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Research paper

Using Arithmetic Weighted and Bhargava Methods to Classify Irrigation Water Quality Index for Shatt-Al Kufa in Najaf Province, Iraq

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Abstract

WQI is a mathematical method used to convert the bulk of the information into a single number to express the data in a simplified and explicable form. This study is concerned with evaluating an applicable WQI for irrigation use at several locations on Shatt Al-Kufa. The ten water quality parameters of pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS), Total Hardness (T.H), Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Sodium (Na^{+}), Potassium (K^{+}), Chlorides (Cl^{-1}) and Sulphate $(SO_4)^{-2}$ were studied over a period of twelve months (January to December 2017) for six selected locations, including Zerkh, Kufa, Manathira, Hira, Mashkhab and Qadisiya on Shatt Al-Kufa, Sodium Adsorption Ratio (SAR) was also calculated. Two methods (Weighted Arithmetic and Bhargava) were applied to categorize the WQI of the raw river water for irrigation use, and then a comparison of the two methods was made to determine the difference between them. The Results of the overall, annual and seasonal WQI values according to both Weighted Arithmetic and Bhargava methods were classified as good in all selected locations with the except of some cases in summer, spring and autumn seasons for Weighted Arithmetic which were classified as excellent (0-25). The difference between the two methods is also presented.

Keywords: *Bhargava method, Kufa, Shatt Al-Kufa, water quality index, weighted arithmetic method.*

1. Introduction

People increases and higher living standards are likely to cause increased demand for the river water. At the same time, more and more irrigation water will be wanted to meet increasing demands for food for growing people; thus, it is important to concern about the river water quality, especially for irrigation uses.

Water pollution can be defined in general as " any variation either natural or artificial that changes the quality of water and disturbs or destroys the balance of ecosystems and natural sources, so that it: causes hazards to public health, detracts from the convenience efficiency and wellbeing of man and his communities, and impairs the beneficial of water" [1].

Water Quality Index (WQI) is one of the most active tools to connect data on the quality of water to concerned citizens and policy makers. Thus, it becomes a significant factor for the assessment and management of water. WQI is defined as a rating reflecting the compound effect of different water quality parameters; it is calculated from the standpoint of the suitability of water for various uses [2].

WQI is a mathematical method used to convert the bulk of the information into a single number to express the data in a simplified and explicable form. It takes data from a number of sources and associates them to advance a total status of a given body of water [3].

Some variables have great significance for one use, but may not be of the similar significance for the other use, i.e. each beneficial use has different water quality requirements. For example, according to Bhargava, Total Dissolved Solid (TDS), Sulphate $(SO_4)^{-2}$, Hydrogen Power (pH), Sodium Adsorption Ratio (SAR), Electrical Conductivity (EC), and Chlorides (Cl^{-1}) are significant for irrigation [4].

Shatt Al- Kufa (Kufa River) is the main source of water needed for drinking, irrigation, industry and other uses in Kufa and Najaf cities. This river has shown decreasing quantity and quality of water because fast growth of agricultural, municipal, and industrial activities especially when coupled with the decreasing in its discharge. It is important then to make detailed studies to assess the suitability of the river water for various purposes

The objectives of this study can be potted by:

- Study the physical and chemical parameters of surface water at different locations in Shatt Al- Kufa and determine the main parameters that are consider the main pollutant to the river.
- Calculate WQI using two different methods (Weighted and Bhargava) to assess the suitability of Shatt Al-Kufa for irrigation use.
- Compare the results of the two methods to find the causes for the decay in water quality.

2. The study area

Kufa is a hottest and driest city in Iraq. It is located south of Baghdad (capital of Iraq) about (170) km and north of Najaf about (10) km. It is sited on the banks of the Euphrates River. Shatt Al-Kufa is one of the two branches of Euphrates River with a length of 73 km and width about 100 m and another branch called Al-Abbasia.

The water level is unstable at the river throughout the seasons of the year. The areas nearby the river are famous in agriculture [5]. The average annual discharge of this river varies from season to season. In agricultural season the rate of discharge (200-230) m^3 /s [6]. This study includes selecting six locations on Shatt Al-Kufa in Kufa city as a case study as shown in Figure (1). The most significant variable in the use of water for irrigation were analyzed in the selected locations to determine WQI. Table (1) illustrates the six selected locations and their local names.

