Application weight mathematical model (WQI) to assess water quality for irrigation: A case study of Tigris river in Nineveh governorate

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Abstract

The current study included a qualitative assessment of the water of the Tigris river in Nineveh governorate for irrigation purposes using the sub-index model (IWQI) that was applied to eleven parameters of irrigation water to identify the quality of the river’s water for irrigation. Water samples were collected monthly from nine sites on the river starting from November until August to conduct physiochemical analyzes, as well as calculating the irrigation parameters. The results indicated that the water quality index values ranged between (29.08 - 41.46). Despite the high values of the index with the course of the river, especially the city of Mosul, due to the drainage of sewage through many estuaries spread on both sides of the river, the water quality in the studied sites was of the excellent water category for irrigation.

Keyword: Water quality index, Tigris river water quality for irrigation purposes

1. Introduction

Wisdom says that “Water is life,” “Health is wealth,” and “Waste to wealth” is the misuse and neglect of the water resources around us, which can be destructive to life, health and wealth [1], therefore, the problem of environmental pollution, including the water ecosystems, is one of the serious problems facing humanity, especially the third world countries, which live, unfortunately, very far from current issues, where abuse and tampering with the environment and water resources are done without taking into account environmental laws and regulations, and as a result of social, industrial and civilizational development etc.

It led to an increase in the demand for water suitable for various uses and this resulted in an increased in wastewater disposal to surface water resources. Unfortunately, reports indicate that one-third of the world’s population will face a serious water crisis in the next few years [2].

The continuing shortage of water resources along with the increase in demand for it will lead to many critical problems for many countries of the world, as the water problem is an important pillar of national security, especially in dry and semi-arid regions whose water sources are from neighboring countries [3], as is the case in the problem of the Al-Nahtha dam on the Nile, which led to the tension of Egyptian and Sudanese attitudes towards Ethiopia, in addition to climatic challenges and scarcity of rain [4], and likewise, the future dimensions of the Iraqi country will be dire due to external challenges such as building dams and irrigation projects in upstream countries, traditional irrigation operations and wasting water consumption [5, 6], which will lead to The water crisis has turned into a global problem.

Therefore, the problems related to water resources must be reviewed seriously and the use of modern scientific management to confront these problems and reduce them to preserve suitable land for future agriculture, such as the use of modern technologies for irrigation and determination of water quality for different uses using modern methods of evaluation such as the use of mathematical models (WQI) [7,8]. In general, the quality of irrigation water depends on several factors, including:

1. Damage to salinity: Represented by both electrical conductivity EC25 and latent salinity P.S [9].
2. Damage to permeability and filtration: Sodium ions are represented by the permeability index (PI), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), as well as the soil salinity [10].
3. Ion toxicity: This includes the toxicity of sodium and chloride ions that degrade the growth and production of plants, which depends on the type of plant and the rate of absorption. The problem of toxicity is often associated with the problem of salinity and permeability [11].
4. Miscellaneous effects: Such as the effect of pH on carbonate balance and the ability to absorb mineral elements by plant roots, etc. As well as the carbonate and bicarbonate ions that affect the pH value, and their high concentrations work on the precipitation of calcium and magnesium ions Mg & Ca leaving sodium ions predominant in the soil solution, which affects the structure and composition of the soil and the plants growing in it [12].
Therefore, the study came to assess the water of the Tigris river in Nineveh governorate for irrigation, using the sub-index model.

2. Materiel and Methods

The current study was conducted in the laboratories of the College of Education for Pure Sciences. Which included the Tigris river from the Mosul dam north of the city of Mosul until the Qayyarah district, and the study area is characterized by a hot, dry climate in summer and cold rainy in winter, bringing the average of rainfalls up to 279 mm for the other two decades, according to the data of the weather station of the city of Mosul, and the study area is about 250 m above the surface level the sea [13]. Nine sites have been identified on the Tigris River in Nineveh Governorate, starting from the Mosul Dam to the Kayara district, as shown in Table 1 and Figure 1. Water samples were collected monthly, starting from January until August(one sample per month from each site) using clean polyethylene bottles, as well as washing them with sample water in the field and in the laboratory, the pH, electrical conductivity, positive and negative ions were determined according to international standard methods [14, 15].

