

A comparison between weighted arithmetic and Canadian methods for a drinking water quality index at selected locations in shatt al-kufa

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Abstract. Shatt Al- Kufa (Kufa River) is the major supply of surface waters in Najaf; the length and width of the river are 73 km and about 100 m respectively. In the various seasons of the year, the water level at the river is unstable, and population increases and higher living standards are likely to cause increased demand for the river water; thus, river water quality is a key concern, especially for drinking purposes.

Water Quality Index (WQI) is defined as a rating reflecting the compound effects of various water quality determinants on the total quality of water. WQI is a mathematical tool used to convert large amounts of water quality data into a single number, providing a simple and explicable tool for managers and decision-makers to use to examine the quality and potential uses of a given body of water.

This study is concerned with assessing an appropriate WQI for drinking use at several locations on Shatt Al-Kufa. The twelve water quality parameters of pH, Turbidity (Turb.), Electrical Conductivity (EC), Alkalinity (Alk.), Total Dissolved Solid (TDS), Total Hardness (T.H), Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Sodium (Na^{+}), Potassium (K^{+}), Chlorides (Cl^{-1}) and Sulphate (SO_4) were studied over a period of ten months (January to October 2014) for nine selected locations, including Zerkh, Kufa, Manathira, Hira, Mashkhab and Qadisiya on Shatt Al-Kufa. Two methods (Weighted Arithmetic and Canadian) were applied to classify the WQI of the treated river water for drinking use, and then a comparison of the two methods was made to ascertain the difference between them.

The Results of the overall and seasonal WQI according to both the Weighted Arithmetic Method and the Canadian method were classified as good (50.1 to 100 and 80 to 94, respectively) in all selected locations with the exception of certain locations in the winter season that applied to both methods.

The results indicate that the difference between the two methods is very small; the high values of EC and high concentrations of SO_4 were the main reasons lowering the water quality index in all locations according to both methods.

Key words: Water quality index, Shatt Al-Kufa, Kufa, Weighted Arithmetic method, Canadian method.

1. Introduction

Water resources are considered the controlling force behind all vital, economic, social, developmental, and environmental events of any country in the world: scarcity in particular affects all development programmes and projects in all areas of life.

The volume of water on Earth is about 1.4 billion cubic kilometres, and this does not increase or decrease. The salt water percentage is almost 97.5%, while fresh water represents only 1.76% of all water, much of which is located permanently freezing places. Thus less than 0.4% of the world's water is in rivers, lakes, reservoirs, the soil and the atmosphere [1].

Water pollution is a serious problem for human health and the environment, and all people require good drinking water quality to maintain their personal well-being. Drinking water should be aesthetically pleasant, clear, colourless and well aerated with no unpalatable taste and odour. Microbiological, physical, chemical and radiological characteristics are also used to determine its suitability in terms of public health [2].

WQI is as a rating that reflects the compound effect of various water quality determinants on the total quality of water [2].



It is a mathematical tool used to convert large amounts of water quality information to a single number, which provides tool for managers and decision – makers seeking to determine the quality and potential uses of a given body of water [3].

Some variables have great importance uses, but may not be of the same importance for others: each use has various water quality requirements. Total dissolved solids (TDS), total hardness (TH), chloride (Cl^-), sulphate (SO_4^{2-}), biochemical oxygen demand (BOD), pH, and calcium (Ca^{+2}) are the effective parameters for drinking purposes [4].

Shatt Al-Kufa (Kufa River) is a branch of the Euphrates River. It passes through Kufa north of Najaf city and supplies water to both cities. This river has shown decreasing quantity and quality of water because of population expansion and increased farming and urbanization; urban and farming wastes have been enlarged significantly and have made their way into the river. Issues with water quality have thus become more significant than quantity issues, making it necessary to conduct detailed studies to evaluate the suitability of this river for various purposes.

1.1 Study purpose

- Determine the physical and chemical parameters of surface water at various positions in the Shatt Al-Kufa.
- Calculate WQI using two different methods (Weighted and Canadian) to evaluate the suitability of treated water samples from different sampling positions of Shatt Al-Kufa for drinking use.
- Compare the results of the two methods so obtain a better view of the reasons for the decline in water quality.

2. The study area

Kufa is known to be one of the hottest and driest place in Iraq. It is situated between $32^{\circ} 04'$ to 32° northern longitude and $44^{\circ} 26'$ to $44^{\circ} 23'$ eastern latitude [5], about 170 km south of Baghdad, the capital of Iraq, and 10 km northeast of Najaf. It is sited on the banks of the Shatt Al-Kufa which is branch of the Euphrates River. After Al-Kifil city, Euphrates river divides into two rivers: Shatt Al-Kufa with a length and width of 73 km and about 100 m respectively, and Al-Abbasiyya. Rainfall water and stored water in ponds and reservoirs are the main source of water for Shatt Al-Kufa, and throughout the year, the water level is unstable. The areas surrounding the river are famous for agriculture, and some residential buildings are placed on the other side [6]. Many towns and villages are located on Shatt Al-Kufa and thus the river represents the major supply for various purposes such as drinking water, irrigation and industrial purposes.

