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Evaluation of Spatio-Temporal Changes in Water Quality in the Middle Section of the Shatt Al-Arab River, Southern Iraq

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ABSTRACT

The Shatt al-Arab river is the main water source in the Basrah province, subjected to significant environmental and hydrological changes that have led to the complete degradation of its ecosystem, particularly the middle section. Nineteen water quality variables were selected to assess spatio-temporal changes in the middle section. Eight variables were chosen with the most significant impact on the Shatt al-Arab River water quality in calculating the water quality index (WQI). These variables were measured every month from December 2020 to November 2021 at five observation stations (Abu-Flous, Mhela, Baradeyea and Maqal) located on the main river and one on the Karmat Ali canal, which connects the Shatt al-Arab River with east Hammar marsh. The study was divided into two seasons of the year, the wet season (December 2020 – May 2021) and the dry season (July 2021 – November 2021), in the calculation of the WQI and its annual calculation. The results of the current study show deterioration in the values of most water quality variables, particularly those related to dissolved salts and organic and bacterial pollution. Water quality was also classified as poor on the WQI scale at all stations for the duration of the study. The results of the WQI indicated the deterioration in the quality of the water middle section, particularly during dry season. The degradation of the waters of the middle section of the Shatt al-Arab River is due to two main factors: increase salinity and organic pollution. In general, the Shatt al-Arab River and the middle section in particular, need comprehensive management, including a clear and expeditious plan to identify and address the degradation of the river's environment, which has a great importance to all residents of the Basrah province.

Keywords: Shatt al-Arab river, middle section, spatio-temporal changes, water quality index.

INTRODUCTION

Most Iraqi aquatic environments suffer from contemporary problems and challenges at an escalating pace. They, therefore, need modern and urgent management to resolve their crises with scientific planning based on solid consultations by establishing competent and managed specialized institutions based on modern artistic and technological foundations that ensure the best sustainability as a wealth for future generations.

The Shatt al-Arab River is one of the most important rivers in southern Iraq. It is the only source of surface water in the Basrah province. Water is used in various areas such as drinking water processing, irrigation of crops, industrial activity, and fishing. Moreover, it is a recreational hub for the city's people (Moyel, 2014). The middle section of the Shatt al-Arab River is exposed to severe pollution conditions as a result of dense populations spread on both banks of the river, as well as the predominance of industrial installations, electric power stations, ports, entertaining areas and tourists on both sides of the river. These substances leave large amounts of pollutants untreated in most of the river (Al-Aboody et al., 2018). The middle section of the Shatt al-Arab River, particularly during the hot summer months, is also exposed to a significant rise in the concentrations of dissolved salts as a result of the incursion of tidal waters from the Arabian Gulf into the upper river owing to the shortage of fresh water fed to the river's stream from its main tributaries. Several factors have combined to reduce the river's freshwater imports, most notably climatic changes and the recurrence of drought in the region (Moyel and Hussain, 2015), as well as altering the hydrological map of river-feeding tributaries by establishing dams and reservoirs them in Turkey, Iran, and Iraq (Asadi and Al-Hello, 2019).

Severe contamination conditions with organic pollutants and nutrients, as well as other conditions such as high salt concentrations, high temperatures, and high solar brightness, have helped to create a serious phenomenon that has a direct impact on the river's environment and on public health, namely the state of bloom or frequent growth of algae bloom (Red Tide), especially in the middle section of the river (Al-Mahmoud, 2019). Algae blooms were recorded during 2015 and 2016 in the middle section of the river. This situation was repeated and spread more widely in 2018. In some reference reports, it was attributed to severe intestinal poisoning and colic that affected some 118 thousand citizens of the Basrah province. The state of bloom also recurred in July 2021, which the researcher observed during his fieldwork. The algal blooming spot spread throughout the river section in Mhela, heading south of the Abu-Flous station and its dimensions. The repetition of algal blooming in the waters of the Shatt al-Arab River, particularly its middle section, indicates a serious state of the ecosystem in that section of the river. It refers to a dangerous shift that threatens that water resource's ecosystem completely and limits its use for various activities. The bloom of these organisms is often linked to human pollution and climate change (Anderson et al., 2002).

Continuous and accelerated changes in the river's environmental characteristics require the continuation of surveillance programs using efficient monitoring tools. These programs have the potential to spatio-temporal changes in water quality, as they are essential to people's lives and to preserve the natural ecosystem of the river from degradation. Numerous studies have been completed to monitor and assess the quality of the Shatt al-Arab River water, indicating the continuous degradation of the river's ecosystem (Al-Tawash et al., 2013; Moyel and Hussain, 2015).