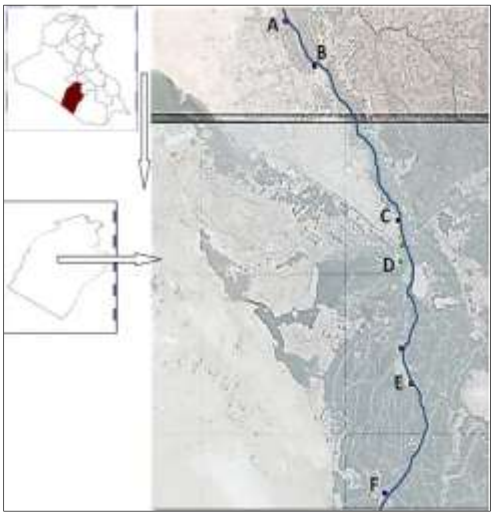


Fig. 1: Location of the study area in Iraq and sampling locations [7]

Table 1: Selected locations on Shatt Al-Kufa

No.	1	2	3	4	5	6
Symbol	A	B	C	D	E	F
Location	Zerkh	Kufa	Manathira	Hira	Mashkhab	Qadisiya

3. Sample collection

Water samples were taken from six positions along Shatt Al-Kufa from the Al- Zerkh area to Al- Qadisiya to determine the water quality index for the period from January 2017 to December 2017, twelve months in all. These samples were analyzed 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 irrigation water parameters at Shatt Al-Kufa during the study period.

Parameters +Standard *	Statistical Indices	Locations					
		A	B	C	D	E	F
pH = 6-8.5	Mean **	7.61	7.44	7.49	7.38	7.371	7.42
	SD	0.394	0.441	0.481	0.473	0.402	0.538
	Max.	8.5	8.2	8.1	8.2	8.2	8.2
	Min.	7	6.9	6.65	6.65	6.9	6.1
EC = 3000 µmho/cm	Mean	1184.25	1251.5	1252.46	1215.38	1278.17	1236.22
	SD	99.34	104.4	100.104	94.99	131.393	104.304
	Max.	1443	1449	1468	1462	1559	1425
	Min.	1072	1114	1158	1104	1104	1119
TDS = 2000 mg/l	Mean	774.5	789.84	792.84	780.42	819.25	776.17
	SD	80.904	96.33	79.4	76.83	98.648	80.831
	Max.	960	964	988	954	1010	912
	Min.	648	652	708	659	659	684
T.H = 500 mg/l	Mean	375.84	407.5	396.84	394	412.25	402.583
	SD	35.263	39.76	36.392	31.35	49.886	46.312
	Max.	443	488	456	456	511	488
	Min.	324	332	340	340	348	340
Ca^{+2} = 400 mg/l	Mean	93.23	101.67	99.084	97.46	101.373	101
	SD	8.67	10.05	9.124	8.58	13.698	12.836
	Max.	110	122	114	114	127	122
	Min.	81	88	83	83	84	84
Mg^{+2} = 150 mg/l	mean	34.73	37.4	36.34	36.14	37.792	36.54
	SD	3.41	3.37	3.36	2.83	4.616	4.323
	Max.	40.9	44.6	41.7	41.7	47.2	44.6
	Min.	29.6	32.2	31.1	31.1	31.8	30.3
Na^{+} = 920 mg / l	mean	86.02	92.66	87.86	90.86	91.925	90.158
	SD	8.97	7.66	8.792	9.15	10.224	10.162
	Max.	111.6	102	110.6	109.3	108.4	108.6
	Min.	73.9	81.2	73	78.2	78	78.2
K^{+} = 78 mg / l	mean	4.6	5	5.71	5.37	5.817	5.292
	SD	0.668	0.691	0.639	0.56	0.741	0.413
	Max.	5.4	6.3	6.6	6.3	7.2	6
	Min.	3	3.3	4.8	4.6	4.6	4.8
Cl^{-1} = 1065 mg/l	mean	120.75	124.4	124.6	123.88	130.875	123.84
	SD	7.75	10.12	10.09	6.97	11.979	10.831
	Max.	133	141	141	136	148	144
	Min.	110	108	106	113	114	114
SO_4^{-2} = 960 mg/l	mean	270.42	298.3	285.92	282.75	298.917	296.34
	SD	33.05	39.32	40.88	37.06	45.888	49.389
	Max.	324	369	351	361	378	393
	Min.	228	238	232	233	236	228
SAR= 26	mean	1.92	2.132	1.913	1.99	1.978	1.95
	SD	0.152	0.339	0.174	0.175	0.21	0.187
	Max.	2.299	3.03	2.4	2.258	2.330	2.378
	Min.	1.74	1.73	1.7	1.768	1.616	1.713

*[8] ** Mean of twelve monthly samples

4. Water quality index (WQI)

WQI is defined as a rating that reflects the composite influence of different water quality variables on the total quality of water [9]. Water quality indices (WQIs) have been advanced to evaluate the appropriateness of water a variety of uses. The idea of WQIs is built on the comparison of the water quality variable with corresponding regulatory standards [10].