In this study Shatt Al-Kufa in Kufa city was selected as a case study. Nine locations were selected on this river for analysis of the water quality parameters considered to be the most important in the use of water for drinking, as illustrated in Figure 1. Table 1 shows the nine selected locations and their local names.

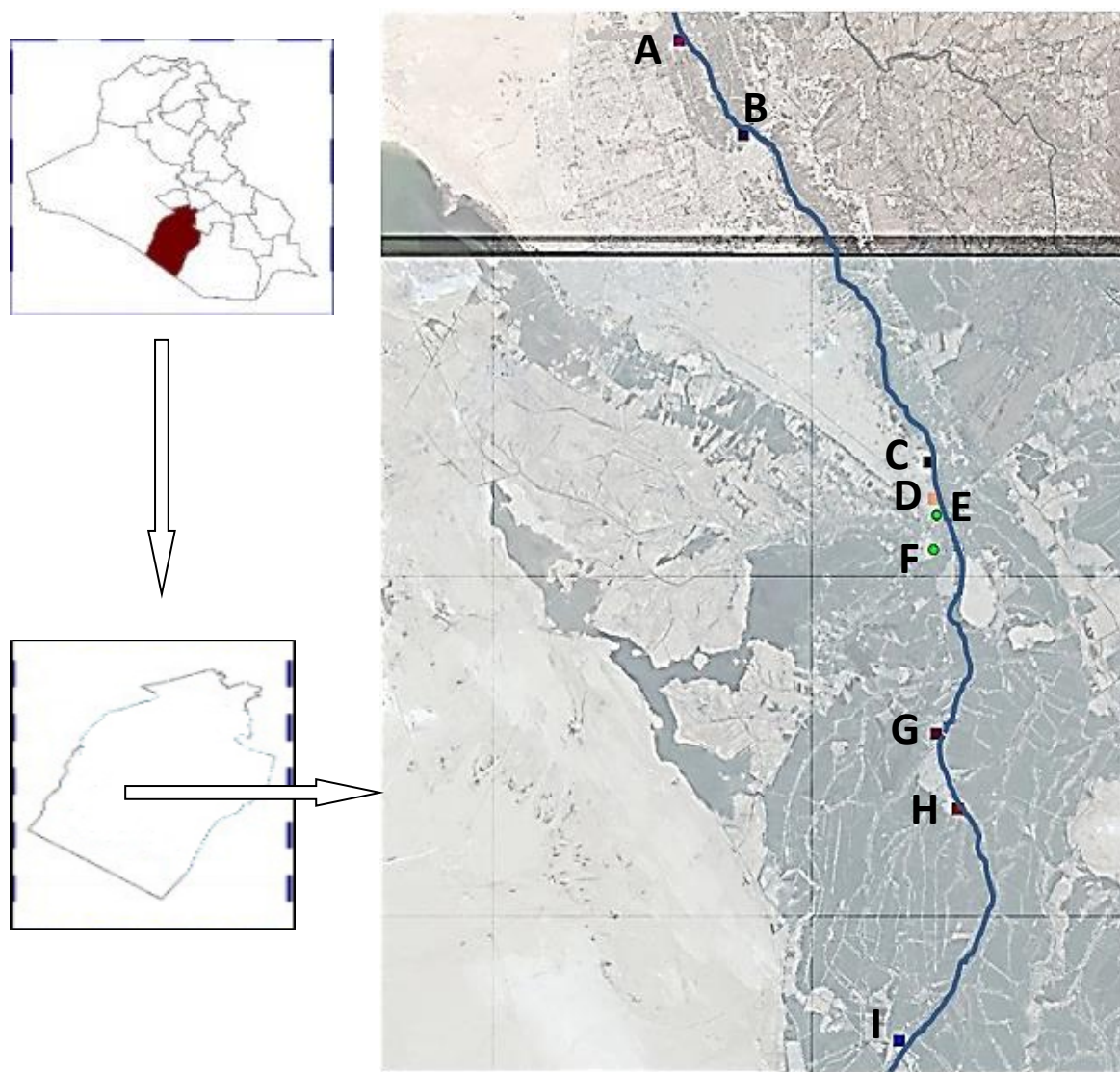


Figure 1. Location of the study area in Iraq and sampling locations

Table 1. Selected locations on Shatt Al-Kufa

No.	1	2	3	4	5	6	7	8	9
Symbol	A	B	C	D	E	F	G	H	I
Location	Zerkh	Kufa	Manathira	Manathira	Hira	Hira	Mashkhab	Mashkhab	Qadisiya

3. Samples collection

Water samples were taken from nine positions along Shatt Al-Kufa from the Al- Zerkh area to Al-Qadisiya to determine the treated water quality index for the period from January 2014 to November

2014, ten months in all. These samples were analysed in the laboratories of the Water Resources Management / Ministry of Water Resources in Iraq. The results of analysis are given in Table 2.

