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Study the Possibility of Using the Treated Industrial Wastewater of North Refineries Company, Baiji-Iraq, for Irrigation Purposes

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Keywords:
Heavy metals; Industrial effluent; Irrigation Water Quality Index (IWQI); North Refinery Company (NRC)-Iraq; Salinity.

Highlights:
- *Assessment of irrigation water quality index (IWQI) in an Alsharqat district, Iraq by using GIS maps.*
- *Set up a real-time monitoring system for the sustainable development of groundwater.*
- *Establishing a risk management module for different purposes not only for agricultural uses.*

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Abstract: In arid and semi-arid regions like the Middle East, where water scarcity is a significant concern, utilizing treated industrial effluent for irrigation purposes is a common practice. The present study aims to assess the quality and suitability of effluent wastewater from the North Refineries Company (NRC) in Baiji, Iraq, for agricultural use using the irrigation water quality index (IWQI) technique. Bimonthly samples were collected from the treated effluent of NRC between November 2011 and mid-February 2012. These samples underwent testing to calculate an average of 17 physical and chemical parameters, including electrical conductivity (EC), pH, sodium, calcium, magnesium, bicarbonate, chloride, nitrate, aluminum, arsenic, copper, iron, lead, manganese, nickel, and zinc. Selecting these parameters is to comprehensively assess water quality and address environmental and health concerns. A salinity hazard was determined by the water's electric conductivity (EC), which ranged between 600 and 850 mg/L and is highly suitable for irrigation. An adsorption ratio for sodium was calculated, which ranged from 0.0034-0.12. CL^-, HCO_3^-, and NO_3^- all had high ratings and suitability except for NO_3^-, which varied from medium-high in suitability for irrigation at (40-47.5) mg/L, 30–62 mg/Las $CaCO_3$, and 0.2–7.2 mg/L, respectively. In this case, the concentrations of Mn and Cu ions were (0.79-0.04 mg/L and 5.6-0.4 mg/L), respectively, which made the water (moderate in suitability) for irrigation. The values of IWQIs ranged between 39.5 and 40.75, and their classifications fell within the first class (High). As a result, the treated wastewater (NRC) can be used for irrigation. However, it is recommended to implement measures such as establishing a proper drainage system to prevent the accumulation of heavy metals or salinity in the soil.

دراسة أمكانية استعمال مياه الفضلات الصناعية المعالجة لشركة المصافي الشمالية – بيجي في العراق لأغراض الري

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الخلاصة

يعد استخدام المياه الصناعية المعالجة كمصدر لمياه الري شائع في المناطق الجافة وشبه الجافة كما في الشرق الاوسط، اذ يكون هنالك شحة في المياه. تقترح الدراسة الحالية استخدام تقنية دليل نوعية المياه لأغراض الري لتقييم نوعية وصلاحية المياه العادمة الخارجة من شركة مصافي الشمال- مصفى بيجي للاستخدامات الزراعية. نتيجة لذلك، كانت هنالك عينتان تأخذ من المياه الخارجة من المصفى كل نصف شهر للفترة (تشرين الثاني ٢٠١١- شباط ٢٠١٢). بعد ذلك، يتم حساب المعدل لـ ١٧ فحص كيميائي وفيزيائي في كل عينة، تشمل هذه الفحوصات الايصالية الكهربائية، الدالة الحامضية، الصوديوم، الكالسيوم، المغنيسيوم، البيكربونات، الكلوريدات، النتريت، الالمنيوم، الزرنيخ، النحاس الحديد، الرصاص، المنغنيز، النيكل والزنك. الغرض من اختيار هذه الفحوصات هو لإجراء تقييم شامل لجودة المياه وللتعامل مع المخاوف البيئية والصحية. تم تحديد أخطار الملوحة بواسطة التوصيل الكهربائي (EC) للماء، الذي تراوح بين ٦٠٠ - ٨٥٠ ملغ/لتر وهو مناسب للري. تم حساب نسبة الامتزاز للصوديوم، والتي تراوحت بين ٠,٠٠٣٤-٠,١٢. اما بالنسبة للكلوريدات والبيكربونات والنترات فقد كانت لديها تصنيفات عالية وملاءمة باستثناء النترات الذي كان فيه التصنيف من متوسط إلى مرتفع في ملاءمة الري عند (٤٠-٤٧,٥) ملغ/لتر، ٣٠-٦٢ ملغ/لتر ككربونات الكالسيوم، و٠,٢-٧,٢ ملغ/لتر، على التوالي. في نفس السياق، كانت تراكيز أيونات المنغنيز والنحاس (٠,٠٤-٠,٧٩ ملغ/لتر و ٠,٤-٥,٦ ملغ/لتر، على التوالي) مما يعني ان الماء متوسط في الملاءمة للري. بالاعتماد على النتائج المتحصلة، تراوحت قيم دليل نوعية المياه للسقي مابين ٣٩,٥-٤٠,٧٥ إذ صنفت هذه القيم ضمن الفئة الاولى (عالي الصلاحية). لذلك فإن المياه العادمة الخارجة من شركة مصافي الشمال (مصفى بيجي) يمكن ان تستخدم للري مع بعض المقترحات مثل تجهيز نظام بزل جيد لتجنب تراكم العناصر الثقيلة أو الملوحة في التربة.

