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New model of long-term changes in spatiotemporal patterns of water quality across Shatt-Al-Arab River by applying GIS technique, from 1976 to 2020

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Abstract

Purpose – Using a combination of the geographical information system (GIS) and the Canadian water quality index (WQI), the current study sought to provide a long-term general assessment of the water quality of the Shatt Al-Arab River (SAAR), focusing on its suitability for living organisms. Likewise, SPSS statistics was used to develop a nonlinear WQI regression model for the study area.

Design/methodology/approach – The study required four decades of data collection on some environmental characteristics of river water. After that, calculate the WQI and conduct the spatial analysis. Eight variables in total, including water temperature, dissolved oxygen, potential hydrogen ions, electrical conductivity (EC), biological oxygen demand, turbidity, nitrate and phosphate, were chosen to calculate the WQI.

Findings – Throughout the study periods, the WQI values varied from 55.2 to 79.83, falling into the categories of four (marginal) and three (fair), with the sixth period (2007–2008) showing the most decline. The present research demonstrated that the high concentration of phosphates, the high EC values, and minor changes in the other environmental factors are the major causes of the decline in water quality. The variations in ecological variables' overlap are a senior contributor to changes in water quality in general. Notably, using GIS in conjunction with the WQI has shown to be very effective in reducing the time and effort spent on investigating water quality while obtaining precise findings and information at the lowest possible expense. Calibration and validation of the developed model showed that this model had a perfect estimate of the WQI value. Due to its flexibility and impartiality, this study recommends using the proposed model to estimate and predict the WQI in the study area.

Originality/value – Even though the water quality of the SAAR has been the subject of numerous studies, this is the only long-term investigation that has been done to evaluate and predict its water quality.

Keywords WQI, Spatial analyses, Ecological factors, Regression model

Paper type Research paper

1. Introduction

The Shatt Al-Arab River (SAAR) is one of the most freshwater sources that flow into the Gulf (Alosairi, Alsulaiman, Petrov, & Karam, 2019). It plays a principal role at the local level, as it is one of the most substantial Iraqi rivers and the prime source of surface water in the Basrah governorate. It is used for various purposes such as drinking, navigation, irrigation and industrial. At the regional level, it has a vital role in supplying the Gulf with nutrients, preserving biological diversity, and reducing salinity in the northwest Arabian Gulf in

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particular and the rest regions of the Gulf in general (Al-Yamani, Madhusoodhanan, Skryabin, & Al-Said, 2019).

Due to the unjust water policies by the riparian countries with Iraq in the Tigris and Euphrates basins, through the construction of dams and the diversion of joint river courses, the SAAR suffered from large fluctuations in salinity as a result of the lack of imported water from the Tigris and Euphrates rivers. Likewise, cutting off the Karun River water from the SAAR, which was fed the SAAR with fresh water previously, stands an impenetrable dam against the wave of salt wedge penetrating from the Gulf. This problem led to a deterioration of the environmental situation and biodiversity of the SAAR (Abed, 2022). Despite the vital importance of the SAAR, it regrettably receives many residues from diverse sources that influence the quality of the water and may impose critical impacts on its biotic and abiotic components (Lazem, 2022). Moreover, Al-Mahmood (2020) mentioned that water discharge in the Shatt al-Arab gradually decreased after the 1990s of the previous century due to the scarcity of rain and the increase in storage activity in the headwaters of the Tigris River.

In current years, attention multiplied in most nations about the effect of anthropogenic on water sources and the acceptability of the quality and quantity of water to retain anthropoid life, prosperity and different residing organisms and to check environmental objectives (Desta, 2021). However, Wu and Lu (2021) defined that the principal purpose of the water quality information data is to estimate the bulk alteration in the concentricity of various components. The stimulus of such an estimate may also be to decide the influence of anthropogenic activities, the improvement of wastewater remedy facilities, or land use changes on water quality over time. Likewise, the water quality index (WQI) was found to be one of the most effective tools used as a tool for assessing the quality of water. The estimate of water quality in the rivers was essential because they are serious for aquatic life, human consumption and irrigation. Therefore, good quality water is needed to maintain the safety and management of rivers (Wu *et al.*, 2020; Iwar, Utsev, & Hassan, 2021).

Interestingly a geographic information system (GIS) is applied in diverse fields to observe and analyze data collected from various locations. Combining GIS and other technologies has become an essential tool to give us direct control over solution expansion, cost reduction and increased accuracy and efficiency of geospatial data (Habeeb and Weli, 2021). So integrating GIS with WQI creates a powerful platform for analyzing and processing big data and mapping geography remotely in less time, at a lower cost, at a higher speed and with more accurate details. Noteworthy, some researchers have applied the WQI to assess the water quality of the SAAR for various purposes, as studies by Lazem (2014), Moyel and Hussain (2015), Karim, Ziboon, and Al-Hemidawi (2016), Mohamed, Hussein, and Lazem (2016), Mohamed, Lazem, and Hussein (2017), Hamdan, Dawood, and Nadeem (2018), and Al-Aboodi, Abbas, and Ibrahim (2018).

However, many researchers have widely used predictive regression models for river water quality studies in recent years as Avila, Horn, Moriarty, Hodson, and Moltchanova (2018), Ewaid, Abed, and Kadhum (2018) and Devagopal *et al.* (2022). In regression analysis, the curve-fitting process is to specify which pattern best fits a particular curve in a data set. As well, allows us to summarize a collection of data points to develop data-driven predictive models (Roy, Al Zubayer, Tabassum, Islam, & Sattar, 2022), which is highly desirable for monitoring the water quality condition.

Therefore, through the integration of GIS with WQI, this study aims to identify the patterns of temporal and spatial changes in water quality by analyzing long-term data collected from 1976 to 2020 to provide basic information on the main trends and problems in water quality for aquatic life in the SAAR, as well as developing a proposed model for estimating and predicting water quality for unstudied and future years.

2. Methodology and materials

2.1 Study area

The climate of the study area, like the rest of Iraq regions, is characterized by dry weather, where the summer season witnesses a significant temperature rise, leading to a high rate of evaporation. Whereas the winter is cold, with which temperatures vary greatly. However, the phenomenon of climate change has emerged recently as of global warming due to the growing human activities, which led to an increase in the concentration of gases that cause this phenomenon. That reflected negatively on the climate, which led to a further rise in temperatures and lower amounts of rainfall (Abed, 2019).

The SAAR is formed by the confluent of the Tigris and Euphrates rivers in the Al-Qurnah district, north of Basrah. It is one of the rivers affected by tidal phenomena due to its location as an estuary in the Gulf. The river flows 120 kilometers to the southwest within Iraqi territory before continuing for another 80 kilometers to form the border between Iraq and Iran before entering the Gulf. Thus, its total length is approximately 200 kilometers, its width ranges from 330 meters in Qurnah to 1250 meters in the estuary, and its depth ranges from 8.5 meters to 24 meters (Al-Lami, 2009; Al-Galibi, 2020). Usually, the low surface of the SAAR and its little slope of less than 1.5 cm/km from north to south helped to slow and limit the speed of its flow. Moreover, the marine characteristics represented by the tides have a direct effect on the change of the cross-section area of the river through the rise in the water level during the tide period and its decrease during the low tide period, which acts as a trocar for many channels connected to the SAAR, which number more than 637 along the riverbed.

Simultaneously, hydrological studies indicate that groundwater levels are high near the SAAR. During the low tidal period, groundwater movement towards the Shatt al-Arab slowly due to the muddy alluvial soil mixture, characterized by its high salinity, therefore harms the river's water quality (Al-Lami, 2009).

Three stations were specified to execute the present study (Figure 1). The first station (30°58'29.7"N 47°28'32.2"E) is located north of the river near the connection of the SAAR with the Al-Swaib channel. The second (30°34'48.9"N 47°46'21.3"E) was a close Sindbad island, and the third (30°26'57.4"N 48°05'21.9"E) proximate Om Al-Rasas island.