Table 2. Statistical information for drinking treated water parameters at Shatt Al-Kufa during the study period

Parameters +Standard *	Statistical Indices	Locations								
		A	B	C	D	E	F	G	H	I
pH WHO = 8.5	Mean**	7.68	7.62	7.61	7.6	7.58	7.64	7.63	7.6	7.53
	SD	0.11	0.18	0.242	0.117	0.119	0.177	0.2	0.182	0.27
	Max.	7.9	7.9	8	7.7	7.8	7.8	8.1	7.8	7.9
	Min.	7.5	7.3	7.3	7.4	7.4	7.3	7.4	7.3	7.1
Turb. WHO = 5 NTU	Mean	5.54	7.84	2.33	2.34	4.21	3.67	3.1	3.13	5.03
	SD	4.88	2.25	1.91	1.69	2.59	1.49	1.8	2.08	2.15
	Max.	13.6	10.7	6.79	5	9.6	5	6.3	7.7	9.4
	Min.	0.4	3.2	0.48	0.90	1.95	1	1.05	0.95	2.4
EC WHO = 1000 µmho /cm	Mean	1376	1508	1350	1329	1407	1380	1381	1422	1472
	SD	336.4	434. 3	264.1	112.8	255	237.6	279.3	278.9	212
	Max.	2231	2596	1887	1441	1901	1825	1916	1817	1676
	Min.	1037	1097	1111	1126	1114	1116	1115	1127	1105
ALK. WHO = 120 mg/l	Mean	118.2	122. 6	119.4	117.4	124.3	123.7	121.8	122.5	124. 5
	SD	7.74	11.1 1	8.321	5.7	5.36	3.145	7.6	10.39	6.87
	Max.	130	146	130	124	132	130	129	138	138
	Min.	110	111	102	108	118	120	104	106	116
TDS WHO =1000	Mean	866	941. 9	841.3	845.7	882.4	854	880.1	906.4	930. 7
	SD	231.2	269. 5	152.0	100.9	161.7	127.7	167.1	167.7	178. 1

mg/l	Max.	1462	1616	1149	966	1157	1032	1179	1166	1178
	Min.	635	678	708	702	682	682	704	698	618
T.H WHO = 500 mg/l	Mean	420.6	452	422.6	414.5	431.6	420.5	422.3	429.4	456.1
	SD	72.39	84.75	61.29	32.96	43.72	24.51	55.02	71.69	46.4
	Max.	602	638	518	460	503	460	528	532	486
	Min.	336	374	330	370	370	396	348	329	353
Ca ⁺² WHO = 200 mg/l	Mean	90.4	100.6	96.1	102	97.03	96.3	90.74	96.82	104.3
	SD	12.89	20.61	17.73	10.94	15.34	17.65	16.93	19.08	14.17
	Max.	114	136.8	122	113.2	117	117.2	118.2	129.2	125.1
	Min.	71.5	73	69.4	82.1	73.92	72.53	73.8	76.42	79.7
Mg ⁺² WHO = 50 mg/l	mean	47.51	51.46	44.5	40	46.51	43.82	46.8	47.03	47.67
	SD	13.73	13.06	7.17	4.1	6.5	9.64	6.79	8.03	6.34
	Max.	84.3	84.5	56.3	46	53.2	53.3	56.7	60.2	56.6
	Min.	30.2	36.4	30.3	35.1	35.1	25.7	35.2	31.7	37.5
Na ⁺ WHO = 200 mg / l	mean	102.0	120.6	112.1	101.1	115.4	104.3	118.4	132.1	127.7
	SD	17.69	29.56	24.02	11.32	22.1	11.06	32.4	40.96	23.33
	Max.	135	170	158	119.3	152.5	124	174	195	150
	Min.	84	86	87	85	93	91	87	88	96
K ⁺ WHO = 12 mg / l	mean	4.88	5.56	5.9	5.3	5.8	5.03	6.3	6.84	6.4
	SD	0.98	1.35	1.7	0.95	1.5	0.96	1.59	2.61	1.52
	Max.	6.8	9.5	9	6.8	8.3	6.5	9.3	12	8.3
	Min.	3.5	4.5	4	4	4	4	4.5	4.5	4