الكلمات الدالة: المعادن الثقيلة، النفايات الصناعية، مؤشر جودة مياه الري، شركة مصافي الشمال (NRC)-العراق، الملوحة.

1.INTRODUCTION

In recent years, water scarcity has become increasingly prevalent in semi-arid and arid regions worldwide [1]. This issue is particularly relevant in densely populated urban areas of the Middle East and southwestern United States [2]. Furthermore, global climate change is essential in making and exacerbating this problem [3, 4]. Historically, industries have discharged untreated wastewater into the environment, disregarding environmental regulations and standards [5]. The discharged industrial wastewater comprises various hazardous and exotic contaminants that degrade water quality for various purposes and impact aquatic life, economy, and human health [6-8]. Subsequently, upgrading wastewater treatment plants that include advanced processes may not be feasible to meet the 2016 – 2019 Federal Sustainable Development Strategy. Efforts have been made globally to reduce and eliminate industrial wastewater generation, employing low-cost and simple treatment processes to prevent the discharge of treated wastewater into the air, soil, and water [9]. Environmental decision-makers are exploring using treated wastewater effluent as an alternative irrigation source, as it contains essential elements for plant growth and helps alleviate pressure on surface and groundwater sources [10]. Various studies have assessed the quality of wastewater from different industries and municipalities for irrigation purposes, such as the textile industry [11], municipal wastewater [7], and agro-industrial sources [12]. The Water Quality Index (WQI) is widely recognized as an effective method for environmental monitoring, as it mathematically combines and simplifies numerous water quality parameters, providing a concise representation of water quality conditions [13, 14]. Therefore, this study aims to monitor and measure the physical and chemical parameters of treated wastewater from the North Refinery Company (NRC) in Iraq and evaluate its suitability for irrigation.

2.MATERIALS AND METHODS

2.1.Study Area

North Refineries Company (NRC) is one of the largest refineries in Iraq with 49,000 m³/d. The NRC is located, as shown in Fig. 1, in Baiji City, Salah Ad-Din province, Iraq, at a latitude of 34°55′45″ North and longitude of 43°29′35″ East. NRC is bordered by the Tigris River from the east, around 3 km from the west bank. This location is about 250 km north of Baghdad, Iraq. The population of Baiji City is around 200,000. These people used to work in oil refineries, trading, and agriculture. Numerous factories were found in the city of Baiji, including the fertilizer plant, the vegetable oil factory, the Baiji Refinery, and electric power plants, the most significant of which are the thermal and gas stations [15]. Therefore, applying refinery water treatment to agriculture will expand the agricultural area along the riverbank while reducing the wastewater discharged quantity into the river.