2.2 Measured factors

A multimeasure device (WTW Multi 350i) was used to measure the water temperatures (WT), dissolved oxygen (DO), potential hydrogen ion (pH) and electrical conductivity (EC). Biological oxygen demand (BOD_5) was measured using five days incubation method. Turbidity (*T*) was measured by turbidity meter model HI 93701 Microprocessor, Hanna. Whereas, Nitrates (NO_3) and Phosphate (PO_4) were measured according to APHA (2005). Also, the Global Positioning System (GPS) waypoint is documented for spatial reference at each location. However, the data collected by previous researchers for more than four decades were also aggregated, prepared and used in this study, such as Hameed (1977), Al-Awadi (1983), Al-Aubaidy and Al-Hello (1996), Hussein and Attee (2000), Jassim (1999), Al-Essa (2004), Hammadi (2010), and Lazem (2014). Therefore, the study was divided into eight periods according to available data.

2.3 Water quality index (WQI)

The Canadian WQI (CCME WQI) was applied in the present study as general WQI (GWQI). A total of eight parameters were considered in calculating the WQI, namely WT, DO, pH, EC, BOD_5, T, NO_3 and PO_4.

The current study considered the Iraqi standards mentioned in the system of river maintenance of pollution No. 25 for the year 1967 to assess the scope of water quality of the SAAR. The WQI applied which was approved by the Canadian Council of Ministers of the Environment (CCME, 2001) as the following equation was used to calculate the WQI:

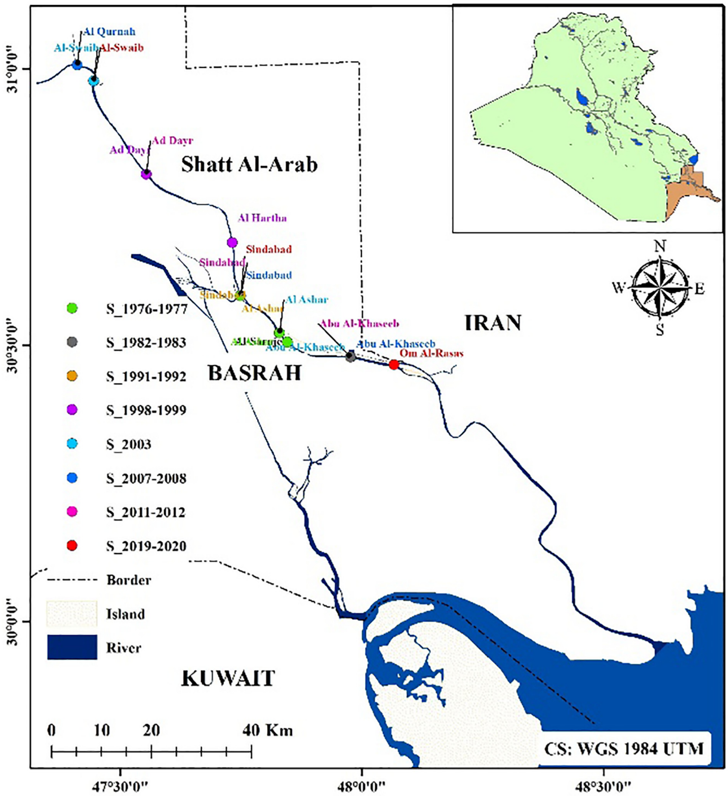

Figure 1.
Map of the SAAR showing the study sites

Source(s): Figure by authors

$$\mathrm{WQI} = 100 - \sqrt{(\mathrm{F1} + \mathrm{F2} + \mathrm{F3})} / 1.732 \tag{1}$$

F1 (Scope): Percent of variables that exceed the permissible value (failed variables).

$$\mathrm{F1} = (\text{Number of failed variables} / \text{Total number of variables}) \times 100$$

F2 (Frequency): Percent of individual exams for every variable exceeded the permissible value (failed tests).

$$\mathrm{F2} = (\text{Number of failed tests} / \text{Total number of tests}) \times 100$$

F3 (Amplitude): the amount by which failed test values fall short of their objectives.

$$\mathrm{F3} = \mathrm{nse} / (0.01\,\mathrm{nse} + 0.01)$$

Where:

$$\mathrm{nse} = \sum_{i=1}^{n} \mathit{excursion} / \text{Number of tests}$$

In cases where the test value must not be greater than the objective:

$$\text{Excursion} = (\text{Failed Test Value}/\text{Objective}) - 1$$

In cases where the test value must not fall below the objective:

$$\text{Excursion} = (\text{Objective}/\text{Failed Test Value}) - 1$$

After determining the WQI value, water quality was ranked by assigning it to one of the following categories: excellent (95–100), good (80–94), fair (65–79), marginal (45–64) and poor (0–44).

2.4 Statistical and spatial analyses

The statistical analyses were performed by the IBM Statistical Package for the Social Sciences (SPSS) program (version 24). Similarly, the spatial analysis method was implemented using the ArcGIS 10.4.1 program. The spatial-temporal variability of WQI was predicted utilizing the spatial analyst tool in ArcGIS and then the standard kriging interpolation process with a spherical semivariogram model. The most basic interpolation method is the ordinary kriging method, which allows the operation of a statistical model that includes autocorrelation. Furthermore, using the interpolated values to create map layers for WQIs, displayed the spatial distribution pattern of WQI across the river. Likewise, a buffer tool was applied to make the map features more visible for the SAAR.

2.5 Development of the WQI regression model

A nonlinear WQI regression model was generated using the IBM SPSS statistics package version 24. The regression relation WQI with years in the SAAR is calculated by Equation (2) which is determined by using curve fitting estimation analysis, which provides 11 model descriptions of the relationship for each regression between WQI and years. For the best-fit relation, we selected the highest value of the coefficient of determination (R^2). Moreover, the nonlinear SAAR-WQI model validation was verified by testing the statistical significance between the values of WQI estimated by the created model and the WQI values calculated by Eq. (1). Likewise, the Canadian index classification has been used for ease of comparison.

$$\text{SAAR} - \text{WQI} = -707.9 * \ln(\text{X}) + 5453.3 \tag{2}$$

Where X is the year.

3. Results and discussion

3.1 Water characteristics

3.1.1 Water temperature (WT). Monthly and local variations in WT are presented in Figure 2 during the eight study periods in the selected sites in the river. The WT (°C) values ranged between (8.6- 29), (12.2- 30.3), (10.2- 29.8), (14- 39.5), (14- 32), (11- 34.8), (10.9- 36.9) and (12.1- 33.4) in the eight consecutive periods. The statistical analysis presented some significant differences ($p < 0.05$) between the first period (1976–1977) with fourth (1998–1999), the eighth (2020) as well as between the fourth period (1998–1999) and sixth (2007–2008). The lowest value of WT was recorded (8.6°C) in the first period during January 1976, and the highest (39.5°C) during September 1998. This significant increase in WT may be due to the influence of the hot water flows released to the SAAR from the Hartha power plant. Later, this affects the aquatic organisms inhabiting the river and can affect metabolic rates and biological activity. The WT has a significant impact on the distribution and abundance of living organisms. Moreover, it influences the water's physical and chemical properties (Jawad, 2021; Häder & Barnes, 2019). The lowest annual average temperature was (20.2°C) in the first

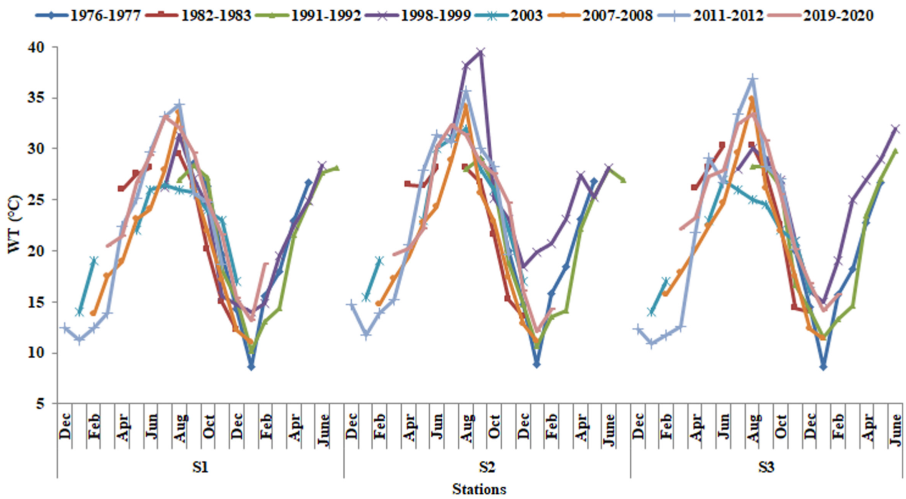

Figure 2. Monthly and local variations in water temperature during the study periods

Source(s): Figure by authors

period, and the highest (was 24.5°C) in the fourth period (Figure 6). Generally, a noticeable increase in temperature is observed compared to the first and second periods, and the reason may be attributed to climatic changes that affect aquatic ecosystems. Despite the differences in some months between the studied periods, the recorded temperature ranges were similar and within their natural ranges.