Cl ⁻¹ WHO = 250 mg/l	mean	127.5	141. 4	137.7	126	143.3	132.5	148.5	155.7	156. 2
	SD	21	28.0 7	27.38	12.31	24.77	12.41	37.72	45.61	27.3
	Max.	170	205. 2	190.8	146.5	188.9	153.9	217.7	226.8	180
	Min.	105.5	111. 5	112	112	118	118	113	113	116
SO ₄ WHO = 250 mg/l	mean	341.3	375. 2	338.4	329	345.7	329.8	342.5	345.1	367. 2
	SD	69.3	94.7 1	65.39	36.49	49.91	32.41	56.54	74.37	42.7 5
	Max.	514	607	434.5	369	422.5	370	443.5	465	400
	Min.	271	291	260	280	280	289	280	243	278

*[7]

** Mean of ten monthly samples

4. Water quality index

WQI is one of the most efficient tools for expressing water quality, which offers a simple, steady unit of measurement to communicate water quality, making it a significant factor in the evaluation and management of surface water [3].

The suitability of water for different uses is assessed by means of various water quality indices (WQIs). These indices reflect the rank of water quality in lakes, streams, rivers, and reservoirs. A comparison of water quality determinants with their respective regulatory standards is the concept behind most WQIs [8].

There are many methods for water quality index quantification. In this study two methods were selected: the Arithmetic Weighted Method and the Canadian Method.

4.1 Arithmetic weighted method

The weighted arithmetic index method is used to calculate the treated water quality index. The most suitable parameters for drinking water were used and compared with the allowable values for drinking water quality as recommended by the World Health Organization (WHO) in order to calculate a WQI as given in the following steps [9, 10 and 11] :

1- Calculation of unit weight factor

$$W_i = K / \text{sum } K \quad (1)$$

where

W_i represents the weighting for the i^{th} determinant and this value varies from (0 to 1) and $\text{sum } W_i = 1$; and

K : is a proportional constant

2- Calculation of the quality rating scale (q_i), which reflects the comparative value of this determinant in the contaminated water with respect to its standard permitted value as follows:

$$q_i = (V_i - V_d) / (S_i - V_d) * 100 \quad (2)$$

where

q_i represents the rating for the i^{th} determinant, and this value varies from 0 to 100:

V_i is the observed value of the i^{th} determinant:

V_d is the ideal value of the i^{th} determinant in pure water; and

S_i is the standard value of the i^{th} determinant.

Zero is the ideal value for all determinants except pH, where $V_d = 7$

3- Calculation of water quality index using the following equation:

$$\text{Overall WOI} = \sum_{i=1}^{i=n} w_i * q_i \quad (3)$$

where:

n is the number of determinants.

Table 3 shows classification of water quality base on the calculated WQI.

Table 3. Classification of WQI values for human consumption [2 and 9]

No.	WQI range	Water type
1	< 50	Excellent water
2	50.1 - 100	Good water
3	100.1- 200	Poor water
4	200.1 - 300	Very poor water
5	> 300.1	Unfit for drinking

4.2 Canadian water quality index (CWQI)

The CWQI adopted the conceptual model of the British Columbia Water Quality Index (BCWQI), which is based on relative sub- indices. There are three factors in the indicator, each of which is scaled between 0 and 100. The values of the three measures of variation from chosen objectives for water quality are collected to construct a vector in an imaginary " objective exceedance" space. The length of the vector is then scaled to an array of between 0 and 100, and subtracted from 100 to create an index which is 0 or close to 0 for extremely poor water quality, and close to 100 for excellent water quality [12]. The following six stages indicates the method for computing the Canadian Council Ministry of the Environment (CCME) WQI [13and14]. These stages includes the computation of F1, F2, Excursion, normalized state of excursion (nse), F3, and hence WQI.

where

$$1.F1 = (\text{Number of failed parameters} / \text{Total number of parameters}) * 100 \quad (4)$$

$$2.F2= (\text{Number of failed tests/overall number of tests}) * 100 \quad (5)$$

3. Excursion: There are two cases to calculate in this step

a. When the test value must not exceed an objective (limitation),

$$\text{Excursion} = (\text{failed test value/objective}) - 1 \quad (6)$$

b Excursion When an objective must exceed the test value,

$$= (\text{objective/failed test value}) - 1 \quad (7)$$

$$4. \text{normalized state of excursions(nse)} = \text{sum (excursion)}/\text{total tests} \quad (8)$$

$$5. F3 = \text{nse} / (0.01 * \text{nse} + 0.01) \quad (9)$$

$$6. \text{WQI} = 100 - [(F_1^2 + F_2^2 + F_3^2)^{1/2} / 1.732] \quad (10)$$

Table 4 shows water quality classification according to CWQI.

Table 4. Water quality categorizations according to CWQI (CCME, 2001) [13]

Class	WQI Value	Water Quality
I	95 - 100	Excellent
II	80 - 94	Good
III	65 - 79	Fair
IV	45 - 64	Poor (Marginal)
V	0 – 44	V. Poor(Poor)

4.3 Canadian water quality standards

The Canadian Water Quality Index (CWQI) is classified using relative sub-indices, that depends on the water quality standards used[8].