Several water management agencies and institutions have encouraged the application of the Water Quality Index in water control and pollution control programs (Abasi and Abasi, 2012; Sutadian et al. 2016; Uddin et al., 2021). Their application plays an essential role in the management of water quality and the identification of water uses. It serves as an appropriate tool for identifying usability and highlighting specific environmental conditions of the water resource, as well as assisting decision-makers in assessing the effectiveness of regulatory programs to manage and protect water from pollution (Karakaya and Evrendilek, 2010). The present study, therefore, aimed to assess the spatio-temporal changes in the water quality of the middle section of the Shatt al-Arab River, to give a realistic assessment and early warning of the river water quality in the study area to ensure better water management and to accelerate the development of solutions and avoid risks.

MATERIALS AND METHODS

Study area

The Shatt al-Arab River is a tidal river and originates from the convergence of the Tigris and Euphrates at Qurna, north of the Basrah province. It continues its course to approximately 200 km in the southwestern direction of the Arabian Gulf. The width of the river at the origin is about 330 meters, about 400 meters in the middle section, and the width at the estuary is about 1250 meters (Al-Asadi, 2016).

The Shatt al-Arab River has a complex hydrological system that has resulted in a unique river environment with characteristics different from the rest of Iraq's river environments. The Shatt Al-Arab is subjected to semi-diurnal tide type, which is characterized by being unequal in range and time (AL-Ramadan and Pastor). After 2008, significant hydrological changes occurred in the rivers and tributaries feeding the Shatt al-Arab river, directly affecting the freshwater reaching its mainstream. The water discharge of the Shatt al-Arab River became utterly dependent on the Tigris River after damming and conversation of the Euphrates River with a dam in 2010 at the city of Al-Madina north of the Basrah province and closing the Karkheh River, which was feeding the Al-Suwaib River East and turning the Karoon River into the Bahminsher River a canal within Iranian territory. The Shatt al-Arab River became

Table 1. GPS of the Shatt al-Arab river stations

Station name	GPS Position	
Abu-Flous	E: 48°0'4.476"	N: 30°27'52.137"
Mhela	E: 47°55'26.108"	N: 30°28'8.039"
Baradeyea	E: 47°51'7.516"	N: 30°30'36.46"
Maqal	E: 47°47'15.764"	N: 30°34'5.84"
Mohammadiyat	E: 47°45'29.629"	N: 30°37'6.066"
Karmat Ali	E: 47°44'30.665"	N: 30°34'32.344"

fed from the Tigris River only through water releases from the regulatory dam of Qal'at Saleh (Al-Asadi, 2017). In the current study, five water sampling stations on the middle section of the Shatt al-Arab River were selected, while the sixth station was chosen on the course of Karmat Ali canal to study the impact of the east Hammar Marsh on the middle section of the Shatt al-Arab River (Table 1, Figure 1).

Field sampling and analytical procedures

Water samples were collected monthly from December 2010 to November 2021. Six water sampling stations were selected. Five are located on the middle section of the Shatt al-Arab River. One station was chosen on the stream of the Karmat Ali canal, which connects the Shatt al-Arab River with East Hammar marsh (Table 1, Figure, 1). The samples were collected, preserved, and transferred to the laboratory for further analysis based on the recommendations adopted in the standard methods (APHA, 2005). The water samples were collected from the middle of the river, using clean 1-liter polyethylene plastic container to collect