3.1.2 Dissolved oxygen (DO). Figure 3 illustrates monthly and local alteration in DO during the eight study periods in the selected sites in the river. The DO (mg/L) values differed between (4.82- 9.76), (4.88- 10.48), (6.4- 9.5), (5.5- 11.6), (5.8- 11.7), (6.1- 10.5), (5.55- 9.92) and (6.4- 10.5) in the eight successive periods. However, the statistical analysis showed significant

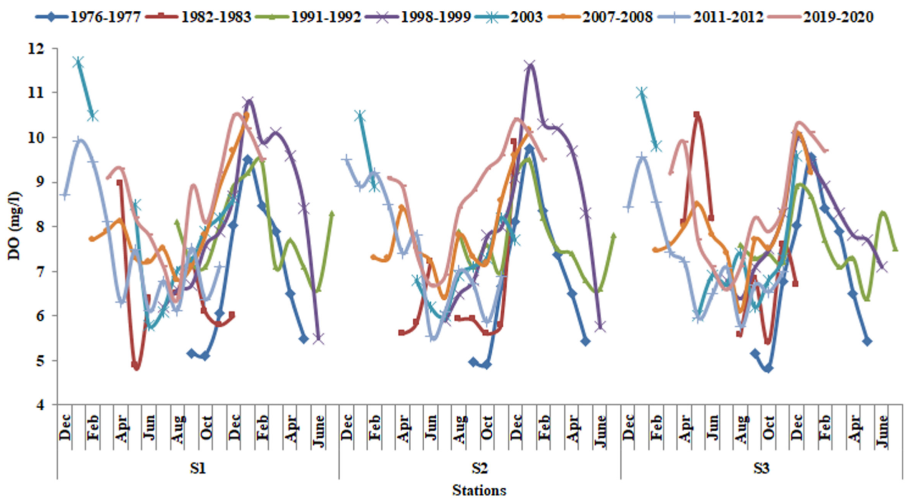

Figure 3. Monthly and local alterations in DO values during the study periods

Source(s): Figure by authors

differences ($p < 0.05$) among periods such: as the first period (1976–1977) and all other periods except the second and eighth periods, the second period (1982–1983) with others periods except for first and seventh periods, the third (1991–1992) and eighth period, the fourth (1998–1999) and seventh period, the fifth (2003) and eighth period, the sixth (2007–2008) and eighth period, also seventh (2011–2012) and eighth period (2019–2020). These significant differences may be attributed to fluctuations in DO values during these periods due to the river's exposure to different environmental conditions (such as the fluctuation of water temperature, salinity, diffusion and aeration, photosynthesis, respiration, decomposition and atmospheric pressure) during these long years. The lowest value of DO was registered (4.82 mg/L) in the first period over October 1976, and the highest (11.7 mg/L) during January 2003. Considering DO is essential for aquatic life to keep organisms alive. However, the results showed decreasing DO concentrations below 5 mg/L in May, September, and October in the first period. This decline may be due to the high consumption of O2 (by aquatic microorganisms) to break down dissolved organic material released from sewage, urban and agricultural runoff. Noteworthy, the human impact factor has a clear role in the SAAR through the projects established, various water policies and the increase in farming, industrial requirements and other uses, which negatively affected the hydrology of the riverbed, such as a decrease in water discharges and deterioration in its quality. The overall DO concentrations over 5 mg/L for all months in all periods indicate good water circulation and DO at acceptable levels for aquatic life. Interestingly, the current work showed that the best annual rate of DO values (8.66 mg/L) was in the eighth period (Figure 6). The cause could be attributed to an increase in water releases and movement as an outcome of the torrential waves and floods that swept through Iraq and neighboring countries by spring floods, which did not happen for more than three decennia (Lazem, 2022).

3.1.3 Potential hydrogen ion (pH). Figure 4 explains monthly and local changes in pH during the eight study periods in the selected locations in the SAAR. The pH values varied between (7.67- 8), (7.16- 8.50), (7- 8.31), (7.2- 8.1), (7.41- 8.13), (6.73- 8.3), (6.99- 8.51) and (7.03- 8.2) in the eight sequential periods. Likewise, insignificant differences were displayed by the statistical analysis ($p > 0.05$) among periods. The lowest pH value was listed (6.73) in the 6th period during December 2007 in Abo Al-kaseeb and the highest (8.51) in the 7th period over

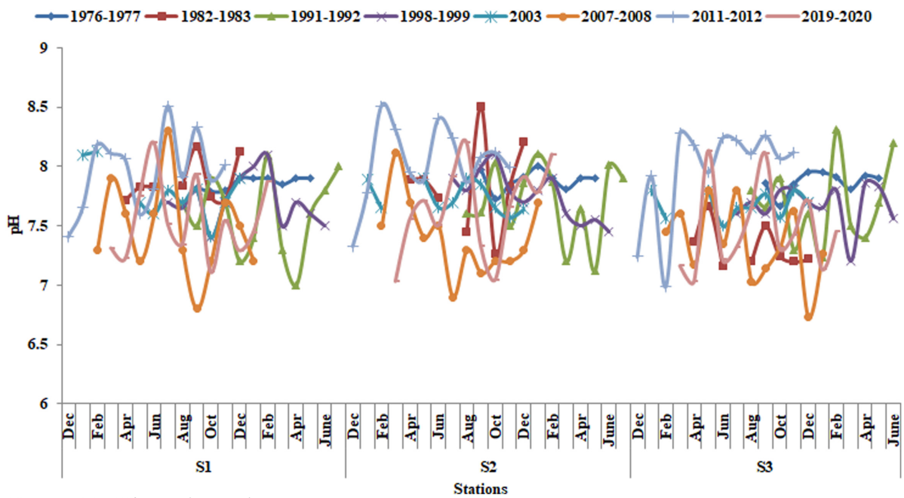

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Figure 4. Monthly and local differences in pH values during the study periods

July- 2012 in Ad Dayr. For all periods, the rate values of the pH ranged from 7.41 to 7.99 (Figure 6). That indicates the waters of the SAAR within the alkaline trend throughout these years. And this is consistent with the nature of the Iraqi water environment (Al-Asadi, Al Hawash, Alkhlifa, & Ghalib, 2019). The cause of alkalinity in the SAAR waters is the presence of carbonate and bicarbonate ions, which is confirmed by all studies conducted on this river (Lazem, 2022).

3.1.4 Electrical conductivity (EC). Monthly and local fluctuations in values of EC are shown in Figure 5 during the eight study periods in the selected sites in the SAAR. The EC (mS/cm) values changed between (0.62- 1.6), (2.19- 6.72), (1.3- 8.13), (1.88- 3.75), (1.72- 4.22), (1.17- 11.09),