2.2.Sample Collection

In this study, old data of NRC-treated wastewater, from November 2011 until Feb. 2012, was used to study the possibility of using WQI as a technique to assess the quality of treated wastewater for irrigation purposes, and during which the refinery under scrutiny was functioning at its maximum capacity and was supported by two treatment plants of differing capacities. Currently, the refinery is functioning at a reduced 40% capacity and is serviced by a single treatment plant. Despite these changes, the data for this period remains of significant value. It offers a comprehensive perspective on the refinery's potential productivity and operational effectiveness, thereby establishing a standard for peak performance [16]. Samples were collected bimonthly from the effluent treated wastewater at the point of discharge from NRC-Baiji using a one-liter sterilized container, and an iced box was used to keep the collected samples cool while transporting them to the lab using standard methods [13]. To test the heavy metals, the samples were acidification (1 ml nitric acid) after filtration with 0.45 µm pore size to keep the metals dissolved and prevent precipitation. Subsequently, those samples were directly sent to the laboratory of NRC after the sampling step to calculate the mean of 17 parameters, i.e., Electrical conductivity (EC) tested by multimeter, Potential of Hydrogen (pH) tested by pH meter, Calcium ion (Ca^{2+}) tested by EDTA titration, Magnesium ion (Mg^{2+}) tested by EDTA titration, Sodium ion (Na+) tested by EDTA titration, Chloride ion (Cl^-) tested by $AgNO_3$ titration, Bicarbonate ion ($HCO3^-$) tested by titration against H_2SO_4, Nitrate ion ($NO3^-$) portable Nitrate test kits, Iron (Fe) and all the other heavy metals were tested by atomic adsorption spectrophotometer, Manganese (Mn), Copper (Cu), Zinc (Zn), Aluminum (Al), Nickel (Ni), Lead (Pb), Arsenic (As), and Sodium using the standard methods [17]. All the samples were kept in the laboratory in a refrigerator at temperatures below 4°C.

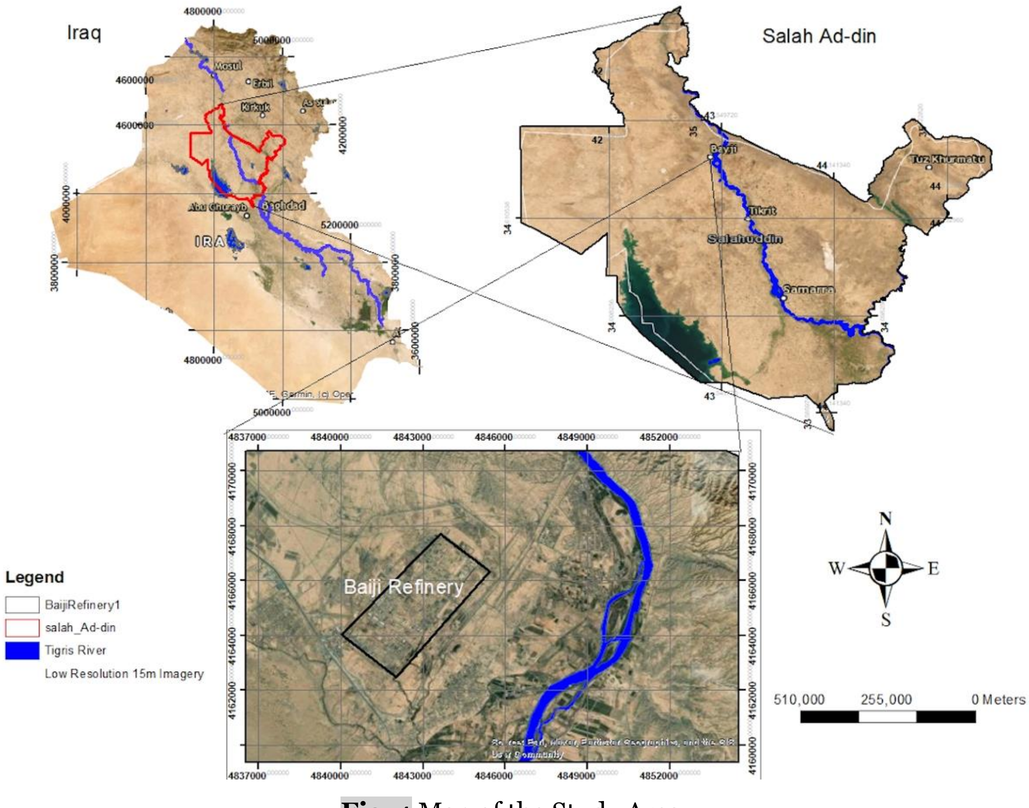


Fig. 1 Map of the Study Area.