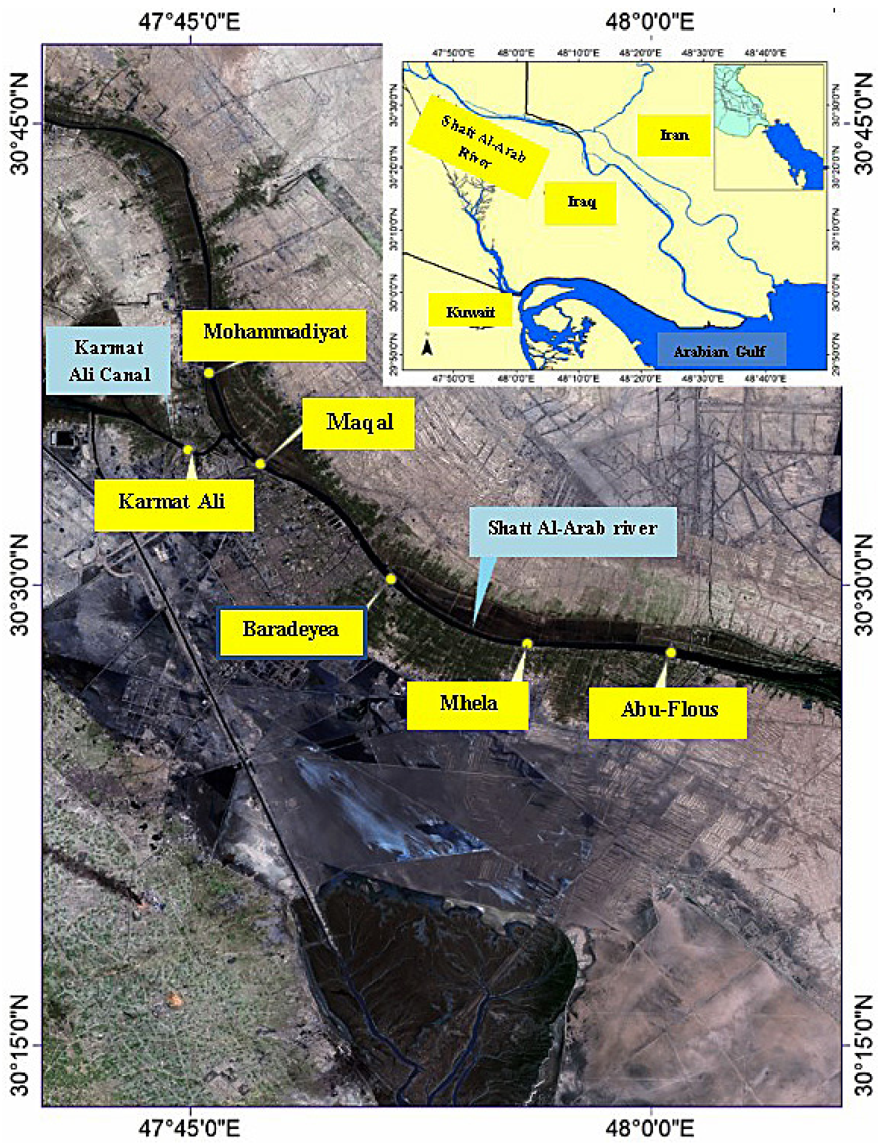

Figure 1. Map for the study area showing the sampling stations

samples about 30 centimeters below surface, sealed tightly and placed in an icebox, and then transported to the laboratory for the required analyses within 24 hours after the collection of samples. The water samples were filtered with a (0.45 µm) filter paper to estimate major ions and nutrients (NO_3 and PO_4).

Water temperature (WT) and electrical conductivity (EC) Wallace pH were measured in *situ* with a portable EC meter model 3110 (WTW company) and portable pH meter Model 3110 (WTW company), after calibrating them using standard solutions. Water turbidity was measured using the turbidity meter model Senso Direct (Lovibond company). Total dissolved solids (TDS) and total suspended solids (TSS) concentrations were measured using the gravimetric method after filtering the appropriate size of the sample. Dissolved oxygen (DO) concentrations were measured directly using the Azid-modified Winkler method. In contrast, biological oxygen demand (BOD_5) concentrations were measured in the Azid-modified Winkler method after the sample incubating at a temperature of 20 for five days. Chemical oxygen demand (COD) concentrations were measured spectrophotometrically using the photo lab (S6) instrument. Total hardness (TH), calcium (Ca^{+2}), and magnesium (Mg^{+2}) concentrations were measured using the titration method with the standard Na_2-EDTA solution. At the same time, sodium (Na^{+1}) and potassium (K^{+1}) concentrations were estimated in the flame photometry method using the Genway device. The Moher's method was also used to estimate chloride (Cl^{-1}) concentrations by titration with silver nitrate. Sulfate (SO_4^{-2}) concentrations were measured using the titration method. Nitrate (NO_3) concentrations were measured by cadmium reduction method, while orthophosphate (PO_4) concentrations were measured by molybdate ascorbic acid method. Fecal coliform bacteria (FC) numbers were determined by membrane filtration method using an MFC agar base at 44.5 °C. All variables were measured using the standard methods described in (APHA, 2005), except for the variable sulfate, which were measured using the method described in Bartram and Ballance (1996).

Water quality index

The Canadian Water Quality Index (CCME WQI), one of the world's most widely used water quality indices, is applied in the current study, as it allows researchers to freely choose suitable variables and guidelines that are appropriate to the local conditions of the water resource and the type of assessment (Sutadian et al., 2016).

CCME WQI is sensitive only if it provides sufficient data to obtain a matrix of numbers that the mathematical model can easily sensitize to give more acceptable results. Calculating the CCME WQI requires at least four variables, measured more than four times to give reliable results (CCME, 2001). The current study period for calculating the CCME WQI was divided into two periods, each representing six months' results. The first period represents the wet months (season) from December 2020 to May 2021. The second period was the dry months (season) from June 2021 to November 2021, as per the index for the thoroughly studied water year as well.