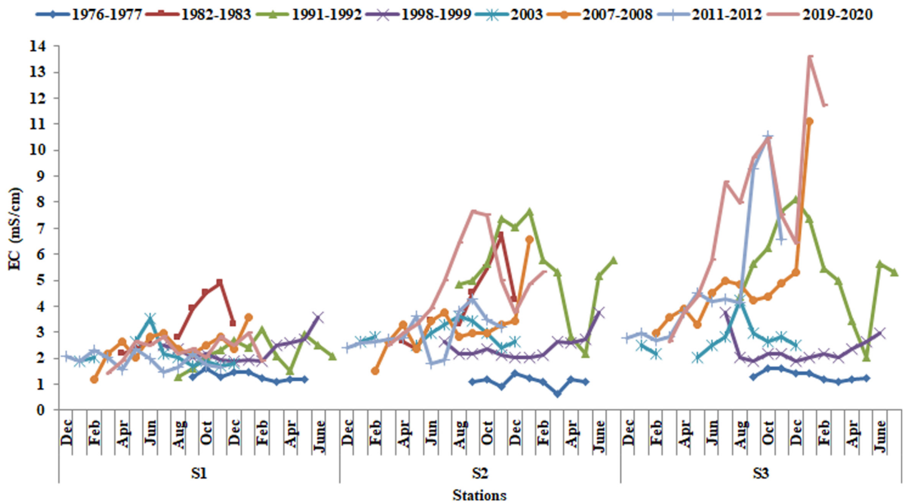

Figure 5. Monthly and local fluctuations in EC values during the study periods

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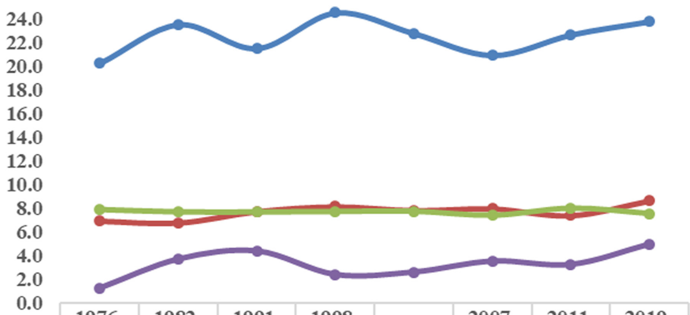

	1976-1977	1982-1983	1991-1992	1998-1999	2003	2007-2008	2011-2012	2019-2020
Tem	20.2	23.5	21.5	24.5	22.7	20.9	22.6	23.8
DO	6.92	6.77	7.74	8.15	7.83	7.97	7.39	8.66
PH	7.87	7.68	7.68	7.72	7.74	7.41	7.99	7.55
EC	1.25	3.70	4.37	2.38	2.60	3.52	3.24	4.97

Figure 6. The annual rates pattern of WT, DO, pH and EC during the study periods

Source(s): Figure by authors

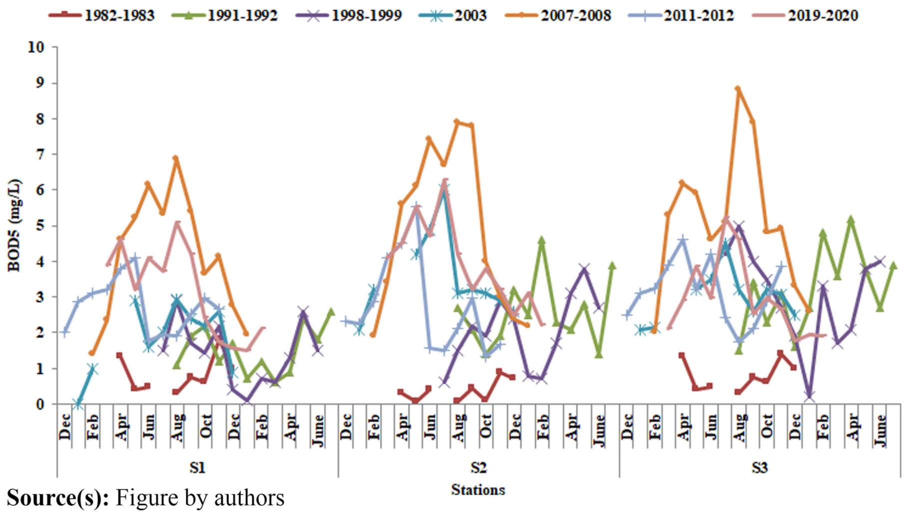

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Figure 7. Monthly and local changes in BOD_5 values during the study periods

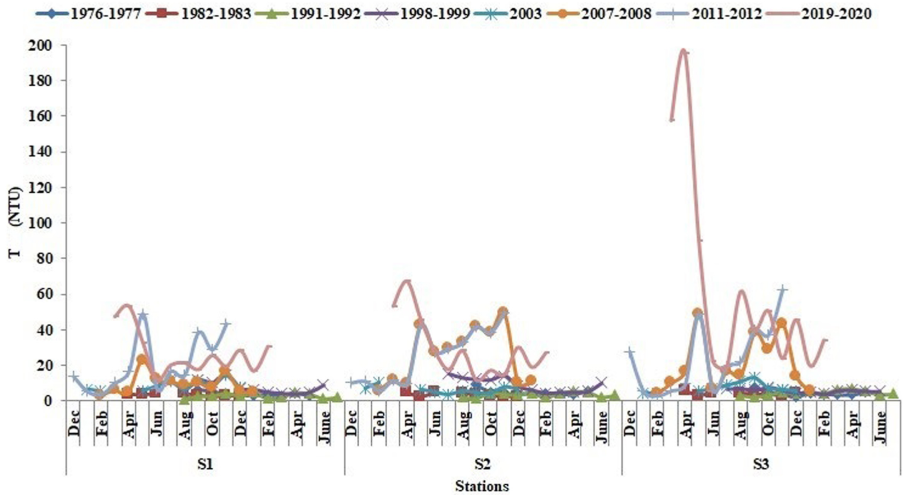

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Figure 8. Monthly and local fluctuations in T values during the study periods

(1.47- 10.54) and (1.41- 13.59) in the eight consecutive periods. Furthermore, the statistical analysis revealed significant differences ($p < 0.05$) among all periods except for the following: the 2nd with 3rd, 6th and 7th, then 3rd with 8th, then 4th with 5th, then 5th with 7th and the 6th with 7th period. The reason for these significant differences may be the wide variation in the EC values during these periods due to the fluctuation and lack of water releases reaching the SAAR. Likewise, the overall value of EC in the river differs from 0.62 (mS/cm) in the first period during March 1977 in Ashar to 13.59 (mS/cm) in the 8th period in January 2020 in Um Al-Rasas. However, the lowest EC rate was (1.25 mS/cm) in the first period and the highest (4.97 mS/cm) in the eighth period (Figure 6). The results noted that the salinity of the SAAR is