2.3.Irrigation Water Quality Index (IWQI)

The five hazardous groups are salinity, infiltration and permeability hazard, specific ion toxicity hazard, trace element toxicity hazard, and miscellaneous effects on sensitive crops hazard. According to Ayers and Westcot (1985) [7] guidelines, each group includes one or more parameters that harm soil quality and crop yield, as shown in Table 1. After calculating their rates (r) and weights (w), all the groups mentioned in Table 1 were combined to give one value known as the irrigation water quality index (IWQI) to reflect the current state of wastewater quality and determine its suitability as a source of water for irrigation purposes. The first group, salinity hazard, includes electrical conductivity (EC), as shown in Table 1, whereas the second group, infiltration and permeability hazard, has two parameters, EC and SAR, and its calculation requires measuring the concentrations of calcium ion (Ca^{+2}), magnesium ion (Mg^{+2}), and sodium ion (Na^{+}), as shown in Table 2. The third group is specific ion toxicity, including chloride ion (Cl^{-}) and sodium toxicity (SAR) hazards. The linear combination of these two hazards is then used to calculate the index value. As a result, the fourth group is trace element toxicity, and many parameters are involved in calculating it, as shown in Table 3. Finally, the last group is miscellaneous effects on sensitive crops, which includes a combination of Nitrate ion ($NO3^{-}$), Bicarbonate ion ($HCO3^{-}$), and pH, which were combined linearly to obtain their index values, as shown in Table 1. The five hazard groups were assigned weight coefficients ranging from 1 to 5 based on their importance in irrigation water quality and effects on crops and soils. After obtaining the rating (***r***) and weighting (***w***) values for all hazard groups, the mathematical Eqs. (1) – (5) were used to calculate the final value of IWQI. The salinity hazard sub-index in this context is (SI_1), and it is calculated using Eq. (1):

$$SI_1 = w_1 * r_1 \quad (1)$$

where
w: Weight value (see Table 1), and
r: Rating value (see Table 1).
The infiltration and permeability hazard (SI2) is the second hazard category (SI_2), which is derived using the EC and SAR values, as indicated in Eq. (2):

$$SI_2 = w_2 * r_2 \quad (2)$$

where
w: Weight value (Table 1), and
r: Rating value (Table 2).

Table 1 IWQ Index Parameters Classification [15, 18].

Hazard	Weight	Parameter	Range	Rating	Suitability
Salinity	5	Electrical conductivity (µS/cm)	EC<700 700≤EC≤3000 EC>3000	3 2 1	High Medium Low
Infiltration and permeability	4	See Table 2			
Specific ion toxicity	3	Sodium adsorption ratio (SAR)	SAR<3 3≤SAR≤9 SAR>9	3 2 1	High Medium Low
		Chloride (mg/L)	Cl^-<140 140≤Cl^-≤350 Cl^->350	3 2 1	High Medium Low
Trace element toxicity	2	See Table 3			
Miscellaneous effects on sensitive crops	1	NO_3-N (mg/L)	NO_3-N<5 5≤ NO_3-N ≤30 NO_3-N>30	3 2 1	High Medium Low
		Bicarbonate (mg/L)	HCO_3^- <90 90≤HCO_3^-≤500 HCO_3^->500	3 2 1	High Medium Low
		pH	7≤pH≤8 6.5≤pH<7 and 8<pH≤8.5 pH<6.5 or pH>8.5	3 2 1	High Medium Low

Table 2 Classification for Infiltration and Permeability Hazard [15, 18].