The CCMEWQI calculation selected eight variables with the greatest impact on the quality of the Shatt al-Arab River water and the usability of its water for the various activities described in Table 2. The final values of the evidence reflecting the state of the water surface were calculated depending on the combination of three mathematical factors (Scope, Frequency and Amplitude). Scope represents the ratio of the variable whose value does not match water standards. At the same time, frequency represents the proportion (tests) the value of which does not match standard water specifications. In turn, amplitude represents the number of failed (tests) values the value of which does not match standard water specifications. By calculating the three main steps, the CCMEWQI can be calculated from the following formula:

$$\text{WQI} = 100 - \sqrt{(\text{F12}+\text{F22}+\text{F32})} \,/\, 1.732 \quad (1)$$

The state of the water quality is expressed by linking the value of the WQI to a numerical

Table 2. Water quality variables and their standards for general water uses a - Iraqi standard for protected general water resource, b - (Liou et al., 2004), c - (Chapman, 1992), d - (US-EPA, 2012)

Variables	Unit	Standards
pH	-	6.5 – 8.5[a]
TDS	mg/L	2000[a]
TSS	mg/L	≤20[b]
DO	mg/L	≥5[a]
COD	mg/L	≤20[c]
NO_3	mg/L	≤15[a]
PO_4	mg/L	≤0.4[a]
FC	cfu/100 ml	≤200[d]

Table 3. Water quality index categories

WQI score	95-100	80-94	65-79	45-64	0-44
Water quality categories	Excellent	Good	Fair	Marginal	Poor

scale (Table 3) divided into five categories, each representing the level of water quality in terms of purity or pollution.

RESULTS AND DISCUSSION

Water quality variables

Water temperature (WT) is one of the most important environmental factors affecting aquatic ecosystems (Wetzel, 2001). The current study showed a clear variation in water station temperatures during the various months of the study. The highest values were recorded during the long summer and the lowest during the short winter months (Table 4). This is due to the nature of Iraq's climate. It is a rather rainy, cold winter and dry, hot summer (Fahad, 2006). No significant differences were recorded in the WT of the stations studied. Minor spatial changes between stations can be explained by different sampling times. The low temperature is expected to be at the beginning of the morning and then rise as midday approaches.

The pH plays an important role in different aquatic ecosystems. It directly affects all forms of aquatic life that live in specific bounds of pH. They are usually sensitive to any change in pH values (Avvannavar and Shrihari, 2007). The results of the current study recorded slight variations in pH values by a range (of 7.81–8.38) over different months and study stations (Table 4). The values recorded do not exceed those recommended in Iraq's Standard for the Conservation of rivers and public Waters from Pollution No. 25 of 1965. WHO's recommended limits for human use fall within the range (of 8.5–6.5) (WHO, 2017).

Electrical conductivity (EC) is the ability of water to conduct an electric current. As the ions transport the electric charge, there is a direct relationship between the amount of dissolved salts in the water and the EC value. Because of this relationship, EC and TDS can measure dissolved salts in water (Gupta et al., 2008). Generally, EC values increase along with concentrations of dissolved salts. Therefore, a strong correlation with TDS, total hardness, and the rest of the major ions (Na^{+1}, K^{+1}, Ca^{+2}, Mg^{+2}, SO_4^{-2}, Cl^{-1}) has been recorded, reflecting the saline content of the Shatt al-Arab river waters in the study area (Table 5). The concentrations of dissolved salts and associated ions recorded significant differences ($p < 0.05$) in the water of the stations studied during the different months of the year. The results showed relatively low values recorded during the wet months from December to May in the samples of the stations studied. It was followed by a clear rise in values during the dry season beginning in June to peak in July and then a gradual decline from August to November (Table 4). This rise during the hot summer months may be due to the upstream incursion of salt wedge from Arabian Gulf due to the decrease of water releases from the Tigris River during regulatory dam Qal'at Saleh towards the Shatt al-Arab river (Lateef et al., 2020; Lafta, 2021) as well as increasing use of river water in irrigation of plantations and in civil and industrial uses, in addition to injection of oil wells that consume large quantities of water and higher evaporation rates due to higher temperatures during the summer (Al Mahmoud, 2019). Clear spatial changes were also recorded in the concentrations of dissolved salts. The highest in the downstream stations was Abu-Flous, followed by Mhela, Baradeyea, Maqal, Karmat Ali, and Mohammadiyat, respectively (Table 6).