4.1. Arithmetic weighted formula

Raw water quality index is computed using the Weighted Arithmetic technique. The most appropriate variables for irrigation water were used and compared with the permissible values for irrigation water quality as suggested by the FAO in order to compute a WQI as set in the next steps [3], [11], [12] and [13]:

1- Computing of unit weight factor

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

Where:
W_i denotes the weighting for the i^{th} variable and this value differs from (0 to 1) and sum W_i = 1; and
K : is a proportional constant
2- Computing of the quality rating scale (q_i), which reflects the relative value of this variable in the polluted water with respect to its standard allowable value as follows:

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

where:
q_i denotes the rating for the i^{th} variable, and this value differs from 0 to 100:
Vi is the observed value of the i^{th} variable:
V_d is the ideal value of the i^{th} variable in pure water; and
S_i is the standard value of the i^{th} variable.
Zero is the ideal value for all variable except pH, where V_d = 7
3- Computing of water quality index using the next equation:

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

where:

n is the number of variables.
Table (3) displays cataloging of water quality base on the computed WQI.

Table 3: Cataloging of WQI values for human uses [13]

No.	WQI range	Water type
1	0-25	Excellent water
2	26-50	Good water
3	51-75	Poor water
4	76-100	Very poor water
5	More than 100	Unfit and unsuitable

4.2. Bhargava method

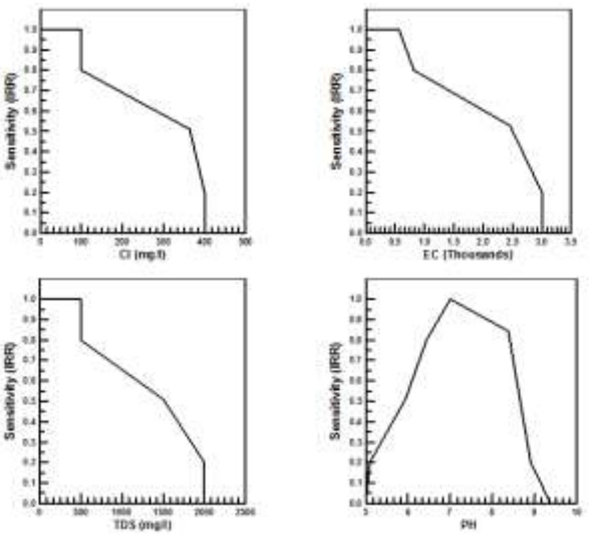
The geometric mean method was proposed and stated by Bhargava, 1983 [4] as:

$$WQI = \left[\prod_{i=1}^{n} f_i(P_i)\right]^{1/n} \times 100 \qquad (4)$$

Where fi (pi) is the sensitivity function for each parameter containing the influence of parameter weight concentration which is connected to a certain action and differs from
(0-1), n is the number of parameters
Bhargava technique is one of the new techniques which are used in many countries. It is simple to deal with comparative variable for various purposes. The main six water quality variables for irrigation use in this index are: Cl^{-1}, EC, TDS, pH, SAR and SO_4^{-2} which were adopted by Bhargava to find WQI according to irrigation purpose
The nature of the sensitivity functions is determined by the influence of a variation in the value of the variable on quality of water as shown in Figure (2).
Five groups are classified in this index to determine the WQI for every action of various water actions. Depending on the parameters which affect that action by using geometric mean method [14]. Table (4) displays cataloging of water quality base on the computed WQI.

Table 4: Water Quality Classification According to [4], [14] and [15]

No.	WQI range	Water type
1	90-100	Excellent water
2	65-89	Good water
3	35-64	Acceptable
4	10-34	Polluted
5	Less than 10	Severe Polluted



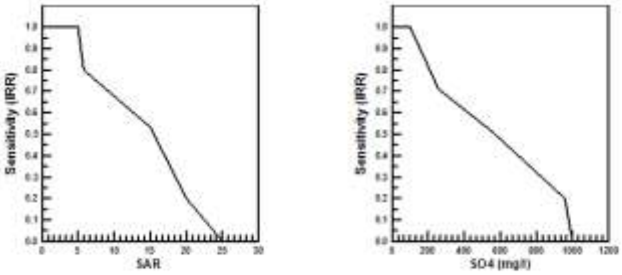


Fig. 2: Sensitivity functions curves according to Bhargava for irrigation purpose [4]