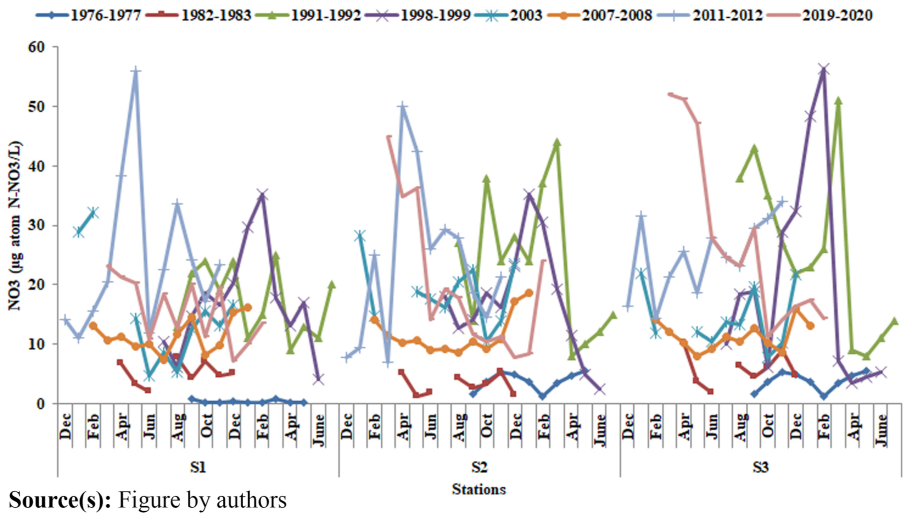

Figure 9. Monthly and local fluctuations in NO_3 values during the study periods

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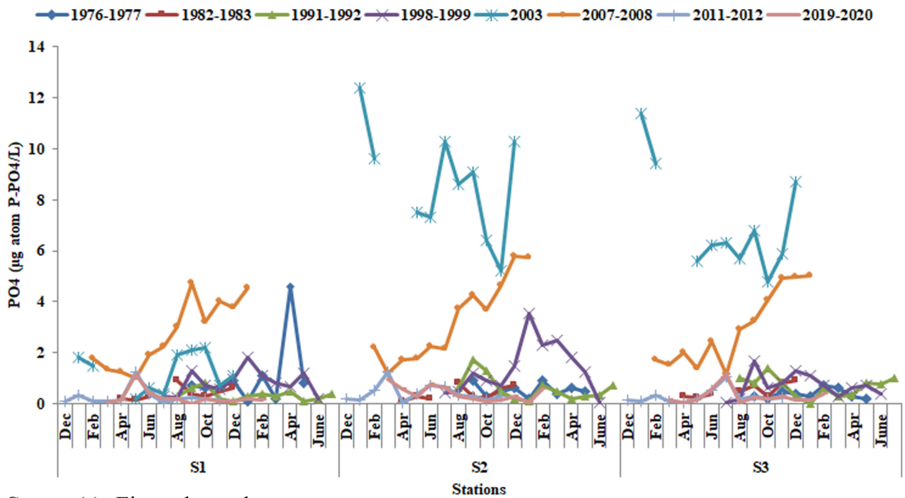
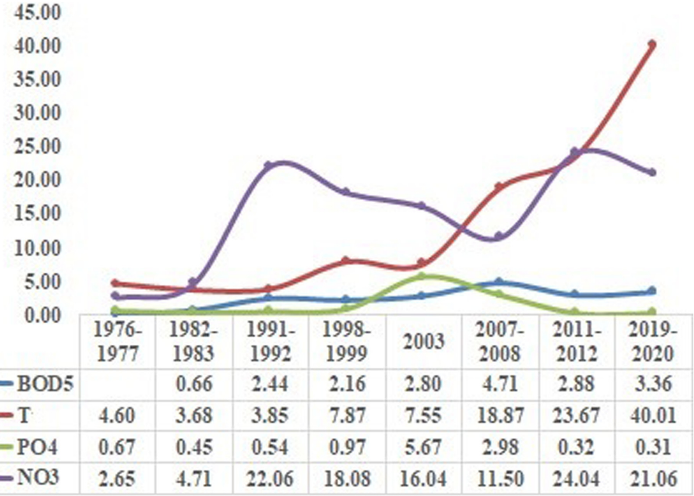


Figure 10. Monthly and local fluctuations in PO_4 values during the study periods

Source(s): Figure by authors

not similar in all-region. It increased towards the lower reach of the river. Therefore, there is evident spatial variation, while the temporal effect did not remark on the different percentages of EC in the SAAR. The reason may be due to the SAAR hydrodynamics, which is influenced by the interference of two forces: the power of saline seawater penetrates for long distances into the SAAR during the tide due to the lack of freshwater flows reaching the SAAR from the Tigris and Euphrates rivers. At the same time, a diversion of the course of the Karun River to the Bahamishir River in Iran, which previously served as a barrier to limit the salt tides' incursion into the SAAR (Al-Aesawi, Al-Nasrawi, Jones, & Yang, 2021). Second, the strength of the freshwater drains supplied to the SAAR from the source. Moreover,



	1976-1977	1982-1983	1991-1992	1998-1999	2003	2007-2008	2011-2012	2019-2020
BOD5		0.66	2.44	2.16	2.80	4.71	2.88	3.36
T	4.60	3.68	3.85	7.87	7.55	18.87	23.67	40.01
PO4	0.67	0.45	0.54	0.97	5.67	2.98	0.32	0.31
NO3	2.65	4.71	22.06	18.08	16.04	11.50	24.04	21.06

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Figure 11. The annual rates pattern of BOD_5, T, PO_4 and NO_3 during the study periods

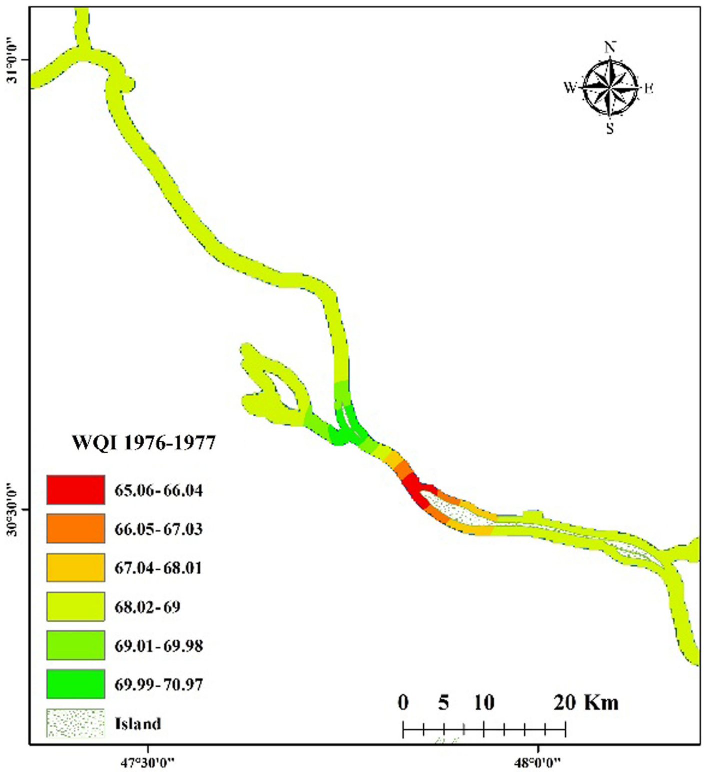

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Figure 12. The pattern of WQI values in the SAAR in the first period

climatic changes increase the amount of evaporation due to high temperatures and the scarcity and fluctuation of rainfall.

3.1.5 Biological oxygen demand (BOD_5). Monthly and local changes in values of BOD_5 are present in Figure 7 during seven study periods in the studied sites in the SAAR. Unfortunately, we could not get the BOD_5 values in the first period (1976-1977). The BOD_5 (mg/L) values fluctuated between (0.07- 1.8), (0.6- 5.2), (0.1-5), (0.01- 6), (1.4- 8.8), (1.33- 5.54) and (1.49- 6.3) for periods second to eighth, respectively. Also, significant differences ($p < 0.05$) appeared among periods, except the third period with the 4th, 5th and 7th, the fifth period with the 7th and 8th, and finally, the seventh with the 8th period.

Generally, the values of BOD_5 were high during the warm months in all periods due to the increase in the activity of microorganisms that decompose organic matter. The highest rate of BOD_5 value (4.71 mg/L) was recorded during the 6th period (2007- 2008), followed by the 8th period with a rate of 3.31 mg/L (Figure 11), and this may be due to reducing the rate of water flow, degradation of organic pollutants or accumulation of wastes refer to anthropogenic actions. However, the lowest values of BOD_5 (0.66 mg/L) were recorded in the second period, reflecting the lack of water pollution with organic materials. Compared to all other periods, the values exceeded the threshold of 5 mg/L in some months, which refers to the water purity reaching its critical state (Effendi and Wardiatno, 2015).