Turbidity is usually closely related to TSS; therefore, TSS is the leading cause of water turbidity. They include living and non-living substances in the form of different-sized suspended materials in the water column, such as clay, sand, and organic and inorganic materials, as well as the presence of phytoplankton and other microorganisms in the water column (Jassby et al., 2003). The current study recorded a high statistically significant positive correlation between turbidity values and TSS in the water of the stations studied ($p < 0.01$, $r = 0.98$) (Table 5). These results are consistent with several studies on the Shatt Al Arab waters that indicated a high statistically significant positive correlation between water turbidity and TSS (Al-Hejuje, 2014; Al-Athab et al., 2019). The current study showed substantial spatial and temporal significant differences ($p < 0.05$) in the values of turbidity and TSS. These differences may arise from various sources responsible for introducing different types of liquid and solid pollutants directly into the Shatt al-Arab River water, such as sewage water, industrial influents from the Hartha and Najibiah power stations, and some small industrial installations (Al-Mahmoud, 2019 and; Lateef, 2020), as well as the tidal currents of the Shatt al-Arab River, which contribute to the resuspension of soft sediments in the river bottom, causing an increase in suspended solids in the water column (Moyel, 2010).

Dissolved oxygen (DO) plays a vital role in different aquatic ecosystems. It is an important environmental factor that safeguards the health of the aquatic ecosystem through its role in the self-purification process in organic pollutant disposal bodies, as well as its direct impact on the activity, abundance, and survival of living organisms (Araujo et al., 2000). The current study shows a clear spatial and temporal variation in DO values. The highest values were recorded in the station water studied during the cold months during the wet season and the lowest during the hot summer months during the dry season of the study (Table 4). These results are consistent with most previous local studies (Issa, 2005; Al-Abbawy, 2012; Adlan, 2022). The causes of high dissolved oxygen values during cold months can be attributed to lower temperatures and salinity compared to hot months and the resulting increase in oxygen gas dissolution on the one hand (Lind, 1979) and to the low rates of degradation of organic waste by microorganisms on the other hand, which was supported by the relatively low results of the values of WT, TDS, the BOD_5, and the COD during that period, which recorded a negative significant correlation ($r = - 0.859$; $p < 0.05$) and ($r = -0.539$; $p < 0.05$) and ($r = -0.590$; $p < 0.05$) and ($r = -0.468$; $p < 0.05$) between DO, WT, TDS, the BOD_5 and the COD recorded, respectively (Table 5). Low DO concentrations during hot months can be explained by high temperatures, salinity, and high consumption rates in oxidizing organic substances, the concentrations of which increased during that period (Al-Hejuje et al., 2017). Increasing the degradation rates of organic substances deposited at the bottom during hot summer months may also deplete the oxygen content dissolved in the water column (Pathani, 1995). At all study stations except Mohammadiyat, DO values were recorded equal to or below the critical limit of (4 mg/L) indicating the degree of severe organic pollution (Hynes, 1970). These results differ from most previous studies on the nature of good ventilation of Shatt al-Arab River waters (Table 6), (Al-Ankush, 2013; Moyel and Hussain, 2015).

Biological oxygen demand (BOD_5) is a measure of the amount of oxygen consumed by microorganisms for the oxidation of biodegradable organic matter. The values of the BOD_5 differed significantly ($p < 0.05$) between the stations and the study months. The results show relatively low values during the cold and moderate months of study and a clear rise during the hot summer months, particularly during the months of July, August, and September (Table 4). The rise in summer month values can be explained by the increase in the release of organic pollutants from their different sources. This increases their degradation rates by microorganisms supported by higher temperatures that increase their activity in organic compound oxidation processes, thus consuming large amounts of dissolved oxygen (Sanchez et al., 2007; Chaturvedi; Bassin, 2010). Those results are consistent with the findings of (Saleem, 2013; Kanani, 2017; Hamdan, 2018). During their studies on the Shatt al-Arab River waters, they noted the high BOD_5 values during the hot summer months due to the high amount of organic waste from different sources of the river and its increased degradation rate. The results of the statistical analysis demonstrated this through significant correlations ($r = 0.502$; $p< 0.05$) ($r = -0.590$; $p < 0.05$) between the values of the BOD_5 and WT and DO concentration, respectively (Table 5). Regarding spatial variability, the Mohammadiyat station recorded the lowest values (Table 6), being located in an area relatively far from the areas of population exposure and receiving fewer organic pollutants that raise oxygen biosynthetic values. The gradual increase in the values recorded at the rest of the stations is noted. High values are observed in the waters of the Baradeyea, Maqal, and Mhela from January to June (Table 6). For the Baradeyea station located in the city center, the increase was the result of its receipt of large quantities of various contaminants of wastewater from dense residential areas spread on the banks of the river, industrial facilities, restaurant tailings, and markets, as well as the tailings of the Sadr Educational Hospital located near the study station. This is consistent with the results obtained by Moyel (2010), Saleem (2013), and Kanani (2017).