Table 1. Details of sampling locations of the Tigris river at Nineveh governorate.

| St. No | Sampling station       | Latitude N | Longitude E |
|-------|------------------------|------------|-------------|
| 1     | Mosul dam lake         | 366199     | 428306      |
| 2     | Badosh                 | 364215     | 429708      |
| 3     | Tried Bridge           | 363769     | 431080      |
| 4     | Nineveh Bridge         | 363633     | 431174      |
| 5     | Al-Howrah Bridge       | 363302     | 431542      |
| 6     | Forth Bridge           | 363220     | 431727      |
| 7     | Al- Bosif village      | 362688     | 431745      |
| 8     | Hamam Alil             | 362077     | 432188      |
| 9     | Qayyarah subdistrict   | 357890     | 432975      |

Figure 1. A map of the study area and the sites for collecting water samples.
The irrigation parameters were also calculated, namely: Sodium adsorption ratio (SAR), Sodium percentage (%Na), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Potential Salinity (PS), Kelly ratio (KR) and Permeability index (PI) as shown by the equations below [8]:

\[
\%Na = \frac{Na \times 100}{Ca + Mg + Na + K} \\
SAR = \frac{Na}{Ca + Mg + Na + K} \\
RSC = (CO_3 + HCO_3) - (Ca + Mg) \\
MH = \frac{Mg}{Ca + Mg} \\
PS = \frac{1}{2} SO_4 + Cl \\
KR = \frac{Ca + Mg}{Ca + Mg + Na} \\
PI = \frac{[Na + HCO_3]}{Ca + Mg + Na} \times 100 
\]
All units are used with the meq/ l.

3. Calculation of the water quality index

The sub-index model indicated by [16, 17] which modified by [13] on eleven parameters to assess the studied water quality for irrigation purposes, as shown in Table 2; Where the weight of each characteristic is determined according to its relative importance, for example, the weight of 5 is placed for electrical conductivity; this is due to its importance and impact on plant growth and soil properties, while weight chloride was given 1 due to its low concentration in the Tigris river water compared to the global standard limits [18, 19], and the water quality index (WQI) is calculated from the following equations [20, 21]:

\[
W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \\
Q_i = \frac{C_i}{S_i} \times 100 \\
S_i = W_i \times Q_i \\
W_{QI} = \sum_{i=1}^{n} S_i 
\]

Where, Ci; the value of the measured i\textsuperscript{th} parameter, Si; Standard limits for the i\textsuperscript{th} parameter., Qi; quality rating of i\textsuperscript{th} parameter, Wi; Relative weight of the i\textsuperscript{th} parameter., Sli; sub-index of the i\textsuperscript{th} parameter.

Table 2. Qualitative properties, standard limits (Si), property weight (wi), and relative weight (Wi) used for calculation (WQI).

| Properties | Units | Si   | Wi     |
|------------|-------|------|--------|
| pH         | 6.5-8.5 | 3    | 0.083333333 |
| EC\textsubscript{25} | dS m\textsuperscript{-1} | 2.000 | 5 | 0.138888888 |
| Cl         | meq. l\textsuperscript{-1} | 4 - 10 | 1 | 0.027777777 |
| HCO\textsubscript{3} | meq. l\textsuperscript{-1} | 1.5 - 8.5 | 2 | 0.0555555555 |
| RSC        | meq. l\textsuperscript{-1} | 1.25-2.25 | 2 | 0.0555555555 |
| % Na       | 60 | 4 | 0.111111111 |
| SAR        | 18 | 4 | 0.111111111 |
| MH         | 50 | 3 | 0.083333333 |
| PS         | meq. l\textsuperscript{-1} | 7 | 3 | 0.083333333 |
| KR         | 1 | 4 | 0.111111111 |
| PI         | 75 - 25 | 5 | 0.138888888 |
| \(\Sigma\) | 36 | 1.000000000 |

