonal variation of the WQI for the raw water for all WTP. It can be seen that all stations had unsuitable water quality except for Al-Ribat and Al-Shauaiba, which were within the limits of poor water quality in autumn. The improvement in water quality for the seasons winter and spring was because of the high discharge of SAR river water. In summer, a deterioration in water quality for all WTPs except for Al-Shauaiba was noted. This was due to the shortage of incoming water to the SAR from the Tigres river. From Figure 6, it can be conclude that the stations that are far from the estuary and influence the salinity wedge were of better water quality. For the Al Shauaiba Old plant, which received water only from the SWC, the water quality was better.

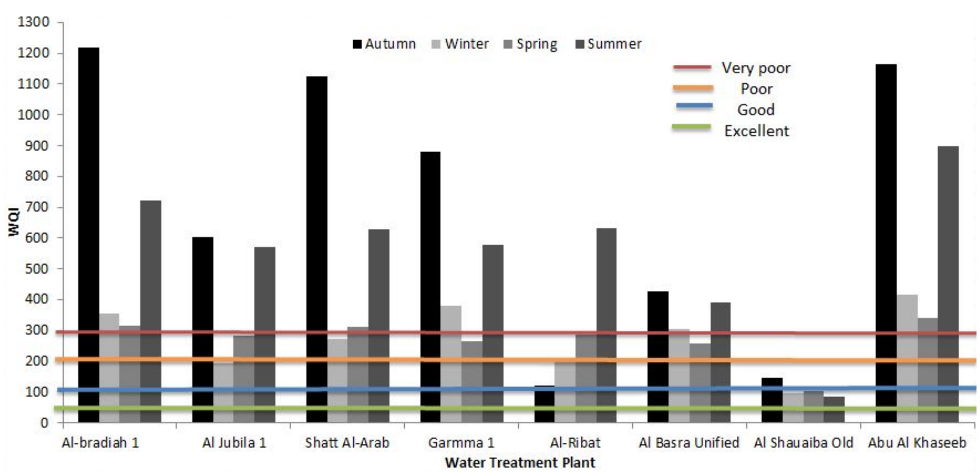

Figure 6. Variation of seasonal water quality index (WQI) for the raw water for all stations.

Figure 7 shows the seasonal variation of the WQI for the treated water for all WTP. A small improvement in water quality after the treatment can be seen. However, most of the WTP were malfunctioning, needed maintenance or were subjected to poor management.

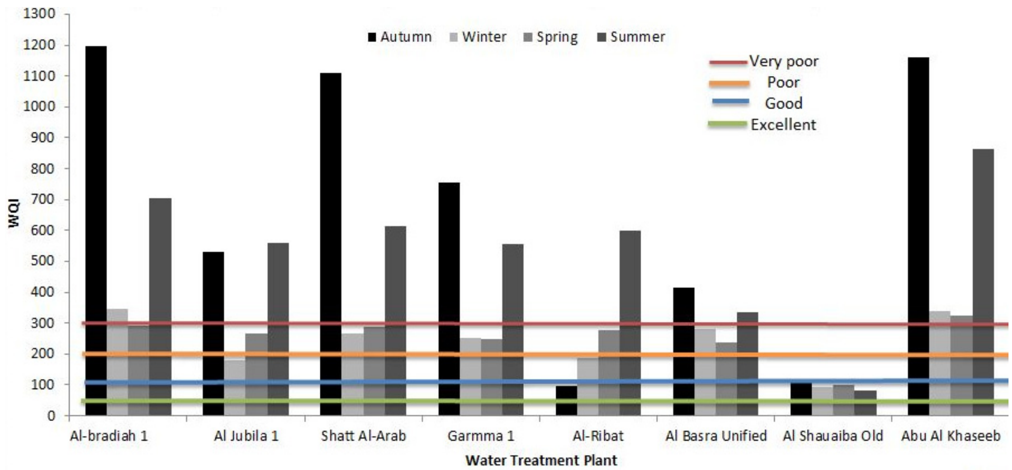

Figure 7. Variation of seasonal water quality index (WQI) for the treated water for all stations.

Efficiency of the Water Treatment Plants

The annual mean values of the water quality index and the corresponding efficiencies are presented in Table 10. It can be seen that the highest efficiency is linked to Al-Garmma 1, which was, however, only about 14%. In comparison, the lowest efficiency was noted for Shatt Al Arab, which was 1.17%. In general, all stations had bad removal efficiencies for all parameters. All plants were designed to remove turbidity and TSS as well as disinfect the water. However, plant maintenance has been neglected. In order to address the chemical pollution challenge, further advanced treatment with, for example, reverse osmosis should be considered.