Chemical oxygen demand (COD) values indicate the severity of total organic contamination of biodegradable and non-biodegradable substances (Westcot, 1979). The results of the current study indicate temporal and spatial differences ($p < 0.05$) in COD values. The highest values were reached during the hot summer months, especially during July, August, and September (Table 4). These results can be explained by the increased release of organic pollutants, liquid, and solid waste from different sources to the river directly (Hamdan et al., 2018). The concentrations of these contaminants usually increase when their rollout is accompanied by a decrease in the amount of water discharge coming into the river, as occurred during the current study months resulting in reduced mitigation and disposal potential. Rising water temperature contributes to increased values by intensifying degradation of organic materials and bioactive activity.

Surface water contains different quantities of organic and inorganic nitrogen compounds, depending on their different sources of pollution and other environmental factors influencing temperature, amount of rain, human and industrial activities, etc. (Wetzel, 2001). Stirling (1985) stated that nitrates are the final compound of the aerobic decomposition of organic nitrogen compounds. Nitrogen fertilizer from agricultural land adjacent to rivers and wastewater is their primary source. Although nitrates are particularly important for aquatic life, they become a source of pollution when their concentration exceeds permissible limits, causing excessive productivity and eutrophication (Sharpley et al., 2003).

The current study showed a significant variation ($p < 0.05$) of nitrate (NO_3) values during the study months, while they were not significant for different stations. The fluctuation of NO_3 values in station waters did not take a single pattern in terms of increase and decrease during the study months. Some stations recorded high values during the cold study months, and others rose during the hot summer months (Table 4). This may be due to the different sources of pollutants that introduce nitrogen material into the stations at different times and quantities, which at different stations have been reflected in NO_3 values during the samples collection. In general, high NO_3 values were observed during the summer months due to the decrease of water imports and the increased release of domestic and industrial wastewater and the wastewater containing large quantities of nitrogen compounds being oxidized by microorganisms to release large quantities of NO_3 (Singh and Gupta, 2016). Saleem and Hussain (2013) noted that the water quality of the Shatt al-Arab River was poor when they applied the Organic Pollution Index. They attributed this deterioration to a lack of water inflow entering the river, resulting in a high concentration of pollutants, including NO_3 (Hameed and Jorany, 2011). High amounts of irrigation water on agricultural land containing nitrogen fertilizer during summer may also increase values. Agricultural lands with nitrogen fertilizer are the primary sources of nitrate in aquatic ecosystems (Dodds, 2006). Regarding spatial changes, study stations Mhela, Baradeyea, and Maqal have recorded the highest values (Table 6), these stations receive large amounts of sewage and domestic and industrial waste (Al-Ankush, 2013). In addition, it is directly affected by the canals linked to the Shatt al-Arab River, which transport quantities of untreated sewage to it. In turn, the water of Mohammadiyat station recorded the lowest values, as it receives relatively lesser quantities of domestic and industrial waste water compared to the rest of the stations located downstream (Table, 6).

Orthophosphate (PO_4) is found in natural waters in various forms, including dissolved, suspended, organic and inorganic. PO_4 is the dominant form of inorganic phosphorus in natural waters (Temponeras et al., 2000). The results of the current study showed a significant variation ($p<0.05$) in the PO_4 values from the temporal aspect, while it was not so from the spatial aspect. As it is noted through the table (6), the PO_4 values did not adopt a specific pattern in the amount of increase and decrease between the studied stations. Rather, the values varied depending on the surrounding local conditions and the impact of the nearby land use effect on each station. The multiplicity and different sources of pollution may contribute to the situation that pollutants enter the Shatt al-Arab River without proper control or management that limits the spread of those sources along the course of the river. In general, high PO_4 values are observed during the months of June and July in all stations. Then, it began to decrease during August and September, with the exception of Baradeyea station; afterwards, it returned and rose clearly in the waters of some stations, especially in the waters of Baradeyea and Maqal stations. The rise during the months of June and July can be explained by the decrease in water revenues during that period and the high concentrations of pollutants, especially organic ones, from sewage water and water from agricultural lands. These results are consistent with the study of Hameed and Al-Jorany (2011), Al-Hejuje (2014) and Moyel (2014), in which they recorded an increase in the PO_4 values during that period. The high concentrations of dissolved salts in that period increased the concentration of PO_4. Clavero et al., 1990 indicated that an increase in salt concentrations stimulates the release of PO_4 from the sediment. Bakan et al. (2010) showed that high temperatures and low oxygen concentration had a role in increasing PO_4 concentration. This may be an additional reason for the increase in PO_4 concentration. As for the high values during the autumn months for some stations, especially Baradeyea and Maqal stations, it may be due to local pollution sources that increased the PO_4 values in them, as these stations are located near the city center with a high population density, in addition to the many uses of land close to it, such as factories, markets, restaurants, marinas for boats and small ships, and others. These results are consistent with the results of the study of Adlan (2022) when they recorded high values of PO_4 in the same study site above during their study of the waters of the Shatt al-Arab River.