After calculating of the IWQI values, the water quality is classified into five categories: water of excellent quality (IWQI <55), good quality (IWQI 50-100), bad quality (IWQI 100-200), very bad (IWQI 200-300) and unfit quality. (IWQI)> 300) [22]. For the purpose of calculating the effect of each parameter on the value of WQI and then judging it, the effective weight (Ewi) is calculated by dividing the Sli by the value of WQI as in the following equation [23]:

\[
E_{wi} = \frac{S_i}{W_{QI}} \times 100
\]

4. Results and Disccations

The results shown in Table (3) indicate that the IWQI values ranged between (29.08 to -41.46) and when compared to the classification of water quality [13], all water samples (100%) under study were from the category of excellent water quality for irrigation, and the reason for this is due to the concentrations of most measured characteristics Ci do not exceed the maximum permissible limits for the use of water for irrigation purposes (Si) and approved in the study [18]. It is also noted from the same table, that the values of the water quality index (WQI) were (29.08) after the exit of water from the Mosul dam, so that the values gradually increased with the course of the river due to the wastewater discharged from villages and farms to the river, so that the highest value of the water quality index was (41.46) at the center of Mosul city (S5) and this is
due to the drainage of the sewagewater of Mosul city to the Tigris river through the estuaries spread on both sides of it, then it gradually decreases to reach (31.09) at Qayyarah district (S9), south of Mosul city.

Table 3. The quality rating (Qi) and Sub-index (Sli) values for each characteristic.

| Sites Param. | S1   | S2   | S3   | S4   | S5   | S6   | S7   | S8   | S9   |
|--------------|------|------|------|------|------|------|------|------|------|
| pH           | 94.12| 93.53| 92.82| 93.18| 91.88| 92.82| 96.47| 92.12| 93.65|
| Sli          | 7.94 | 7.792| 7.735| 7.765| 7.657| 7.732| 8.039| 7.67 | 7.804|
| EC25         | 20.85| 21.90| 22.40| 23.45| 24.70| 22.90| 23.65| 22.85| 21.86|
| Cl           | 7.00 | 7.643| 8.100| 8.800| 8.600| 8.743| 8.700| 8.643| 8.243|
| HCO3         | 0.194| 0.212| 0.225| 0.244| 0.239| 0.243| 0.241| 0.240| 0.229|
| RSC          | 54.40| 55.60| 56.00| 56.40| 57.20| 57.20| 56.80| 56.40| 55.60|
| PI           | 3.022| 3.089| 3.111| 3.111| 3.133| 3.178| 3.156| 3.133| 3.088|
| %Na          | 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000|
| SAR          | 16.47| 17.18| 16.60| 17.86| 17.23| 17.23| 16.50| 17.38| 17.89|
| MH           | 1.767| 1.739| 1.778| 2.011| 1.978| 1.978| 1.889| 1.950| 1.906|
| PS           | 5.156| 5.199| 5.387| 4.973| 4.969| 4.968| 4.733| 4.963| 4.835|
| KR           | 13.53| 15.26| 16.56| 17.93| 19.04| 19.04| 18.64| 18.11| 17.46|
| PI           | 1.127| 1.271| 1.379| 1.494| 1.587| 1.587| 1.554| 1.509| 1.455|
| WOI value    | 29.08| 36.22| 36.43| 37.05| 41.46| 36.29| 36.23| 36.37| 31.09|
| Status       | Excell.| Excell.| Excell.| Excell.| Excell.| Excell.| Excell.| Excell.| Excell.|