Table 10. Annual mean values of the water quality index (raw and treated water) and the efficiency.

Station	WQI (Raw)	WQI (Treated)	Efficiency (%)
Al-bradiah 1	651.29	634.827	2.53
Al Jubila 1	403.64	392.387	2.79
Shatt Al Arab	579.65	572.866	1.17
Al-Garmma 1	524.12	452.966	13.58
Al-Ribat	309.16	289.690	6.30
Al Basra Unified	343.04	319.245	6.94
Al Shauaiba Old	107.44	96.566	10.12
Abu Al Khaseeb	705.40	671.535	4.80

3.4. Application of Cluster Analysis

Cluster analysis can be used as a tool for analyzing the relationships between water quality parameters and sampling stations. The raw and treated water quality parameters for all WTP have been processed using SPSS statistical software. The results of the cluster analysis are shown in Figure 8 for raw water. Clusters I and II consist of four stations each: Al-Ribat, Al Basra Unified, Al Jubila 1 and Al Shauaiba Old, and Al-bradiah 1, Abu Al Khaseeb, Shatt Al Arab and Al-Garmma 1, respectively. This classification indicates stations with similar raw water properties. The effect of salinity intrusion from the Arabian Gulf on the WTPs that are located near the estuary is indicated by cluster II. It is worth noting that Al-Garmma 1 is effected by the Euphrates river, which is a tributary to SAR and has bad water quality. Other stations, which are represented by Cluster I, are linked to better water quality compared to Cluster II. This is due to the source of water being either located far away from the estuary or being influenced by SWC feed.

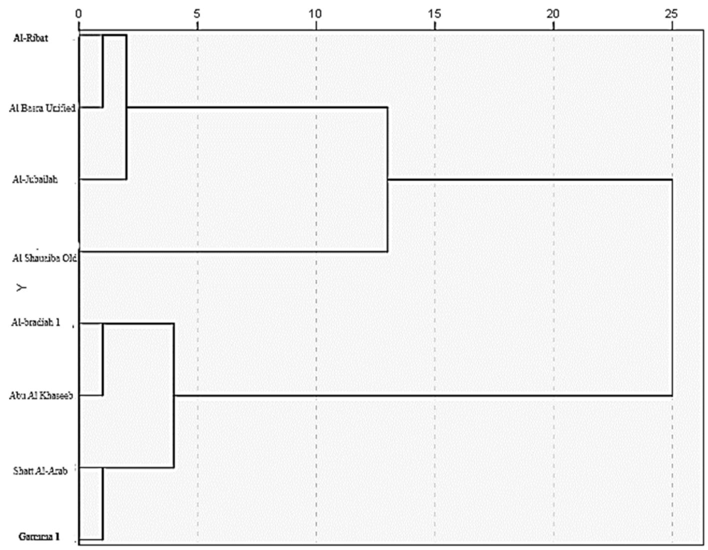

Figure 8. Dendrogram of the raw water for the WTPs.

The dendrogram shown in Figure 9 groups raw water quality parameters into three statistically significant clusters: cluster I corresponds to turbidity, K, pH, Mg, alkalinity and Ca; cluster II comprises TH, SO_4 , Na and Cl; and cluster III is linked to TDS and EC. Some of these groupings are intutitive in terms of some of the corresponding parameter relationships, e.g., for cluster I, an increase of pH leads to an alkalinity increase, and for cluster 3, an increase of TDS leads to an EC increase.

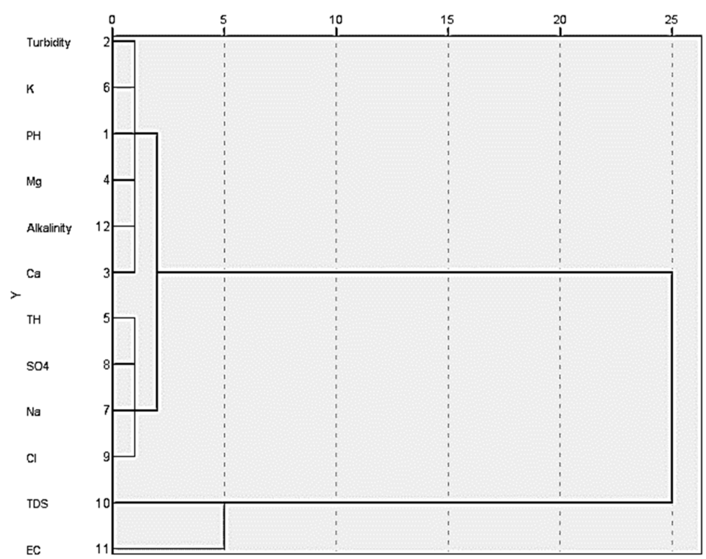

Figure 9. Dendrogram of the water quality parameters of raw water.