	SAR					Rating	Suitability
	< 3	**3-6**	**6-12**	**12-20**	**> 20**		
EC	> 700	> 1200	> 1900	> 2900	> 5000	3	High
	700-200	1200-300	1900-500	2900-1300	5000-2900	2	Medium
	< 200	< 300	< 500	< 1300	< 2900	1	Low

As a result, the third hazard group (SI_3) is specific ion toxicity, which contains dual parameters (SAR, Chloride), as indicated in the weighted average Eq. (3):

$$SI_3 = \frac{w_3}{n}\sum_{j=1}^{2} r_j \quad (3)$$

where
j: Number of the contributed parameters
w: Weight value of the group parameters (Table 1)
r: Rating value of the group parameters (Table 1)
Trace element toxicity is the fourth hazard group (SI_4), which is determined using the weighted average Eq. (4) and numerous factors indicated in Table 3:

$$SI_4 = \frac{w_4}{n}\sum_{j=1}^{2} r_j \quad (4)$$

where
j: Number of the contributed index
n: The total number of the used trace elements available for the analysis
w: Weight value of the group parameters (Table 1)
Miscellaneous effects are the final group that includes the pH of water, bicarbonate ions, and nitrate-nitrogen [19]. This group is formulated as a weighted average Eq. (5):

$$SI_5 = \frac{w_5}{3}\sum_{m=1}^{3} r_m \quad (5)$$

where:
m: The incremental index
w: Weight value of the group parameters (Table 1)

Finally, Eq. (6) is used to sum all previous sub-indices to calculate the final value of IWQI, compared to the values in Table 4, indicating the suitability of the studied water resource for irrigation purposes.

$$IWQI = \sum_{i=1}^{5} SI_i \quad (6)$$

where:
i: The number of the contributed sub-index
SI: The sub-index of hazard groups

Table 3 Classification for Trace Elements Toxicity [15, 20].

Parameters	Rating	Range	Suitability
Al < 5.0	3	Al	High
5.0 ≤ Al ≤ 20.0	2	(Mg/L)	Medium
Al > 20.0	1		Low
As < 0.1	3	As	High
0.1 ≤ As ≤ 2.0	2	(Mg/L)	Medium
As > 2.0	1		Low
Cu < 0.2	3	Cu	High
0.2 ≤ Cu ≤ 5.0	2	(Mg/L)	Medium
Cu > 5.0	1		Low
Fe < 5.0	3	Fe	High
5.0 ≤ Fe ≤ 20.0	2	(Mg/L)	Medium
Fe > 20.0	1		Low
Pb < 5.0	3	Pb	High
5.0 ≤ Pb ≤ 10.0	2	(Mg/L)	Medium
Pb > 10.0	1		Low
Mn < 0.2	3	Mn	High
0.2 ≤ Mn ≤ 10.0	2	(Mg/L)	Medium
Mn > 10.0	1		Low
Ni < 0.2	3	Ni	High
0.2 ≤ Ni ≤ 2.0	2	(Mg/L)	Medium
Ni > 2.0	1		Low
Zn < 2	3	Zn	High
2 ≤ Zn ≤ 10	2	(Mg/L)	Medium
Zn > 10.0	1		Low

Table 4 Classification for Irrigation Water Quality Index [15, 21].

IWQI	Suitability for Irrigation Purposes
< 22	Low
22-37	Medium
> 37	High

3. ASSESSMENT OF INDIVIDUAL HAZARD GROUPS

3.1. Hazards of Salinity

The Electrical conductivity (EC) values in the samples are represented in Fig. 2. The highest values were observed in November 2011, while the lowest values were observed in early January 2012. It is clear from Fig. 2 that the EC had high values, increasing with time. Beyond increasing EC values, the reason is attributed to the type of produced wastewater quality because of desalting and oil refining processes, as well as rainfall, which cleans the instruments of the various units polluted with oil materials and dust and leads to sweep all of them to the wastewater treatment unit of NRC-Baiji [18].

3.2. Infiltration and Permeability Hazard

SAR is calculated depending on the values of Ca^{2+}, Mg^{2+}, and Na^{+}, determined for all samples in this study. The results showed that SAR was between 0.0034 and 0.12, as shown in Fig. 3. The highest values were in the middle of November 2011, while the lowest values were in the middle of February 2012 due to purifying the water to use for cleaning and industrial processes and because of rainfall during this time of year.