It is noticed from Table (3) that the Sli sub-index values used to calculate the water quality index (WQI) were slightly higher for some of the studied properties, especially the values of pH, bicarbonate ions (HCO3), magnesium hazard (MH), and the permeability index (PI), as well as the effect of relative weight (Wi) of these parameters that was reflected in the IWQI values. This confirms the relatively high EWi values for these characteristics compared to other parameters that ranged between (20.96-39.55), (7.67-10.39), (13.06-17.73) and (22.67- 38.57) consecutively, as shown in Table (6). While the sub-index (Sli) values were significantly low for all studied sites for each values of electrical conductivity (EC25), chloride ions (Cl), Potential Salinity (PS), sodium percentage (% Na), sodium adsorption ratio (SAR) and Kelly rate (KR). Which reflected positively on the values of the IWQI making it an excellent water category and confirms the values of effective weight of each recipe (Ewi) as it did not exceed (9.95, 0.737, 4.679, 6.394, 0.682 and 4.417) consecutively, as shown in Table (4).

Table 4. The effective value of ith Tigris river water parameter for irrigation use.

| Sites Param. | S1   | S2   | S3   | S4   | S5   | S6   | S7   | S8   | S9   |
|--------------|------|------|------|------|------|------|------|------|------|
| pH           | 39.55| 21.45| 21.23| 20.96| 18.47| 21.32| 22.19| 22.11| 25.10|
| EC25         | 9.950| 8.373| 8.539| 8.791| 8.270| 8.780| 9.067| 8.727| 9.762|
| Cl           | 0.670| 0.584| 0.618| 0.660| 0.580| 0.670| 0.665| 0.659| 0.737|
| HCO3         | 10.39| 8.503| 8.540| 8.456| 7.670| 8.765| 8.711| 8.614| 9.932|
| RSC          | 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000|
| %Na          | 6.290| 5.255| 5.062| 5.355| 4.620| 5.281| 5.062| 5.309| 6.394|
| SAR          | 0.670| 0.531| 0.544| 0.602| 0.530| 0.604| 0.579| 0.597| 0.682|
| MH           | 17.73| 14.31| 14.79| 13.42| 11.99| 13.70| 13.06| 13.65| 15.55|
| PS           | 3.876| 3.498| 3.785| 4.032| 3.830| 4.377| 4.289| 4.149| 4.679|
| KR           | 4.240| 3.452| 3.409| 3.692| 3.131| 3.579| 3.445| 3.849| 4.416|
| PI           | 22.67| 34.24| 33.49| 34.08| 28.87| 33.01| 32.93| 33.35| 38.57|
As for the studied characteristics of the water of the Tigris river, the results shown in Table (4, 5) indicate that the concentration of potential salinity PS of the Tigris river water fluctuated between (0.772 and 1.428) and thus the water is of good quality for irrigation of all types of soils according to the Doneen classification [13], this decrease in the values is due to the decrease in the concentrations of chloride and sulfate ions that did not exceed (0.732 and 1.77) meq. \(L^{-1}\), as well as the case for the electrical conductivity that is of good quality water for irrigation (\(C_{25}\). Because the values not exceeding (565). \(\mu S. cm^{-1}\). Thus, there is no problem of salinity damage. As for the hazard of permeability and infiltration for irrigated soils, there is no problem because the SAR and RSC values are within the global permissible upper limits, as is the case with the PI values which ranged between (38.21 to 49.535), where the water of the Tigris river for the studied sites is of good quality for irrigation according to [18] as shown in the table (6). Likewise, for Specific ion toxicity expressed by sodium and chloride ions, there is no problem due to their low concentrations, which ranged between (0.317 to 0.739) and (0.336 to 0.732) meq. \(L^{-1}\) respectively, but their high concentrations cause toxicity problems. Symptoms of sodium toxicity appear in the form of burns in the leaves and along the edges of the paper, and its continuation leads to tissue death, as well as the toxicity of chloride ions, which begins as severe burns at the tops of the leaves and then develops to the edges, and a number of advanced cases occur early defoliation[24].