3.5. Irrigation Water Quality Assessment

The EC and SAR values are plotted in a Wilcox diagram (Figure 10) for the winter season, which is considered to be the best season with regard to water quality. The water samples of Al Shauaiba Old are located in class C3-S1, which is considered as admissible regarding the Wilcox classification (Table 6). The water has high salinity but low Na content, and can be used for irrigation for all types of soil at only a low risk of exchangeable Na. Other water samples are located in classes C4-S3 and C4-S4, which are classified as very poor in terms of water quality. Hence, the class C4 is unsuitable for irrigation. Since the winter season is considered the best season in this study, it can be summarised that none of the stations are suitable for irrigation, except for Al Shauaiba Old, which shows good water quality for all seasons.

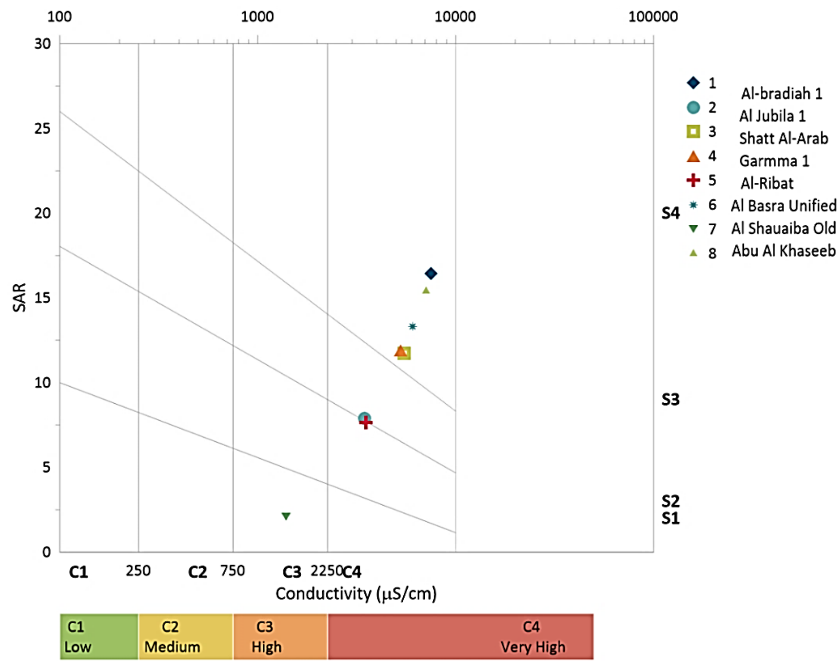

Figure 10. Wilcox diagram for irrigation water quality assessment.

4. Conclusions and Recommendations

Results show that the water quality is currently unsatisfactory for drinking purposes for all WTPs, except for Al Shauaiba Old, which shows good water quality for all seasons. The other WTPs ranged in terms of water quality between unsuitable and poor. The WTPs that are located near the estuary were worse than others. The wet season was linked to better water quality than the dry season.

The main reason for water deterioration is insufficient water quantity supplied to the city and the intrusion of a salinity wedge to the SAR, which is the main water source for most WTPs in this area. The results also show that most of the studied WTPs treat water with very low efficiency rates due to operation and maintenance challenges.

The water samples of Al Shauaiba Old are located in class C3-S1, which is considered as admissible regarding the Wilcox classification. The water has high salinity but low Na content, and can be used for irrigation for all types of soil at only a low risk of exchangeable Na. Other water samples are located in classes C4-S3 and C4-S4, which are classified as very poor in terms of water quality.

The authors recommend the following measures for improving the water quantity and quality situation for Basra and other regions facing similar challenges according to three lists of priority. High priority:

- To develop sustainable and alternative water supply sources such as constructed wetlands for raw water and wastewater treatment as well as lakes/ponds and reservoirs for rainwater harvesting.
- To continuously monitor the water supply network conveying treated water to the consumers, avoiding any uncontrolled water contamination.
- To establish public education plans for consumers to reduce the water demand during the hot season.