5. Analysis and discussion of results

Physical and chemical variables at six locations along Kufa River were analyzed in order to calculate the WQI. These variables were pH, EC, TDS, T.H, Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-1} and SO_4^{-2}. SAR was also calculated. The descriptive statistical analyses for the collected water quality variables are presented in Tablel (2).
Comparison between the values of the physical and chemical variables with the standards of irrigation quality suggested by [8] displayed that the annual mean values of all studied positions were under the largest permissible limits.
The annual, seasonal and overall means of the raw water quality indices were calculated by the Weighted Arithmetic and Bhargava methods for all studied positions and are denoted graphically in Figures (3 to 12).
Based on the WQI rate computed by equation 3, water classified into five groups extending from Excellent to Unfit for human uses, as in Table (3). The proportionality constants (K) and the unit weights (wi) for all selected variables with standard values are set in Table (5).
The annual and seasonal Weighted Arithmetic WQI for irrigation use were classified as good (26-50) for all selected locations with the except of locations **A**, **B, C** in the summer and autumn seasons, locations **D** and **E** in the summer season and location **F** in the spring and summer seasons which were Excellent (0-25) when coordinated against the cataloging of the Weighted Arithmetic method. Rates extended from (23.283 to 30.273). The greatest value (23.283) found in location **D** in summer season while the smallest value (30.273) found in location **B** in winter season
The calculated overall WQI values of all locations during the period study was (26.1103) which implied that the water was commonly " Good quality for irrigation" as presented in Figure (3). The calculated overall WQI values of all locations during winter, spring, summer and autumn seasons were (29.23, 26.23, 23.80 and 25.16) respectively which implied that the water quality index reduced in winter season and increased in summer, autumn and spring seasons because the increase of discharge water lead to the improvement of the quality.
The results of the WQI for Bhargava method were seen that the annual, seasonal and overall WQI for irrigation use were classified as good (65-89) for all selected locations. Rates extended from (77.67 to 82.04). The largest value (82.04) found in position **B** in the summer season while the smallest value (77.67) found in position **A** in the winter season.
The computed overall WQI values of all locations during the period study was (79.645) which implied that the water was commonly good quality for irrigation as presented in Figure (4).
The computed overall WQI values for all locations during winter, spring, summer and autumn seasons were (78.323, 79.718, 80.761 and 79.545) respectively which implied that the WQI reduced in winter season and increased in the other seasons for the same reason in Weighted Method.

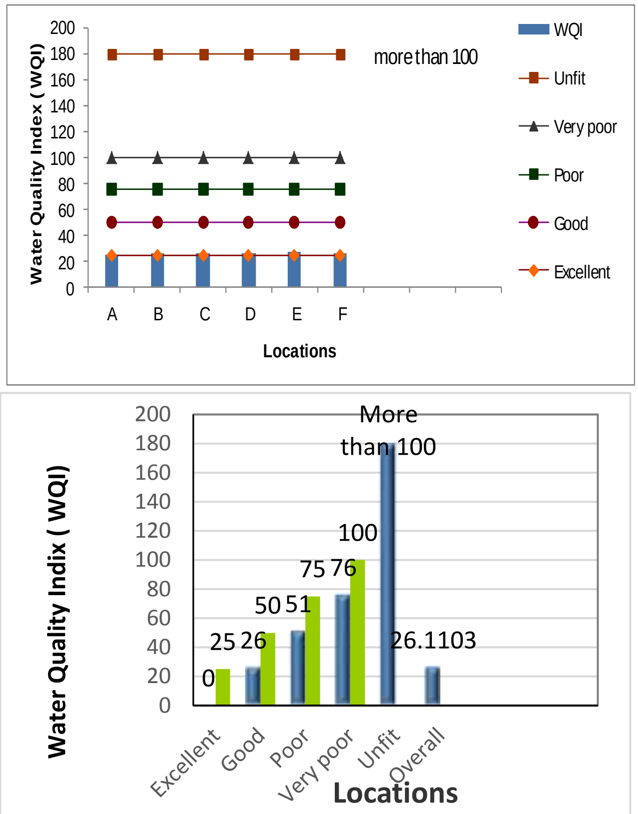


Fig. 3: Annual and overall means of WQI for irrigation use according to weighted arithmetic method for studied locations in Shatt Al-Kufa during the studied period.

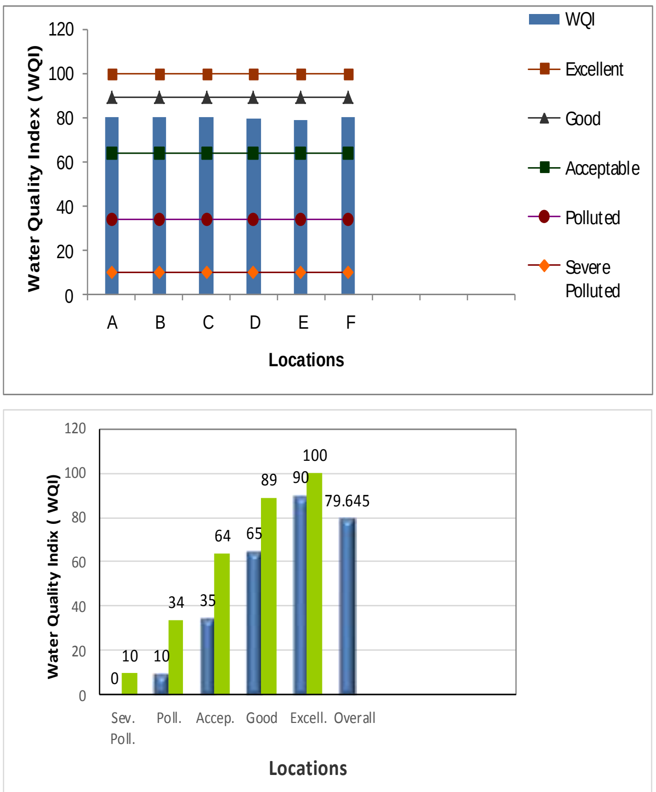


Fig. 4: Annual and overall means of WQI for irrigation use according to Bhargava method for studied locations in Shatt Al-Kufa during the studied period.