### Table 5. Range, mean and (Sd) of the physicochemical properties of the Tigris river waters in Nineveh Governorate

| Paramet. Site | pH  | EC\(_{25}\) | Ca  | Mg  | Na  | K  | HCO\(_{3}\) | Cl  |
|---------------|-----|------------|-----|-----|-----|----|------------|-----|
| S1            | Min.| 7.90       | 379.0| 2.550| 0.810| 0.317| 0.048      | 2.440| 0.336   |
|               | Max.| 8.10       | 453.0| 3.050| 1.550| 0.521| 0.066      | 2.800| 0.563   |
|               | Mean| 8.00       | 416.5| 2.800| 1.270| 0.452| 0.056      | 2.720| 0.490   |
| ± Sd          |     | 0.09       | 27.70 | 0.160 | 0.220 | 0.059 | 0.005      | 0.134 | 0.070   |
| S2            | Min.| 7.90       | 390.0| 2.750| 0.910| 0.417| 0.048      | 2.460| 0.394   |
|               | Max.| 8.10       | 486.0| 3.150| 1.610| 0.523| 0.069      | 2.880| 0.647   |
| Mean          |     | 8.05       | 437.8| 2.900| 1.400| 0.483| 0.059      | 2.780| 0.535   |
| ± Sd          |     | 0.12       | 36.82| 0.130 | 0.230 | 0.029 | 0.006      | 0.176 | 0.079   |
| S3            | Min.| 7.70       | 398.0| 2.850| 1.220| 0.421| 0.056      | 2.560| 0.422   |
|               | Max.| 8.10       | 488.0| 3.250| 1.580| 0.530| 0.076      | 2.860| 0.676   |
| Mean          |     | 8.05       | 447.8| 3.000| 1.420| 0.494| 0.065      | 2.800| 0.567   |
| ± Sd          |     | 0.15       | 34.68| 0.120 | 0.120 | 0.034 | 0.006      | 0.186 | 0.088   |
| S4            | Min.| 7.80       | 420.0| 2.850| 0.900| 0.426| 0.064      | 2.520| 0.478   |
|               | Max.| 8.05       | 515.0| 3.300| 1.630| 0.739| 0.076      | 2.900| 0.676   |
| Mean          |     | 7.92       | 469.3| 3.050| 1.370| 0.536| 0.069      | 2.820| 0.616   |
| ± Sd          |     | 0.10       | 28.86| 0.175 | 0.170 | 0.087 | 0.005      | 0.160 | 0.058   |
| S5            | Min.| 7.50       | 455.0| 2.850| 1.140| 0.469| 0.064      | 2.580| 0.450   |
|               | Max.| 8.10       | 565.0| 3.500| 1.880| 0.630| 0.097      | 2.940| 0.704   |
| Mean          |     | 8.11       | 494.4| 3.200| 1.370| 0.538| 0.080      | 2.860| 0.602   |
| ± Sd          |     | 0.18       | 30.74| 0.220 | 0.230 | 0.046 | 0.010      | 0.179 | 0.084   |
| S6            | Min.| 7.70       | 412.0| 2.900| 0.980| 0.434| 0.051      | 2.600| 0.450   |
|               | Max.| 8.20       | 500.0| 3.500| 1.690| 0.586| 0.074      | 3.100| 0.732   |
| Mean          |     | 7.89       | 457.8| 3.100| 1.390| 0.520| 0.066      | 2.860| 0.612   |
| ± Sd          |     | 0.17       | 30.30| 0.175 | 0.240 | 0.040 | 0.007      | 0.186 | 0.085   |
| S7            | Min.| 7.60       | 432.0| 2.750| 0.980| 0.434| 0.064      | 2.600| 0.450   |
|               | Max.| 8.20       | 503.0| 3.500| 1.990| 0.652| 0.082      | 2.940| 0.704   |
| Mean          |     | 7.84       | 472.9| 3.150| 1.390| 0.508| 0.068      | 2.840| 0.609   |
| ± Sd          |     | 0.18       | 24.67| 0.200 | 0.390 | 0.065 | 0.005      | 0.142 | 0.085   |
| S8            | Min.| 7.60       | 408.0| 2.750| 0.900| 0.456| 0.056      | 2.640| 0.422   |
|               | Max.| 8.00       | 489.0| 3.300| 1.720| 0.573| 0.087      | 2.920| 0.732   |
| Mean          |     | 7.83       | 456.5| 3.050| 1.310| 0.516| 0.067      | 2.820| 0.605   |
| ± Sd          |     | 0.14       | 23.74| 0.160 | 0.290 | 0.039 | 0.011      | 0.158 | 0.094   |
| S9            | Min.| 7.70       | 388.0| 2.700| 0.900| 0.434| 0.053      | 2.660| 0.450   |
|               | Max.| 8.20       | 486.0| 3.200| 1.630| 0.569| 0.066      | 2.860| 0.676   |
| Mean          |     | 7.96       | 437.1| 2.940| 1.140| 0.488| 0.059      | 2.780| 0.577   |
| ± Sd          |     | 0.14       | 29.32| 1.530 | 0.240 | 0.050 | 0.005      | 0.100 | 0.079   |
Finally: the pH values were within the appropriate limits for irrigation according to the classification of Ayers and Branson [18], while the bicarbonate ions were relatively high, whose rates ranged between (2.44 to 3.10) meq. l⁻¹ and thus the water is considered to be the problem increase according to Ayers and Branson classification [18].