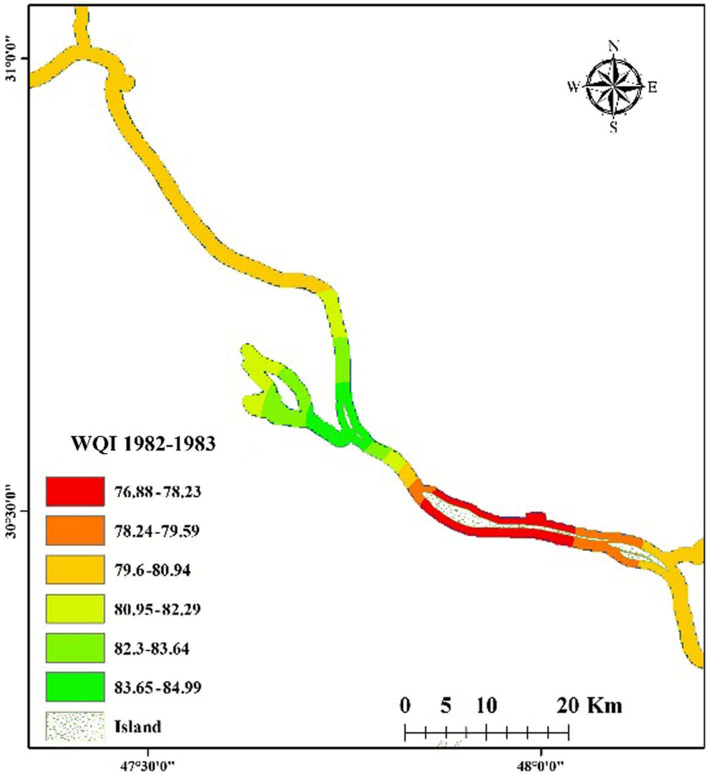

Figure 13. The pattern of WQI values in the SAAR in the second period

Source(s): Figure by authors

3.1.6 Turbidity (T). Figure 8 clarifies monthly and regional alteration in T during the eight examination periods in the specified sites. The T (NTU) values vary between (2.57- 9.15), (2.1- 5.8), (1.3- 7.2), (4.1- 15.29), (3.69- 14.79), (3.21- 49.8), (3.2- 62.5) and (11.43- 195.4) in the eight successive periods. Although there were insignificant differences ($p > 0.05$) among periods 1 to 5 and also between periods 6 and 7, the statistical test exhibited significant differences ($p < 0.05$) among periods 6 to 8 and all other periods. However, the overall turbidity values in the river varied from 1.3 (NTU) in August 1991 to 195.4 (NTU) in April 2019. Furthermore, Figure 11 illustrates the lowest rate of turbidity values was 3.68 (NTU) in the second period (1982-1983), and the highest was 40.01 (NTU) in the eighth period (2019-2020). Generally, the turbidity of water is caused by suspended particles such as clay and silt, as well as fine pieces of organic and inorganic materials, besides plant and animal plankton and other microorganisms such as protozoa (Pournou, 2020).

Interestingly, the study showed that the rates of turbidity values in the SAAR had taken an upward pattern, especially in the latest three periods. The reasons may be attributed to the reduction in water discharge rates from the Tigris and Euphrates rivers, tidal currents' arrival from the Gulf, contributing to the accumulation of suspended matter, and an increase in the number of pollutants that drain directly into the river without treatment. Furthermore, the decline in the density of aquatic plants in the river (which act as natural filters for the suspended matter) is due to the high salinity level. Likewise, a significant increase in turbidity values in the recent period (2019-2020) from March to May due to the large amounts of water

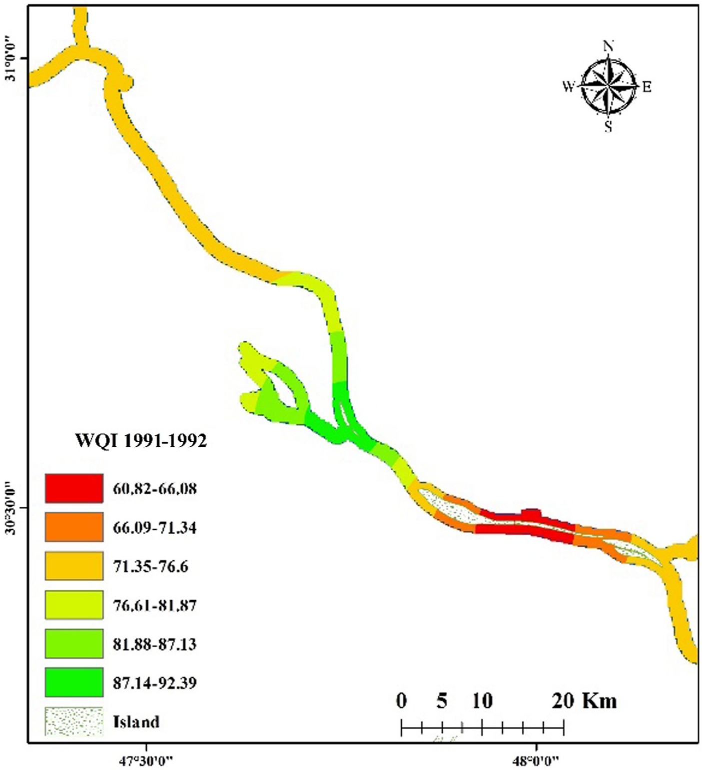

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Figure 14.
The pattern of WQI values in the SAAR in the third period

drained in the SAAR during the flood season, which washed the soil and agricultural lands, then mixed with the river water (Al-Amery and Al-Saad, 2022).

3.1.7 Nitrates (NO_3). Figure 9 presents monthly and spatial changes in NO_3 during the eight examination periods in the selected sites in the SAAR. The NO_3 (μg atom N-NO3/L) values differ between (0.20- 5.5), (1.30- 10.20), (8.00- 51.00), (2.38- 56.27), (4.69- 32.23), (7.30- 18.60), (6.87- 55.95) and (7.08- 52.13) in the eight consecutive periods. Likewise, significant differences ($p < 0.05$) seemed among most periods, except between first and second; third and fourth, seventh, eighth; fourth and fifth, eighth; seventh and eighth. Others, the overall nitrates values in the river varied from 0.2 (μg/L) in October, January and May in 1976-1977 to 56.27 (μg/L) in February 1999. Thereupon, the lowest rate of NO_3 values was 2.65 (μg/L) in the first period (1976-1977), and the highest was 24.04 (μg/L) in the seventh period (2011-2012) (Figure 11). At first glance, a decrease in nitrate concentrations is observed in the first and second periods. At the same time, the results recorded a significant increase in nitrate values during the periods from the third to the eighth. The reason may be due to the decrease in the river discharge and high concentrations of pollutants entering the river (directly or through the channels scattered on both sides) carrying large quantities of sewage and agricultural and industrial waste. They contain nitrogen compounds oxidized by microorganisms and release large amounts of nitrates directly into the water (Wu, Hao, Cai, Liu, & Xing, 2021).

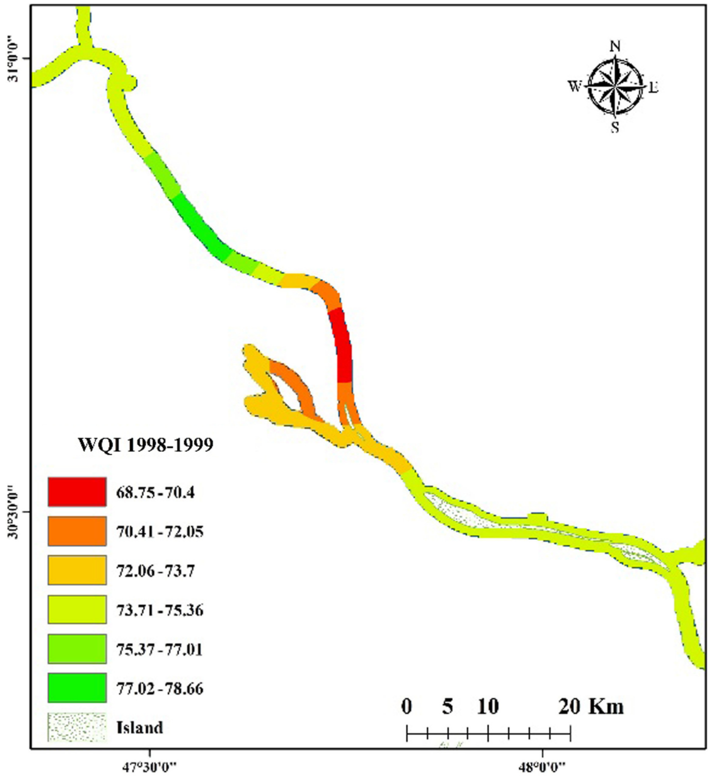

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Figure 15.
The pattern of WQI values in the SAAR in the fourth period

3.1.8 Phosphate (PO_4). Monthly and local variations in values of PO_4 are displayed in Figure 10 during the eight study periods in the investigated sites in the SAAR. The PO_4 (μg atom P-PO_4/L) values wiggled between (0.10- 4.60), (0.10- 0.90), (0.01- 1.70), (0.05- 3.56), (0.18- 12.40), (1.02- 5.78), (0.03- 1.25) and (0.02- 1.16) for all periods respectively. Although insignificant differences ($p > 0.05$) appeared among most periods, there were significant differences ($p < 0.05$) among periods five, six, and the other periods. Interestingly, phosphate concentrations significantly increased in the fifth and sixth periods compared to the rest of the periods, especially in the cold months. Rain helps release phosphate from the soil. It is one of the sources of phosphate dissolved in water (Hellmann *et al.*, 2022). Similarly, faint concentrations of PO_4 were recorded during the summer. And this may be explained by the consumption of phosphate by algae and aquatic plants. However, the lowest value of PO_4 was recorded (0.01 μg/L) in the third period over January 1992 and the highest (12.4 μg/L) during January 2003. Likewise, the rate of PO_4 values in the SAAR varied from 0.31(μg/L) in the eighth period (2019-2020) to 5.67 (μg/L) in the fifth period (Figure 11).