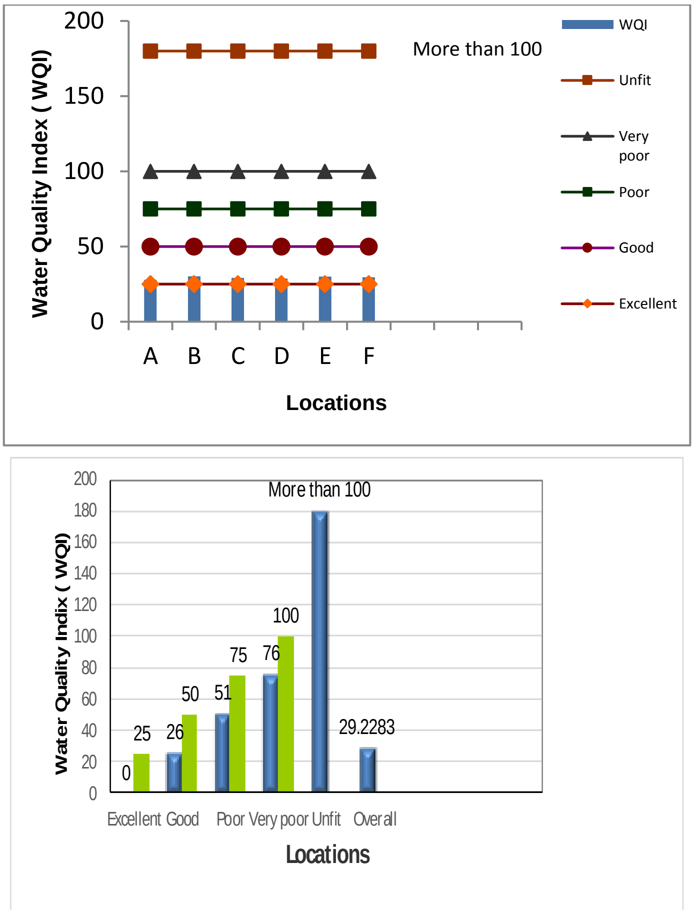


Fig. 5: Seasonal and overall means of WQI for irrigation use according to weighted arithmetic method for studied locations in Shatt Al-Kufa during winter season.

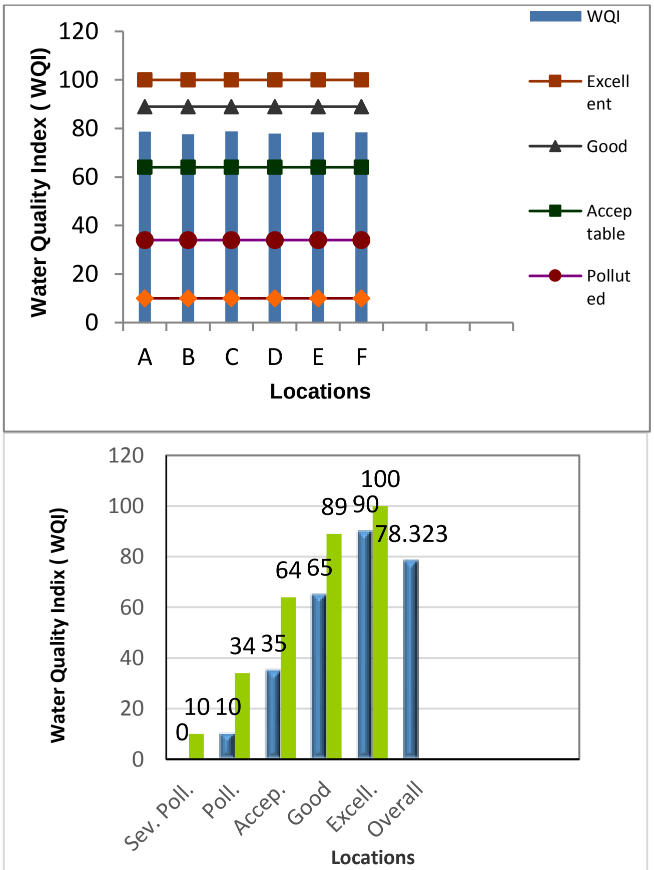


Fig. 6: Seasonal and overall means of WQI for irrigation use according to Bhargava method for studied locations in Shatt Al-Kufa during winter season.