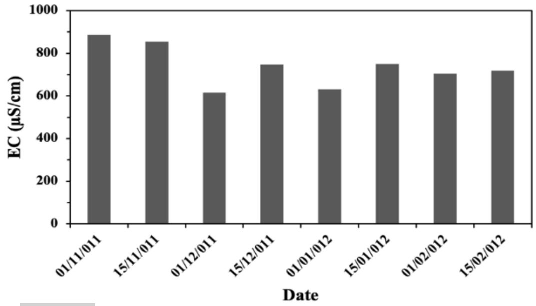


Fig. 2 Electrical Conductivity (EC) Values During the Study Period.

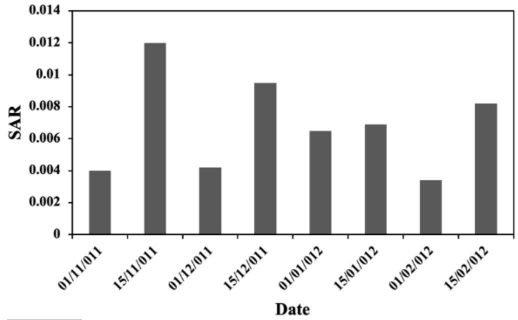


Fig. 3 SAR Values During the Study Period.

3.3. Specific Ion Toxicity

The results explained that the concentrations of Chloride ions in the effluent wastewater ranged between 40 mg/L and 47.5 mg/L, as shown in Fig. 4. At the beginning of November 2011, the concentration of Cl^{-} increased due to cooling operations and producing distilled water, which contains high concentrations of Cl^{-}. On the other hand, refinery companies always remove Cl^{-} ion from crude oil to avoid any problems that may occur in the following processes, such as scaling formation and corrosion problems.

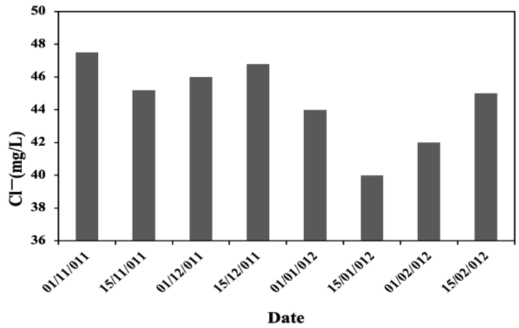


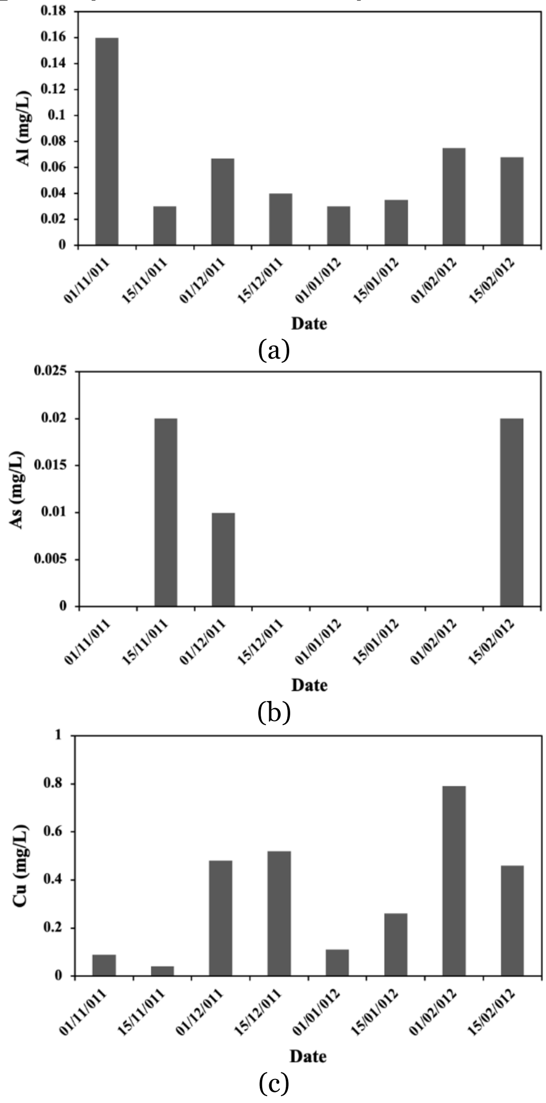
Fig. 4 Concentrations of Chloride Ion During the Study Period.