Medium priority:

- To improve and control water resource management strategies to achieve adequate water supply and reduce saline intrusion challenges.
- To construct water storage facilities to address water scarcity challenges.
- To build water holding facilities to store access water and control flooding linked to snow melts during spring.
- To manage stored water in a strategic manner to address sea water salinity wedge formation.
- To construct activated carbon units to improve water color, taste and smell.

Low priority:

- To build compact desalination units such as reverse osmosis at the site of the conventional water treatment plant to reduce salinity (TDS) to the appropriate levels.
- To control point source pollution negatively affecting raw water quality such as domestic and industrial wastewaters as well as drainage waters due to agricultural activities.
- To increasing the capacity and efficiency of water treatment plants.
- To continuously monitor WTP maintenance.
- Improve the technical management capacity, budget and skill development for technicians.

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References

1. Reza, R.; Singh, G. Assessment of ground water quality status by using water quality index method in Orissa, India. *World Appl. Sci. J.* **2010**, *9*, 1392–1397.
2. Janna, H.; Al-Samawi, A.A. Performance Evaluation of Al-Karkh Water Treatment Plant in the City of Baghdad. *Int. J. Adv. Res.* **2014**, *2*, 823–829.
3. WHO. *Guidelines for Drinking-Water Quality: Recommendations*, 3rd ed.; World Health Organization: Geneva, Switzerland, 2004; Volume 1.
4. Ibrahim, A.Q.; Onyenekwe, P.C.; Nwaedozie, I.M. An efficiency assessment of Lower Usuma water treatment plant in Abuja Metropolis, Nigeria. *IOSR J. Environ. Sci. Toxicol. Food Technol.* **2014**, *8*, 46–53.
5. Mohammed, A.A.; Shakir, A.A. Evaluation the Performance of Al-Wahdaa Project Drinking Water Treatment Plant: A case study in Iraq. *Int. J. Adv. Appl. Sci.* **2012**, *1*, 130–138.
6. Alobaidy, A.H.; Maulood, B.K.; Kadhem, A.J. Evaluating raw and treated water quality of Tigris River within Baghdad by index analysis. *J. Water Resour. Prot.* **2010**, *2*, 629–635.
7. Zhang, K.; Achari, G.; Sadiq, R.; Langford, C.H.; Dore, M.H. An integrated performance assessment framework for water treatment plants. *Water Res.* **2012**, *46*, 1673–1683.
8. Varadhajan, R.B. *Importance of Biological Parameters of Water Quality to Reform Water Quality Index in Practice*; Advances in Environment, Computational Chemistry and Bioscience; WSEAS Press: Montreux, Switzerland, 2009, pp. 199–204.
9. Hamdan, A.N.A. The Assessment of the quality of water treatment plants effluent of Basrah City for irrigation. *Wasit J. Eng. Sci.* **2016**, *4*, 36–52.
10. Human Right Watch. *Basra is Thirsty Iraq's Failure to Manage the Water Crisis*; Report 22nd July 2019; ISBN: 978-1-6231-37502. Available online: http://www.hrw.org (accessed on 26 November 2020).
11. Al-Jeebory, A.A.; Ghawi, A.H. Performance Evaluation of AL-Dewanyia water treatment plant in Iraq. *Al-Qadisiyah J. Eng. Sci.* **2009**, *2*, 836–853.