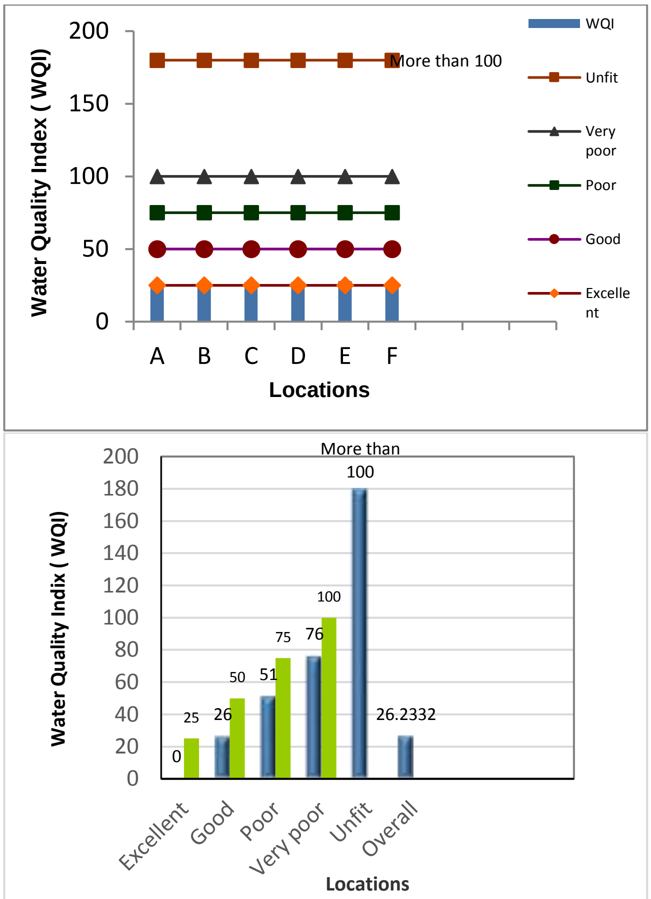


Fig.7: Seasonal and overall means of WQI for irrigation use according to weighted arithmetic method for studied locations in Shatt Al-Kufa during spring season.

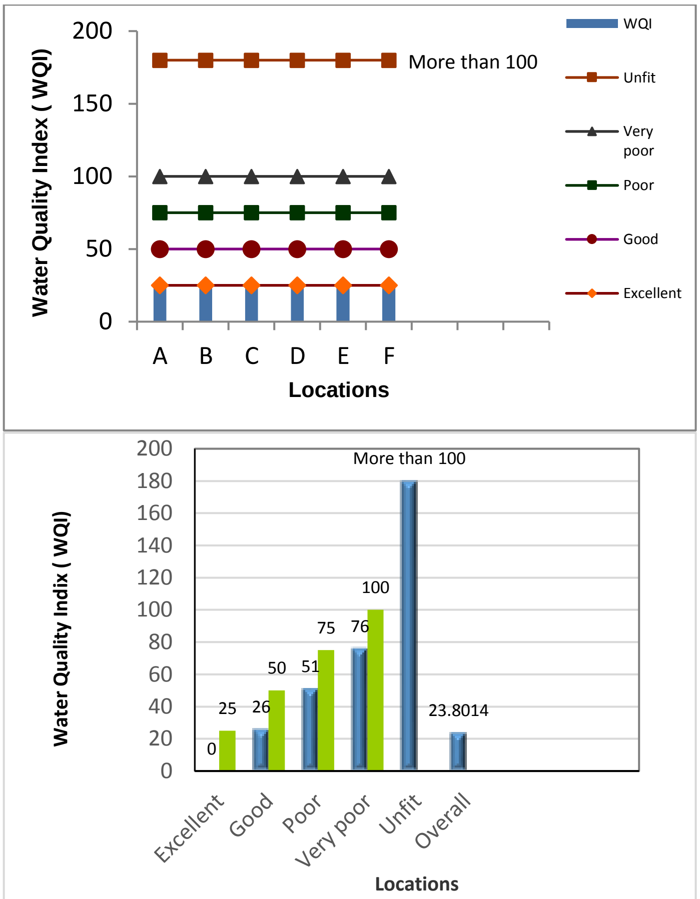


Fig. 9: Seasonal and overall means of WQI for irrigation use according to weighted arithmetic method for studied locations in Shatt Al-Kufa during summer season.