| Table 6. Range, mean and (Sd) of the physicochemical properties of the Tigris river waters |
|-----------------------------------------------------------|
| Paramet. | Sites | SO₄ | RSC | P.S | %Na | SAR | MH | KR | PI |
|-----------|-------|-----|-----|-----|-----|-----|-----|-----|-----|
| S1        | Min.  | 0.812 | -0.660 | 0.772 | 8.2870 | 0.241 | 23.410 | 0.0910 | 42.518 |
| Max.      | 1.602 | 1.830 | 1.092 | 11.158 | 0.451 | 36.567 | 0.1270 | 52.696 |
| Mean      | 0.914 | -1.288 | 0.947 | 9.8820 | 0.318 | 30.938 | 0.1110 | 47.452 |
| ± Sd      | 0.800 | 0.373 | 0.035 | 0.8556 | 0.041 | 4.7677 | 0.0108 | 3.3930 |
| S2        | Min.  | 0.791 | -1.180 | 0.873 | 7.8360 | 0.300 | 22.410 | 0.1070 | 43.412 |
| Max.      | 1.395 | -1.690 | 1.230 | 14.199 | 0.422 | 36.920 | 0.1210 | 47.005 |
| Mean      | 1.067 | -1.504 | 1.068 | 10.309 | 0.313 | 31.198 | 0.1129 | 44.783 |
| ± Sd      | 0.153 | 0.189 | 0.155 | 1.5702 | 0.690 | 5.0675 | 0.0036 | 1.1904 |
| S3        | Min.  | 1.020 | -1.470 | 0.963 | 8.9720 | 0.290 | 28.720 | 0.1000 | 42.709 |
| Max.      | 1.375 | -1.880 | 1.334 | 10.825 | 0.356 | 35.660 | 0.1230 | 45.121 |
| Mean      | 1.185 | -1.658 | 1.159 | 9.9584 | 0.320 | 32.323 | 0.1118 | 43.923 |
| ± Sd      | 0.133 | 0.144 | 0.154 | 0.6074 | 0.100 | 2.4819 | 0.0075 | 1.0314 |
| S4        | Min.  | 1.041 | -1.020 | 1.111 | 9.8820 | 0.308 | 23.680 | 0.1110 | 44.062 |
| Max.      | 1.458 | -1.850 | 1.334 | 13.622 | 0.383 | 36.790 | 0.1200 | 49.535 |
| Mean      | 1.278 | -1.567 | 1.255 | 10.714 | 0.362 | 29.836 | 0.1231 | 45.453 |
| ± Sd      | 0.130 | 0.296 | 0.123 | 1.1259 | 0.200 | 3.6994 | 0.0149 | 2.0581 |
| S5        | Min.  | 1.250 | -1.430 | 1.168 | 9.5650 | 0.273 | 25.960 | 0.1070 | 41.632 |
| Max.      | 1.583 | -2.000 | 1.381 | 11.565 | 0.411 | 39.740 | 0.1330 | 45.126 |
| Mean      | 1.463 | -1.810 | 1.333 | 10.339 | 0.356 | 29.813 | 0.1168 | 43.091 |
| ± Sd      | 0.128 | 0.208 | 0.148 | 0.5979 | 0.097 | 4.7627 | 0.0078 | 1.2249 |
| S6        | Min.  | 1.145 | -1.360 | 1.216 | 8.3570 | 0.310 | 21.870 | 0.0920 | 41.589 |