Six drinking water quality parameters were compared with their standards as taken from World Health Organization Guidelines. The water quality parameters which were used in this method are illustrated in Table 5, along with their standards for drinking use.

Table 5. Drinking Water Quality Standards Used in the Canadian WQIS for Shatt Al-Kufa Locations

No.	Water Quality Determinant	Unit	Standard
1	Chlorides	mg/ l	250
2	Sulphates	mg/ l	250
3	Total Dissolved Solid	mg/ l	1000
4	Total Hardness	mg/ l	500
5	pH	Unit less	6.5 – 8.5
6	Calcium	mg/ l	200

5. Results and discussion

Physical and chemical parameters at nine locations along Kufa River were analysed in order to determine the WQI. These parameters were pH, Turb., EC, Alk., TDS, T.H, Ca^{+2} , Mg^{+2} , Na^+ , K^+ , Cl^- and SO_4 . The descriptive statistical analyses for the collected water quality parameters are shown in Table 2.

Comparison between the values of the physical and chemical parameters with the corresponding values taken from WHO guidelines (WHO, 2004) for drinking water showed that the overall mean values of all studied positions were below the maximum allowable limits with the exception of the mean EC values for all locations, the mean values of Turbidity for locations **A** and **B**, and the mean values for Alkalinity in locations **B**, **E**, **F**, **G**, **H** and **I**.

The overall and seasonal means of the treated water quality indices were computed using the Weighted Arithmetic and Canadian methods for all studied locations and are represented graphically in Figures 2 to 6.

Based on the WQI value calculated using equation 3, water was categorized into five groups ranging from Excellent to Unfit for drinking, as in Table 3. The proportionality constants (K) and the unit (weights W_i) for all twelve chosen parameters with standard values are given in Table 6.

The overall and seasonal Weighted Arithmetic WQIs for drinking use were classified as good (50.1 to 100) for all studied locations with the except of locations **B**, **C**, **G** and **H** in the winter season only which were Poor (100.1 to 200) when matched against the classifications of the Weighted Arithmetic technique. Values ranged from 76.1 to 119.5. The best value (76.1) occurred in location **D** in the Summer while the worst value (119.5) occurred in location **B** in the winter.

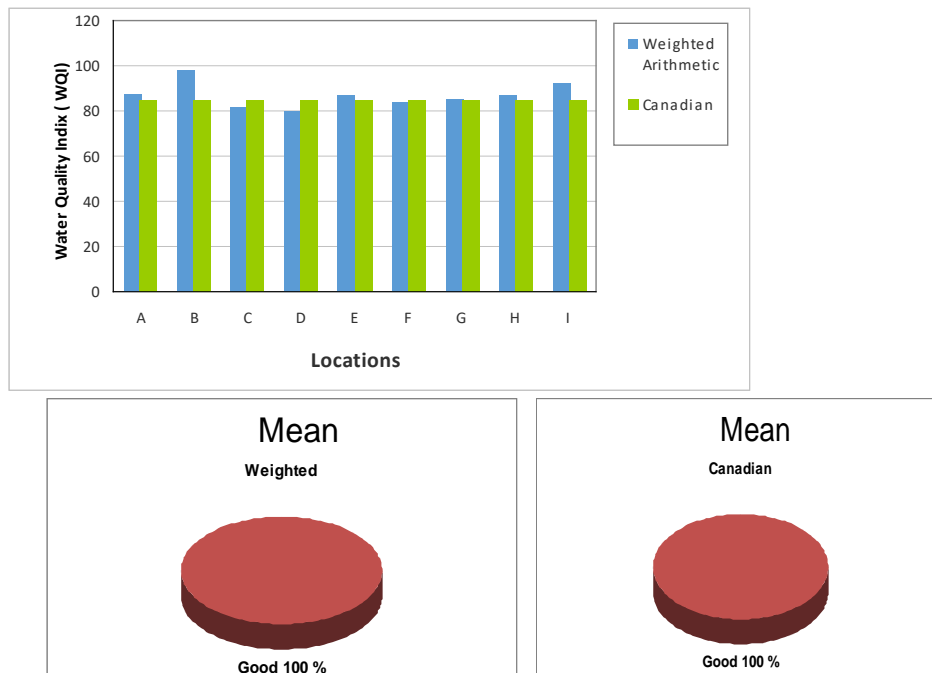


Figure 2. Comparison of meank WQIs of drinking use according to Weighted Arithmetic and Canadian methods for selected locations in Shatt-Al Kufa during the study period.