The lowest values were recorded in the water of Mohammadiyat station. This can be explained by its relative away distance from sources of pollution with low sewage water and the presence of aquatic stations that consume and reduce PO_4 concentration. (Al-Kenzawi and Al-Rawi, 2009). Yang et al. (2008) showed that the PO_4 concentrations that support the growth and blooming of algae ranged from 0.005 to 0.05 mg/L; therefore, and through the results obtained, it is clear that the concentrations recorded in all study stations were high enough to support the phenomenon of eutrophication if other factors were available.

Fecal coliform (FC) bacteria are frequently used in water quality monitoring programs. It has been adopted by many environmental agencies and institutions and researchers around the world as an efficient indicator for detecting water contamination with human and animal excreta (Servaise et al., 2007; Tyagi et al., 2006). This type of bacteria is found naturally in the intestines of humans and warm-blooded animals. Their presence in natural waters is an indication of their contamination with human and animal pollutants, which may often contain other more dangerous pathogens such as pathogenic bacteria such as cholera and typhoid, as well as viruses and parasites (Johnson et al., 1999). Therefore, international institutions and agencies concerned with the environment and

Table 4. Seasonal variations in water quality variables

Water variables	Wet season				Dry season				Annual			
	Minimum	Maximum	Mean	S.D.	Minimum	Maximum	Mean	S.D.	Minimum	Maximum	Mean	S.D.
WT (C°)	13.90	29.70	19.67	5.12	23.40	32.90	27.91	3.28	13.90	32.90	23.79	5.96
pH	7.75	8.38	8.04	0.17	7.73	8.26	7.97	0.15	7.73	8.38	8.00	0.16
EC (mS/cm)	2.53	6.45	4.33	0.74	3.94	29.10	10.44	5.79	2.53	29.10	7.38	5.12
TDS (mg/L)	1607.00	4101.00	2752.83	472.89	2706.00	18501.00	6640.03	3666.77	1607.00	18501.00	4696.43	3250.99
TSS (mg/L)	10.00	59.00	30.75	11.81	9.00	72.00	30.22	14.59	9.00	72.00	30.49	13.18
Turbidity	6.58	36.40	19.52	7.15	5.96	46.60	19.81	9.64	5.96	46.60	19.67	8.43
DO (mg/L)	3.90	8.60	6.68	1.26	2.80	6.60	4.79	1.09	2.80	8.60	5.73	1.51
BOD_5 (mg/L)	3.60	9.60	6.00	1.52	3.00	16.30	7.41	3.37	3.00	16.30	6.71	2.69
COD (mg/L)	17.00	95.00	35.81	15.33	18.00	146.00	51.25	28.94	17.00	146.00	43.53	24.27
NO_3 (mg/L)	4.19	17.84	9.69	2.83	5.32	16.89	10.13	2.69	4.19	17.84	9.91	2.75
PO_4 (mg/L)	0.21	1.85	0.65	0.34	0.08	5.18	1.49	1.26	0.08	5.18	1.07	1.01
FC (cfu/100 ml)	1300.00	82000.00	16527.78	16562.36	1100.00	73000.00	16375.00	18755.76	1100.00	82000.00	16451.39	17568.21
TH (mg/L)	720.00	1500.00	1145.56	162.87	760.00	2500.00	1285.36	332.68	720.00	2500.00	1215.46	269.43
Ca^{+2} (mg/L)	152.00	272.00	220.75	24.60	140.00	311.00	224.39	37.70	140.00	311.00	222.57	31.66
Mg^{+2} (mg/L)	77.00	226.00	135.42	31.66	310.00	2388.00	912.36	468.41	77.00	2388.00	523.89	511.56
Na^{+1} (mg/L)	411.00	881.00	656.50	94.67	468.00	3398.00	1078.97	608.27	411.00	3398.00	867.74	481.72
K^{+1}(mg/L)	10.80	23.10	16.79	2.59	12.30	99.20	35.82	23.43	10.80	99.20	26.30	19.12
Cl^{-1} (mg/L)	460.00	1379.00	928.69	204.84	424.00	5748.00	1604.36	1095.46	424.00	5748.00	1266.53	853.22
SO_4^{-2}(mg/L)	376.00	1292.00	796.17	227.18	799.00	1594.00	1046.25	210.55	376.00	1594.00	921.21	251.30

Note: S.D. – standard deviation.