| Max.      | 1.562 | -2.250 | 1.428 | 14.129 | 0.382 | 36.060 | 0.1460 | 47.031 |
| Mean      | 1.336 | -1.716 | 1.380 | 10.381 | 0.344 | 30.490 | 0.1167 | 44.108 |
| ± Sd      | 0.136 | 0.315 | 0.153 | 1.9789 | 0.088 | 4.7060 | 0.0177 | 2.2938 |
| S7        | Min.  | 1.145 | -1.480 | 1.022 | 8.2820 | 0.283 | 23.240 | 0.0910 | 38.302 |
| Max.      | 1.770 | -2.430 | 1.532 | 12.601 | 0.437 | 38.560 | 0.1410 | 46.478 |
| Mean      | 1.393 | -1.794 | 1.305 | 9.9009 | 0.340 | 28.403 | 0.1123 | 42.926 |
| ± Sd      | 0.209 | 0.343 | 0.189 | 1.0177 | 0.120 | 5.0840 | 0.0149 | 2.9024 |
| S8        | Min.  | 1.125 | -1.240 | 1.140 | 9.5310 | 0.306 | 24.620 | 0.1020 | 36.531 |
| Max.      | 1.666 | -2.550 | 1.394 | 11.749 | 0.401 | 38.480 | 0.1360 | 48.351 |
| Mean      | 1.362 | -1.774 | 1.268 | 10.340 | 0.351 | 29.784 | 0.1260 | 43.664 |
| ± Sd      | 0.201 | 0.521 | 0.194 | 0.8815 | 0.082 | 5.2255 | 0.0228 | 4.6685 |
| S9        | Min.  | 0.937 | -1.000 | 1.012 | 8.6860 | 0.303 | 21.950 | 0.1040 | 38.210 |
| Max.      | 1.666 | -2.360 | 1.394 | 12.664 | 0.412 | 36.380 | 0.1470 | 47.476 |
| Mean      | 1.289 | -1.516 | 1.222 | 10.734 | 0.343 | 29.011 | 0.1236 | 43.161 |
| ± Sd      | 0.206 | 0.5118 | 0.089 | 1.3716 | 0.091 | 4.7482 | 0.0161 | 3.8076 |

Conclusions

1. Low values of most of the studied parameters such as electrical conductivity, chloride, sulfate, calcium, magnesium and bicarbonate ions of the Tigris river water, which were within the internationally permitted limits for irrigation.
2. The water under study is from type C; of good quality for irrigation, according to the USSL classification.
3. All values of Na%, SAR, RSC, PI, KR and P.S were within the appropriate limits for irrigation, which reflected positively on the Sli sub-index values and WQI values that were of excellent quality for irrigation. This is confirmed by the EWl values of the studied parameters.
4. Finally, we recommend continuing periodic studies of the waters of the Tigris River while applying modern irrigation techniques to conserve water and prevent waste.
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