3.4. Trace Element Toxicity

The range of concentrations of Al, As, Cu, Fe, Pb, Mn, Ni, and Zn ions were (0.16-0.03) mg/L, (0.02-0) mg/L, (0.79-0.04) mg/L, (0.58-0.01) mg/L, (0.012-0.001) mg/L, (5.6-0.4) mg/L, (0.038-0.05) mg/L, and (0.42-0.18) mg/L, respectively, as shown in Fig. 5 (a-h). In this context, wastewater is generated by the oil extraction, refining, and petrochemical industries; consequently, it contains a high concentration of heavy metals, such as Fe, Cr, Ni, Cu, and Mn ions [22]. Therefore, the results revealed high Mn and Cu ions concentrations during the study period.

3.5.Miscellaneous Effects

As shown in Fig. 6 (a-c), the concentrations of HCO_3^- and NO_3^- ions were between (62-30) mg/L as $CaCO_3$ and (7.2-0.2) mg/L, respectively, while the pH values were between (7.1-8.05). The results revealed that NO_3^- ion concentrations were unstable during the research phase. The maximum level was noted at the beginning of December 2011 due to a delay in discharging the wastewater at the time, in which Ca^{2+} used the sludge used to separate the water from the oil in the sewage system to accumulate. The lowest concentration of HCO_3^- ion was detected in mid-December 2011, while the highest concentration was detected in mid-January 2012. The alkalinity of refinery effluent wastewater is higher than that of wastewater discharged from distillation and refining processes that contain alkaline chemicals. Also, this study demonstrates that the pH values generally tend toward alkalinity [23].



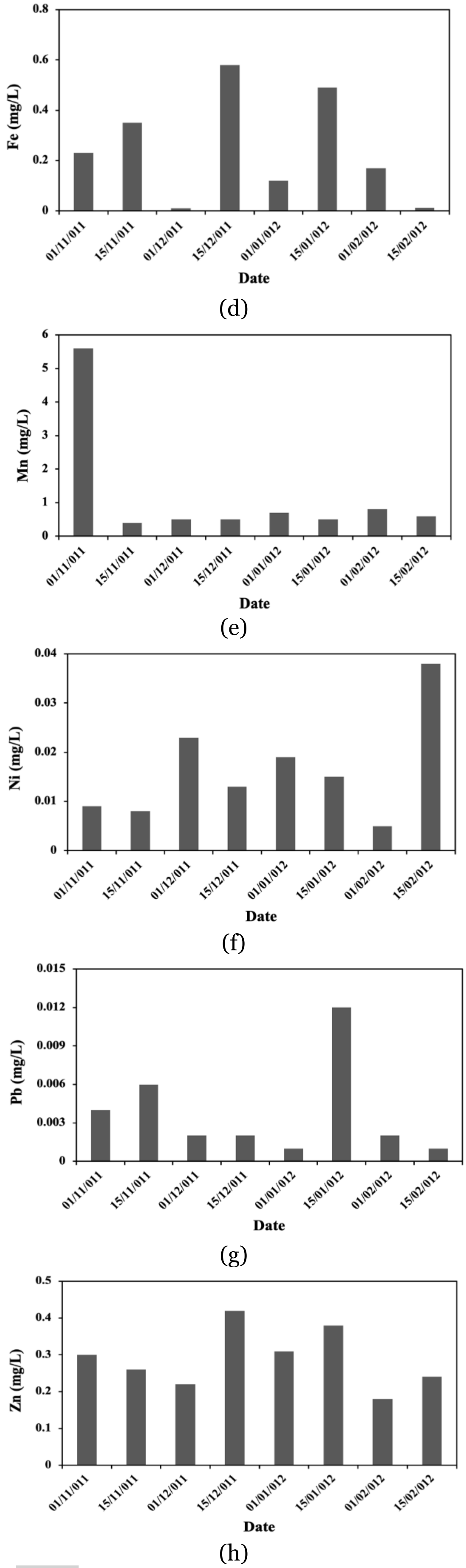
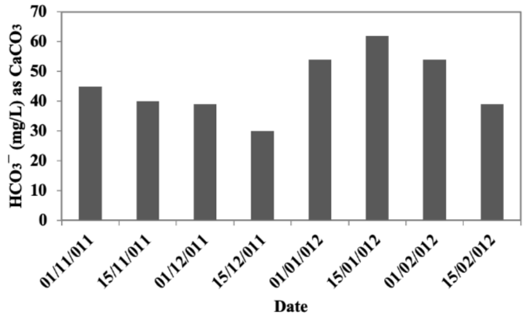
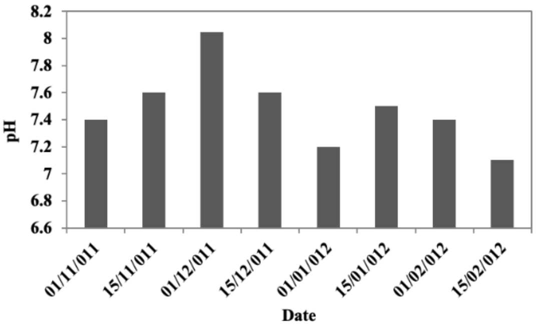