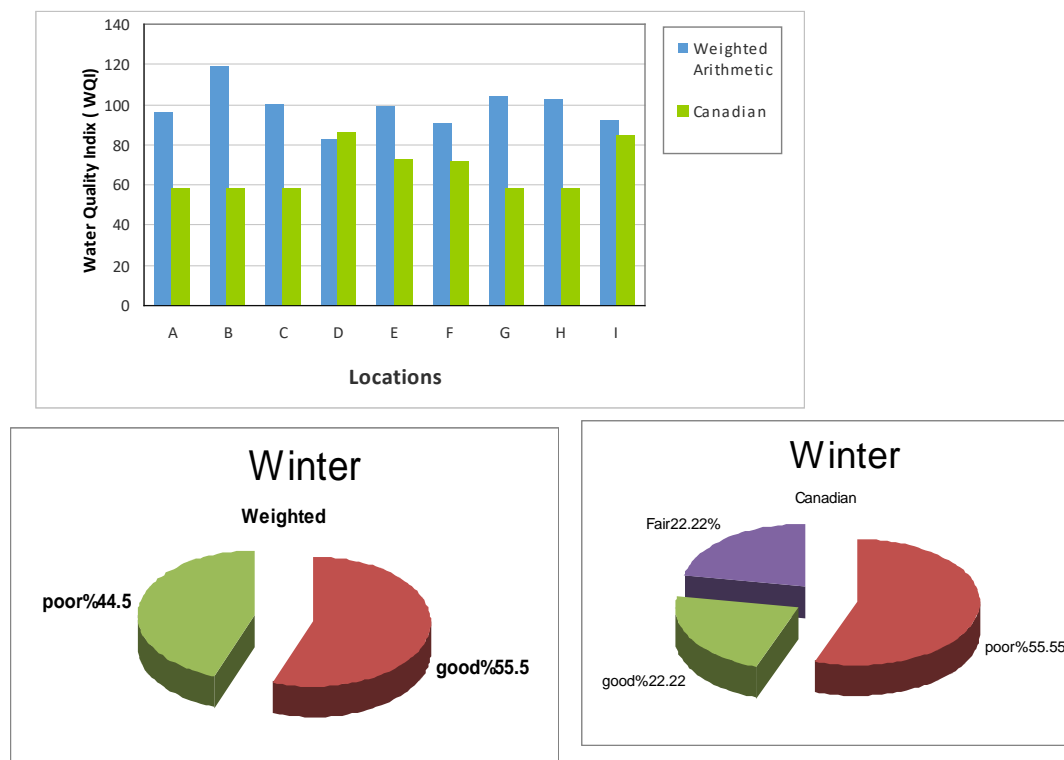


Figure 3. Comparison of mean WQIs for drinking use according to Weighted Arithmetic and Canadian methods for selected locations in Shatt-Al Kufa during Winter.