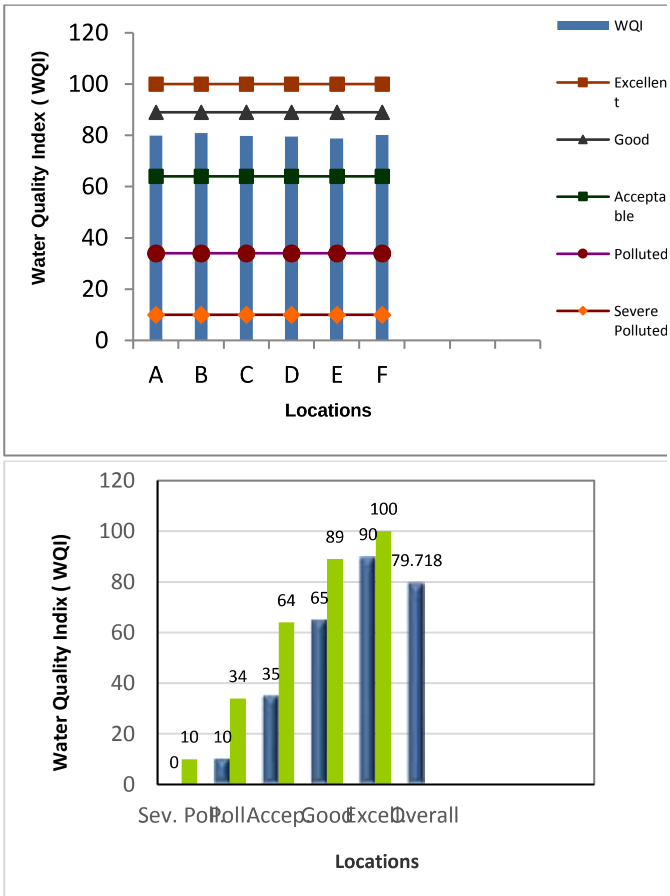


Fig. 8: Seasonal and overall means of WQI for irrigation use according to Bhargava method for studied locations in Shatt Al-Kufa during spring season.

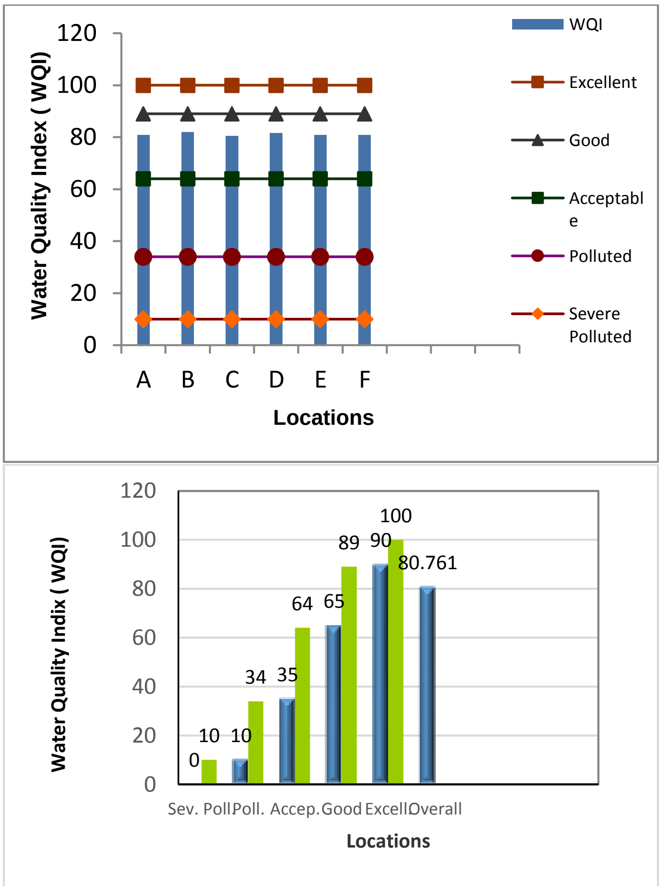


Fig. 10: Seasonal and overall means of WQI for irrigation use according to Bhargava method for studied locations in Shatt Al-Kufa during summer season.