12. Abdal-Hussein, N.A. Evaluation of raw and treated water quality of Hilla River within Babylon province by index analysis. *Mesop. Environ. J.* **2015**, *1*, 16–25.
13. Shakir, E. Assessment of nutrient content of raw water close to water treatment plants located in Baghdad City. *Desalin. Water Treat.* **2016**, *57*, 18229–18233.
14. Al-Anbar, L.J.; Al-Imarah, F.J.; Essa, A.M.; Mohammad, I.K.; Aymen, F.G. Assessment of Water Quality for Drinking Water Supplies Plants at Basrah, Iraq. The Fifth Scientific Conference of Faculty of Sciences. *J. Kerbala Univ.* **2017**, *1*, 98–187.
15. Mohammed, R.A. Water Quality Index for Basrah Water Supply. *Eng. Technol. J.* **2013**, *31*, 1543–1555.
16. Al Chalabi, A.S. Assessment of Drinking Water Quality and the Efficiency of the Al-Buradieiah Water Treatment Plant in Basra City. *Nat. Environ. Poll. Technol*. 2020,19, 1057-1065.
17. Hamdan, A.N.A. Evaluation of water treatment plants quality in Basrah Province, by factor and cluster analysis. *J. Water Land Dev.* **2020**, *46*, 10–19.
18. Al-Badran, F.A. Determination of Water Quality Index and Suitability of Shatt Al Arab River and Treated Water for Some Treated Plants in Basrah. *Basra J. Eng. Sci.* **2013**, *13*, 50–62.
19. Al-Kaabi, M.M.S. The water crisis in Basrah Governorate-its causes, effects and ways to address them. *Basra Stud. J.* **2019**, *33*, 77–116.
20. JICA. *The Feasibility Study on Improvement of the Water Supply System in Al-Basrah City and Its Surroundings*; Final Report, January 2007; Ministry of Municipalities and Public Works: Baghdad, Iraq, 2007.
21. Gatea, M.H.; Dakhil, A.J.; Dawood, A.S. Evaluation of water quality parameters for Shatt Al-Basrah Canal in Basrah authorities. *Sci. J. Univ. Zakho* **2018**, *6*, 177–181.
22. APHA. *Standard Methods for the Examination of Water and Wastewater*, 21st ed.; American Public Health Association (APHA), American Water Works Association, and Water and Environment Federation: Washington, DC, USA, 2005.
23. Hamdan, A.N.A. The use of water quality index to evaluate groundwater quality in West of Basrah Wells. *Kufa J. Eng.* **2017**, *8*, 51–64.
24. Dawood, A.S.; Hamdan, A.N.; Khudier, A.S. Assessment of water quality index with analysis of physio-chemical parameters. Case study: The Shatt Al-Arab River, Iraq. *Int. Energy Environ. Found.* 2018, 93-106..
25. Rokbani, M.K.; Gueddari, N.; Bouhlila, R. Use of geographical information system and water quality index to assess groundwater quality in El Khairat Deep Aquifer (Enfidha, Tunisian Sahel). *Iran. J. Energy Environ.* **2011**, *2*, 133–144.
26. ICS. *Iraqi Criteria and Standards for Drinking Water Chemical Limits*; ICS: 13.060.20, IQS: 417:2009, Second Update 2009 for Chemical and Physical Limits; Governmnet of Iraq: Baghdad, Iraq, 2009.
27. Shrestha, S.; Kazama, F.; Nakamura, T. Use of principal component analysis, factor analysis and discriminate analysis to evaluate spatial and temporal variations in water quality of the Mekong River. *J. Hydroinform.* **2008**, *10*, 43–54.
28. Simeonov, V.; Simeonova, P.R. Tsitouridou. Chemometric quality assessment of surface waters: Two case studies. *Chem. Eng. Ecol.* **2004**, *11*, 449–469.
29. FAO. *The State of Food and Agriculture: Investing in Agriculture for a Better Future*; Food and Agriculture Organization (FAO) of the United Nations: Rome, Italy, 2012.
30. USEPA. *Guidelines for Water Reuse*; EPA/600/R-12/618; United States Environmental Protection Agency (USEPA): Washington, DC, USA, 2012.
31. Sebastian, A.; Frassetto, L.A.; Sellmeyer, D.E.; Morris, R.C., Jr. The evolution-informed optimal dietary potassium intake of human beings greatly exceeds current and recommended intakes. *Semin. Nephrol.* **2006**, *26*, 447–453.
32. Hakerlerler, H.; Oktay, M.; Eryüce, N.; Yagmur, B. Effect of Potassium Sources on the Chilling Tolerance of Some Vegetable Seedlings Grown in Hotbeds. In *Food Security in the WANA Region, The Essential Need for Balanced Fertilization*; Johnston, A.E., Ed.; International Potash Institute: Horgen, Switzerland, 1997, pp. 317–327.
33. Cakmak, I. The role of potassium in alleviating detrimental effects of abiotic stresses in plants. *J. Plant Nutr. Soil Sci.* **2005**, *168*, 521–530.
34. Maas, E.V.; Grattan, S.R. Crop yields as affected by salinity. *Agronomy*. **1999**, *38*, 55–110.
35. Pravina, P.; Sayaji, D.; Avinash, M. Calcium and its role in human body. *Int. J. Res. Pharm. Biomed. Sci.* **2013**, *4*, 659–668.

36. Hannouche, A.; Ghassan, C.; Ruban, G.; Tassin, B.; Lemaire, B.J.; Joannis, C. Relationship between turbidity and total suspended solids concentration within a combined sewer system. *Water Sci. Technol.* **2011**, *64*, 2445–2452.
37. Rusydi, A.F. Correlation between conductivity and total dissolved solid in various type of water: A review. *IOP Conf. Ser. Earth and Environ. Sci.* **2018**, *118*, 12019–12025.