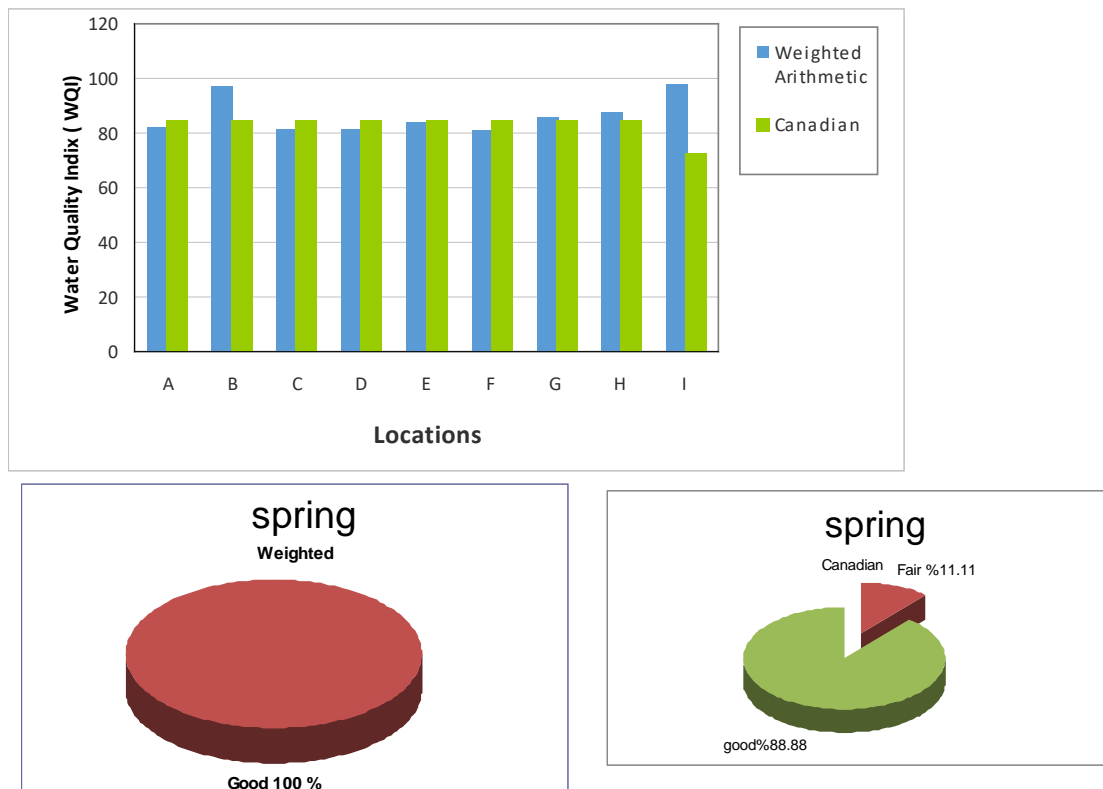


Figure 4. Comparison of mean WQIs for drinking use according to Weighted Arithmetic and Canadian methods for selected locations in Shatt-Al Kufa during Spring.

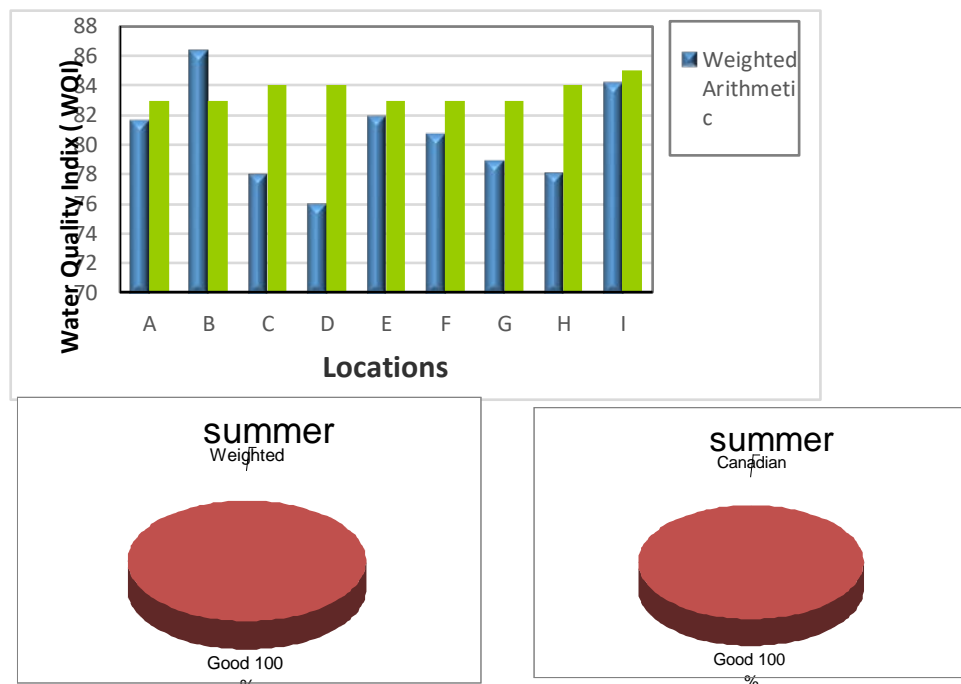


Figure 5. Comparison of mean WQIs for drinking use according to Weighted Arithmetic and Canadian methods for selected locations in Shatt-Al Kufa during Summer.