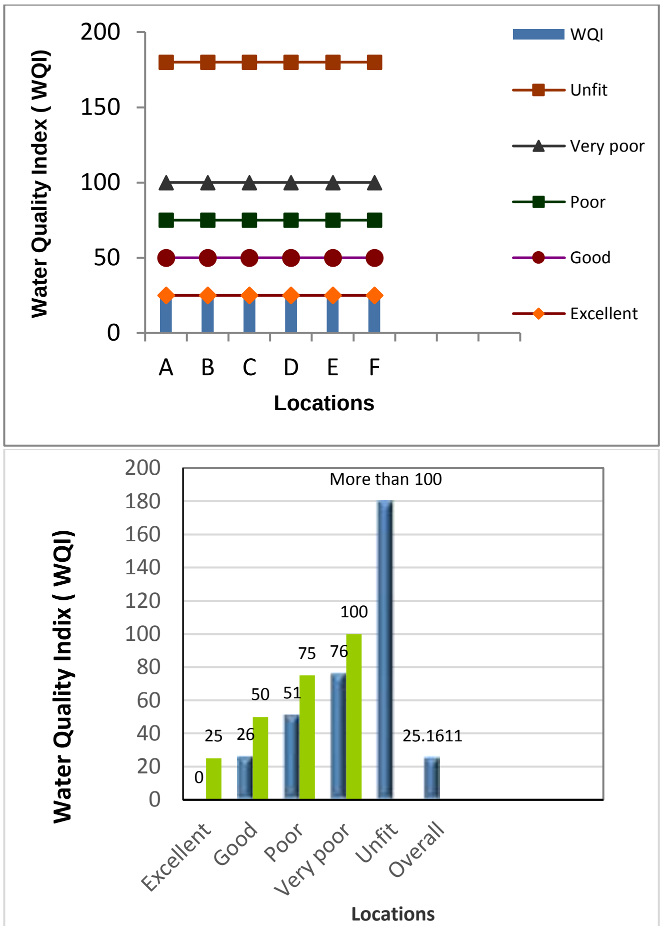


Fig. 11: Seasonal and overall means of WQI for irrigation use according to weighted arithmetic method for studied locations in Shatt Al-Kufa during autumn season.

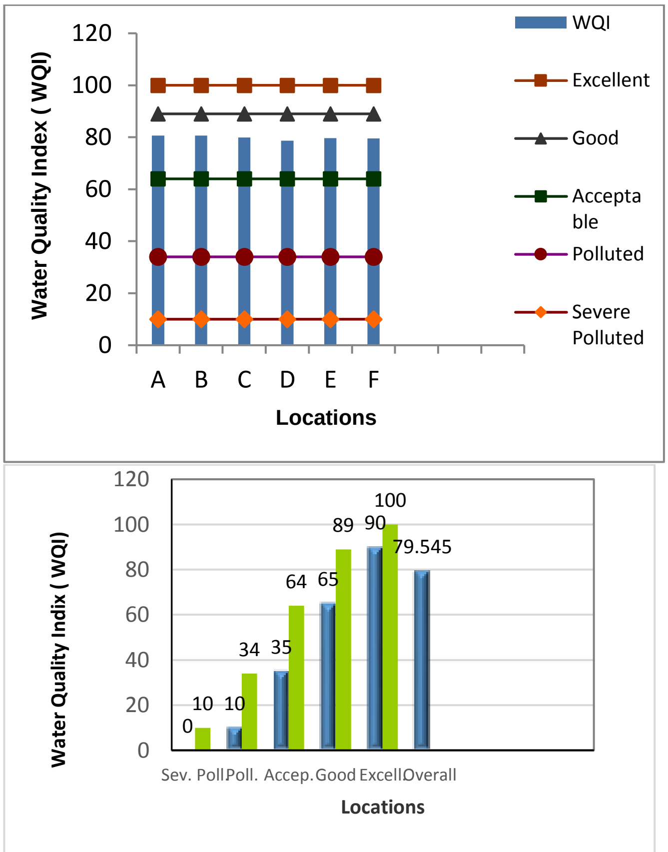


Fig. 12: Seasonal and overall means of WQI for irrigation use according to Bhargava method for studied locations in Shatt Al-Kufa during autumn season.

Table 5: Water quality standards for irrigation [8], and relative weight of selected parameters [13]

Parameters	Standard value (Si)	Proportional (weight K)	Unit weight factor (Wi)
pH	8.5	1.33	0.0555
EC.	3000	3.33	0.1389
TDS	2000	3.33	0.1389
T.H	500	1.33	0.0555
Ca^{+2}	400	2.33	0.0972
Mg^{+2}	150	2.33	0.0972
Na^{+}	920	2.67	0.1113
K^{+}	78	1.33	0.0555
Cl^{-}	1065	2.67	0.1113
SAR	12	3.33	0.1389
		23.98	1.00

6. Conclusions and recommendations

1-The values of EC were extended (1184.25 to 1278.17) µmho/cm, while TDS values were (774.5 to 819.25) ppm. The concentrations of Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} were between (93.25and101.67) ppm, (34.75 and 37.792) ppm, (86.02 to 92.66) ppm and (4.6 to 5.817) ppm respectively. The chloride and sulphate concentrations ranged (120.75 to 130.875) ppm and (270.42 to 298.917) ppm respectively. The concentrations of total hardness was between (375.84 to 412.25) ppm, while the values of pH and SAR ranged (from 7.42 to 7.61) and (1.915 to 2.132) respectively.
2- The results presented that the annual mean values of variables for all selected locations were within the maximum allowable of [8] for irrigation water.
3- The annual, seasonal and overall computed WQI values were classified as good in all selected location according to Bhargava method.
4- According to weighted arithmetic method, the annual, seasonal and overall computed WQI values were classified as good in most calculations with the except of some cases in summer, spring and autumn seasons which were classified as Excellent.
5- The index in two selected methods reduced in winter season and increased in spring, summer and autumn seasons.

The following recommendations can be drawn:
1-Other environmental evaluation programs can be applied such as remote sensing and GIS.
2- Further contaminants can be studied such as heavy metals.

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