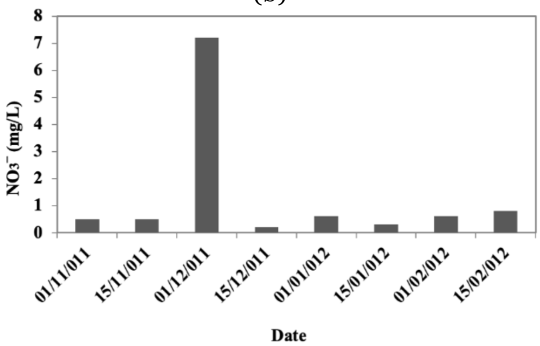
Fig. 5 (a-h): Trace Element Concentrations During the Study Period.



(a)



(b)



(c)

Fig. 6 (a-c): Miscellaneous Effects Concentrations During the Study Period.

3.6.Irrigation Water Quality Index (IWQI)

After completing the first step of sub-indexes for all hazardous groups, IWQI was calculated by adding the five sub-indexes. As shown in Fig.7, the IWQI values ranged between (40.75) and (39.5). As a result, they were classified as first class (high), which is considered a suitable source for irrigating crops with little impact on soil quality.

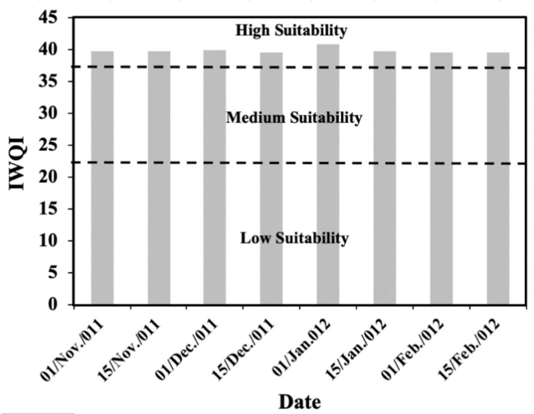


Fig. 7 IWQI Values During the Study Period.

4.CONCLUSIONS

This study is regarded as the first attempt to evaluate the quality of treated refinery wastewater for irrigation purposes using the WQI technique and its effect on the soil. Once the calculations are completed, the results will be a good indicator for farmers and non-technical decision-makers. On the other hand, this study aimed to find a solution for the massive amount of treated industrial wastewater effluent from NRC that is endangering the water quality of the Tigris River as a water supply for drinking. The study included sampling wastewater effluent at various time intervals. Tests were conducted to determine whether water was suitable for irrigation based on many parameters. There was minimal salinity indicated by electric conductivity. The infiltration and permeability for irrigation were determined using the SAR and EC values. The results showed that they were within rating three with a high appropriate value for irrigation. For irrigation purposes, all heavy metal readings were within the permissible limits. The IWQI results revealed that the wastewater quality was suitable for irrigation because its values were in the first class (High). On the other hand, this study suggests that a good drainage system should be installed for safety to avoid polluting groundwater with heavy metals or saline water.

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