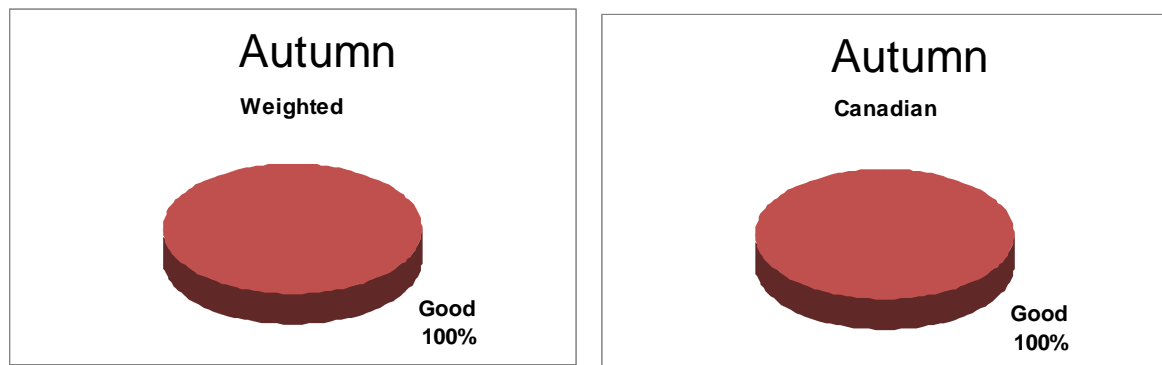
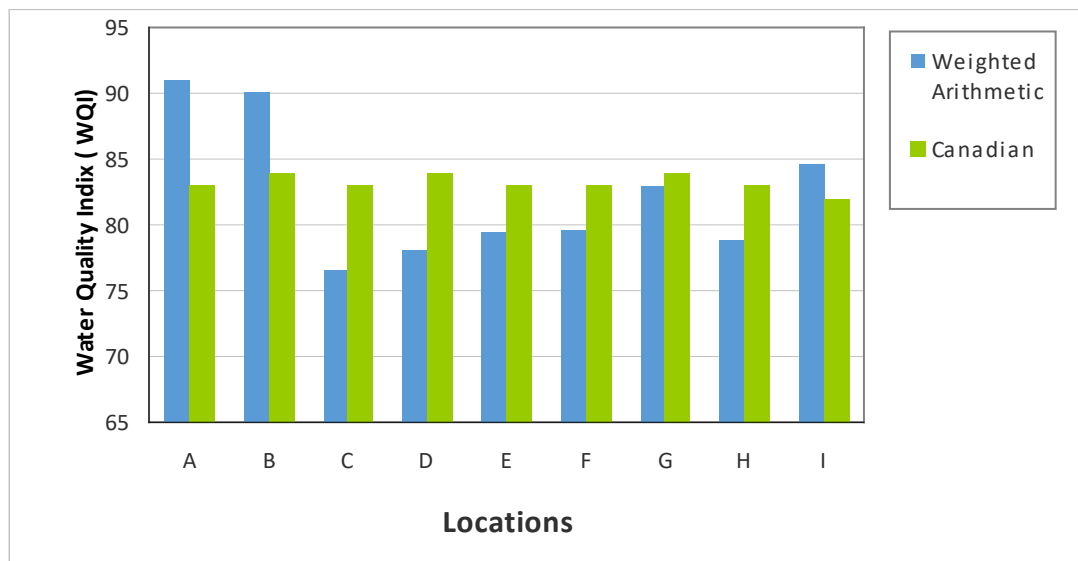


Figure 6. Comparison of mean WQIs for drinking use according to Weighted Arithmetic and Canadian methods for selected locations in Shatt Al-Kufa River during Autumn.

Table 6. Guidelines for drinking water quality WHO (2004), and comparative weight of selected parameters.

Parameters	Standard value (Si)	Proportional (weight K)	Unit weight factor (Wi)
pH	8.5	4	0.1176
Turb.	5	3	0.088
EC	1000	4	0.1176
Alk.	120	3	0.088
TDS	1000	4	0.1176
T.H	500	2	0.0588
Ca ⁺²	200	2	0.0588
Mg ⁺²	50	2	0.0588
Na ⁺	200	2	0.0588
K ⁺	12	1	0.029
Cl ⁻	250	3	0.088
SO ₄	250	4	0.1176

Equations (4 to 10) were used to determine the final results of the treated drinking WQI according to the Canadian technique for the nine studied positions on Shatt Al-Kufa during the study.

The average and seasonal Canadian WQIs for drinking use were classified as good (80 to 94) for all studied positions except positions **A, B, C, G** and **H** in winter, which were Poor (45 to 64) and positions **E** and **F** in the same season, which were Fair (65 to 79) when matched with the five classifications of the Canadian technique with values between 59 and 85. The best value (85) occurred in all positions in spring, while the worst value (59) occurred in positions **A, B, C, G** and **H** in winter. From Figures (2 to 6), it is clear that the index reduced in winter and improved in the other seasons. The cause of the reduced index was the existence of high values of EC (1037 to 2596) and high concentrations of SO_4 (243 to 607 ppm) in all positions.

6. Conclusions

1. The values of EC were (1037 to 2596) $\mu\text{mho/cm}$, while TDS values were (618 to 1616) ppm. The concentrations of Ca^{+2} , Mg^{+2} , Na^+ and K^+ were between (69.4 and 136.8) ppm, (25.7 and 84.5) ppm, (84 to 195) ppm and (3.5 to 12) ppm respectively. The chloride and sulphate concentrations ranged (between 105.5 to 226.8) ppm and (243 and 607) ppm respectively. The concentrations of alkalinity and total hardness were between (102 to 146) ppm and (329 to 638) ppm respectively, while the values of pH and Turbidity ranged (from 7.1 to 8.1) and (0.4 to 13.6) NTU respectively.

2. The results showed that the overall mean values of parameters for each studied position were within the maximum permitted by the WHO (2004) for drinking water with the exception of the mean values of EC, two mean values of Turbidity, and six mean values of Alkalinity.

3. The index used in both methods decreased in winter and improved in the other seasons.

4. The cause of index reduction was the existence of high values of EC and high concentrations of SO_4 in each position.

7. Recommendations

1- Further environmental assessment programs such as remote sensing and GIS.

2- Developing the work to study other pollutants such as hydrocarbon compounds.

8. References

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