3.2 Water quality index (WQI)

The Canadian WQI provides wobbling differences in WQI values among periods. Values varied between (64.94- 70.94), (76.91- 85.02), (60.72- 92.49), (68.72- 78.71), (51.15- 75.16), (51.56- 62.01), (56.74- 65.40), and (47.25- 68.53) for all periods respectively (Figures 12–19). However,

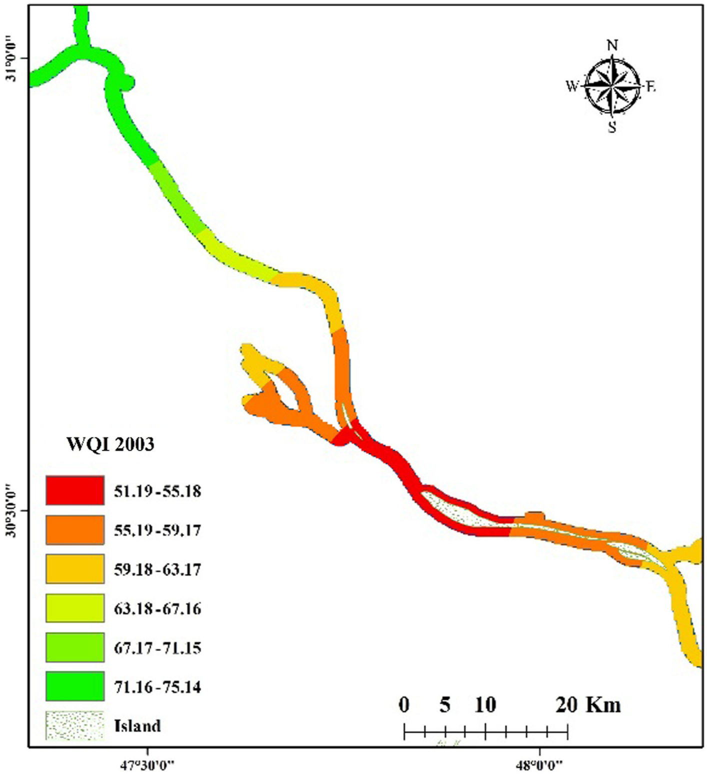

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Figure 16.
The pattern of WQI values in the SAAR in the fifth period

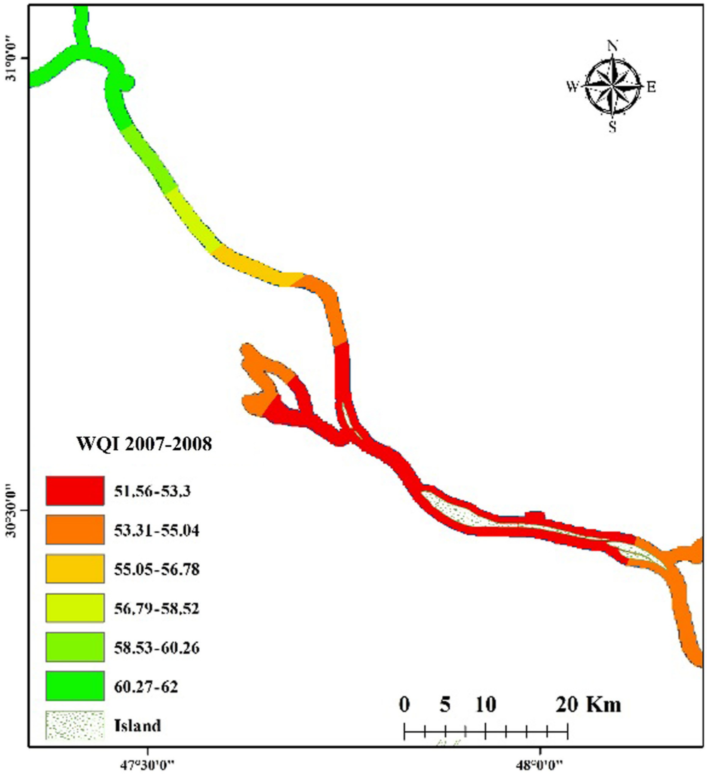

Figure 17.
The pattern of WQI values in the SAAR in the sixth period

Source(s): Figure by authors

during the study periods, the WQI rate values in the SAAR ranged from 55.2 to 79.83, classified as four (marginal) and three (fair) (Figure 20). The lowest WQI value (55.2) was found in the sixth period (2007-2008), while the highest (79.83) was found in the second period (1982-1983). Interestingly, results showed that the sixth period (2007-2008) is the most deteriorating water quality. The index value reached 55.2, categorized within category four (marginal), due to the significant rise in PO4. As a consequence of the decrease in the rate of river discharge during this period (Al-Mahmood, 2020) led to an increase in the concentration of pollutants entering the SAAR, which are rich in phosphates from washing powders, sewage as well as land drainage water. At the same time, this deterioration also coincided with a rise in BOD_5 values (in some months of the study), which negatively affected the value of the GWQI, as rising water temperature leads to an increase in the activity of microorganisms that increases the decomposition of organic matter (Niloy, Haque, & Tareq, 2021).

Likewise, the fifth (2003), seventh (2011-2012) and eighth (2019-2020) periods recorded the same categorization within category four (marginal), according to the value of the GWQI. The main reason for the deterioration of water quality was the increase in PO_4 values recorded in the fifth period. However, the decline was in all factors (in some months) except for DO in the seventh period (2011-2012). Similarly, the retrogradation in the last period (2019-2020) was due to increased EC values. In addition, the increase in turbidity and PO_4 values exceeded

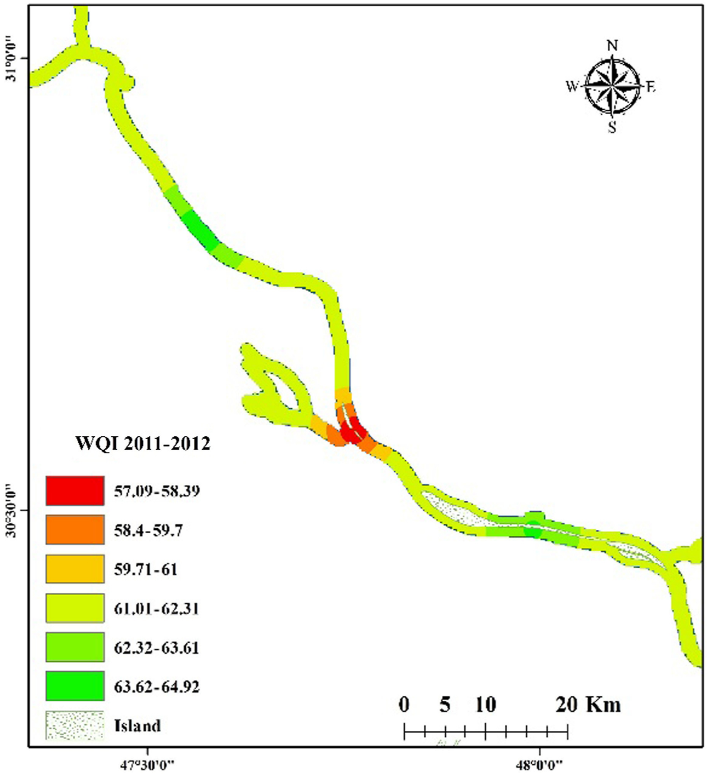

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Figure 18. The pattern of WQI values in the SAAR in the seventh period

standards despite the occurrence of the spring flood in this period, which had not occurred for three decades (Lazem, 2022), causing washing of soil and agricultural lands, a drift of pollutants into the SAAR, thus increasing the EC, turbidity and PO_4.

Noticeably, the second period (1982-1983) was the best (79.83) in GWQI, classified within category three (fair). It had differentiated by the scarcity of deviations from the standards specified within the system of river maintenance from pollution. So a relative quality occurred to GWQI in the SAAR compared to the rest of the periods. Likewise, during this period, plenty of water was discharged into the SAAR coming from the Tigris and Euphrates (Al-Mahmood, 2020), which works to reduce the salts and pollutants entering the river. Moreover, pushed salt intrusion coming from the Gulf, therefore, positively reflected on water quality.

At the same time, we could note that the third, fourth and first periods recorded 76.21, 73.98 and 67.34 sequentially, categorized within category three (fair). However, the EC and PO_4 were the prime cause affecting the water quality in the third period. Also, in the fourth and first periods, PO_4 was the main factor effect on water quality more than other water characteristics.

Because of the different periods between the years studied, a nonlinear regression model was adopted to help us understand the problem better. For this reason, Figure 21 shows the nonlinear regression model of the SAAR over the years. However, the regression model recorded a positive intensity correlation ($R^2 = 0.986$). As Chicco, Warrens, and Jurman (2021)

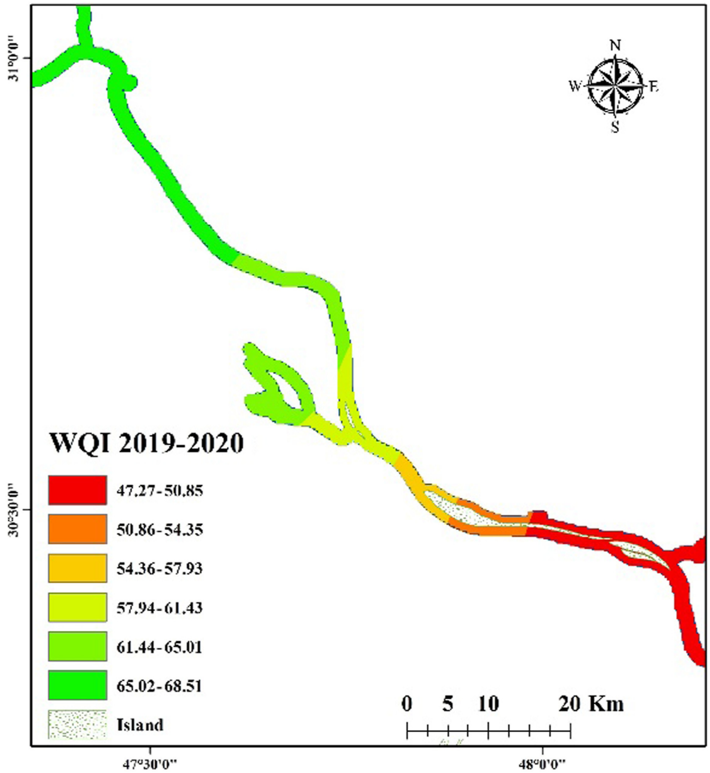

Figure 19.
The pattern of WQI values in the SAAR in the eighth period

Source(s): Figure by authors

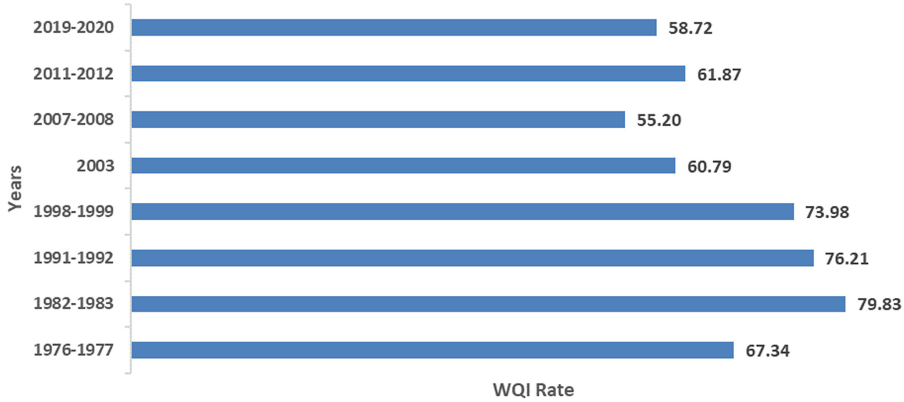

Figure 20.
The WQI rate values in the SAAR in all periods

Source(s): Figure by authors

mentioned, it only gets a high positive R-squared if the regression correctly predicts most of the values of each type of event studied. Thus, the regression model will allow us to estimate the water quality values in the unstudied and the coming years. After all, the results of WQI

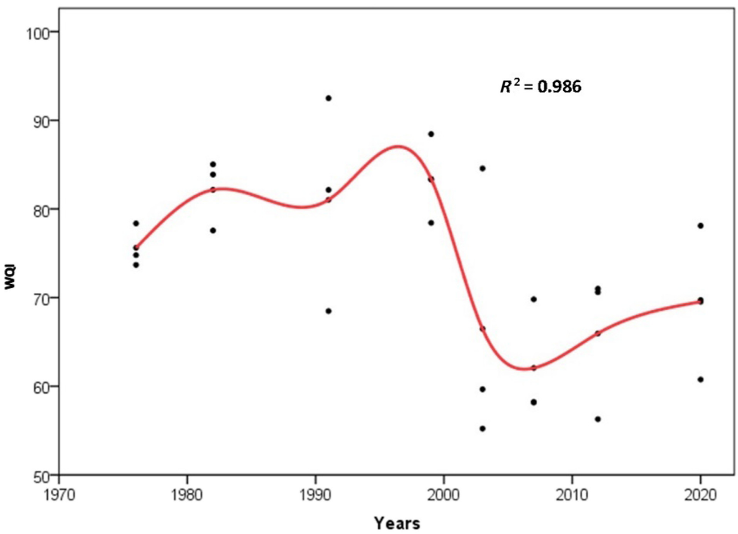

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Figure 21. Graph of non-linear WQI regression model of the SAAR

calculated by Eq. (2) for the SAAR are listed in Table 1. However, 87.5% of WQI values are within category three (Fair), and 12.5% are within category two (Good). However, this new model was tested ($P < 0.001$) using other observational data. As seen, equation (2) showed a great ability to predict water quality values over the years because the standard deviation has less variance and the values are more flexible, which is consistent with what Harding, Tremblay, and Cousineau (2014) said that the standard error and standard deviation values decrease when the variance decreases and the sample size is appropriate. Therefore, the novelty of this study lies in finding a new model which is dynamic and easy to use instead of various methods for evaluating and predicting water quality indicators in the study area for untaught periods and future years.

Table 1. WQI estimates and statistical parameters of water quality classification for the Canadian model (Equ. 1) and the proposed model (Equ. 2)

Years	WQI	Category	SAAR-WQI	Category
1976	75.61	Fair	81.17	Good
1982	82.15	Good	79.02	Fair
1991	81.03	Good	75.81	Fair
1999	83.38	Good	72.98	Fair
2003	66.48	Fair	71.56	Fair
2007	62.06	Marginal	70.15	Fair
2012	65.96	Fair	68.39	Fair
2020	69.53	Fair	65.58	Fair
Average	73.28		73.08	
Max	83.38		81.17	
Min	62.06		65.58	
Std. Deviation	8.33		5.31	
Std. Error	2.95		1.88	

Source(s): Table by authors

4. Conclusion

The study showed significant differences in water quality between the studied periods. The best value of WQI recorded in the second period (1982-1983) reached 79.83. The disparity between the WQI values between the studied periods is due to the fluctuations in the amount of water revenue that supplies the Shatt al-Arab. The primary reason for the decay of water quality in the remnant periods is the rise of PO4 besides EC due to the ascent amount of pollutants, salt intrusion from the Gulf, furthermore the slight changes in the rest of the environmental factors. Generally, variations in ecological characteristics and their overlap are significant causes for changes in water quality which cannot be attributed to a specific factor unless changes are massive and extreme. And at the same time, the other factors must be within their natural limits and didn't exceed the threshold of water criteria specified. However, we developed a new model for SAAR as a function of the WQI values computed from the Canadian model. The results showed a strong correlation between the WQI values estimated from this proposed model and those calculated from the Canadian model. Therefore, it can be recommended to use the built model to evaluate the WQI for the study area in future years.

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