Table 5. Pearson correlation between water quality variables

Variables	WT	pH	EC	TDS	TSS	Turb.	DO	BOD_5	COD	NO_3	PO_4	FC	TH	Ca	Mg	Na	K	Cl	SO_4
WT	**1**	**-0.479**	**0.558**	**0.558**	-0.025	0.027	**-0.859**	**0.502**	**0.330**	0.086	0.159	0.042	**0.238**	0.034	**0.680**	**0.430**	**0.527**	**0.369**	**0.748**
pH	**-0.479**	1	-0.031	-0.031	0.081	0.066	**0.524**	**-0.284**	-0.202	-0.222	-0.138	-0.085	0.002	0.051	-0.087	0.020	-0.011	0.042	**-0.399**
EC	**0.558**	-0.031	**1**	**0.999**	**0.238**	**0.308**	**-0.534**	**0.671**	**0.524**	0.151	0.184	**0.320**	**0.818**	**0.525**	**0.951**	**0.939**	**0.946**	**0.905**	**0.679**
TDS	**0.558**	-0.031	**0.999**	**1**	**0.242**	**0.311**	**-0.534**	**0.667**	**0.521**	0.149	0.179	**0.319**	**0.819**	**0.527**	**0.950**	**0.939**	**0.945**	**0.905**	**0.679**
TSS	-0.025	0.081	**0.238**	**0.242**	**1**	**0.982**	0.077	-0.027	-0.094	-0.082	-0.007	**0.281**	**0.267**	0.108	0.215	0.204	0.192	**0.253**	**0.259**
Turb.	0.027	0.066	**0.308**	**0.311**	**0.982**	**1**	0.034	0.034	-0.049	-0.042	0.021	**0.316**	**0.320**	0.141	**0.279**	**0.275**	**0.265**	**0.323**	**0.301**
DO	**-0.859**	**0.524**	**-0.534**	**-0.534**	0.077	0.034	**1**	**-0.590**	**-0.468**	**-0.239**	-0.159	-0.117	**-0.322**	-0.198	**-0.582**	**-0.486**	**-0.507**	**-0.428**	**-0.627**
BOD5	**0.502**	**-0.284**	**0.671**	**0.667**	-0.027	0.034	**-0.590**	**1**	**0.825**	**0.416**	0.016	**0.524**	**0.587**	**0.354**	**0.600**	**0.711**	**0.673**	**0.670**	**0.599**
COD	**0.330**	-0.202	**0.524**	**0.521**	-0.094	-0.049	**-0.468**	**0.825**	**1**	**0.435**	0.065	**0.431**	**0.441**	0.220	**0.488**	**0.538**	**0.485**	**0.484**	**0.369**
NO_3	0.086	-0.222	0.151	0.149	-0.082	-0.042	**-0.239**	**0.416**	**0.435**	**1**	**0.314**	**0.474**	0.215	**0.253**	0.084	0.202	0.174	0.210	0.181
PO_4	0.159	-0.138	0.184	0.179	-0.007	0.021	-0.159	0.016	0.065	**0.314**	**1**	0.119	0.087	0.008	**0.234**	0.173	0.141	0.149	0.206
FC	0.042	-0.085	**0.320**	**0.319**	**0.281**	**0.316**	-0.117	**0.524**	**0.431**	**0.474**	0.119	**1**	**0.302**	**0.263**	**0.248**	**0.338**	**0.296**	**0.364**	**0.299**
TH	**0.238**	0.002	**0.818**	**0.819**	**0.267**	**0.320**	**-0.322**	**0.587**	**0.441**	0.215	0.087	**0.302**	**1**	**0.802**	**0.677**	**0.867**	**0.806**	**0.878**	**0.492**
Ca	0.034	0.051	**0.525**	**0.527**	0.108	0.141	-0.198	**0.354**	0.220	**0.253**	0.008	**0.263**	**0.802**	**1**	**0.369**	**0.601**	**0.596**	**0.674**	0.205
Mg	**0.680**	-0.087	**0.951**	**0.950**	0.215	**0.279**	**-0.582**	**0.600**	**0.488**	0.084	**0.234**	**0.248**	**0.677**	**0.369**	**1**	**0.830**	**0.875**	**0.798**	**0.702**
Na	**0.430**	0.020	**0.939**	**0.939**	0.204	**0.275**	**-0.486**	**0.711**	**0.538**	0.202	0.173	**0.338**	**0.867**	**0.601**	**0.830**	**1**	**0.953**	**0.958**	**0.612**
K	**0.527**	-0.011	**0.946**	**0.945**	0.192	**0.265**	**-0.507**	**0.673**	**0.485**	0.174	0.141	**0.296**	**0.806**	**0.596**	**0.875**	**0.953**	**1**	**0.918**	**0.638**
Cl	**0.369**	0.042	**0.905**	**0.905**	**0.253**	**0.323**	**-0.428**	**0.670**	**0.484**	0.210	0.149	**0.364**	**0.878**	**0.674**	**0.798**	**0.958**	**0.918**	**1**	**0.559**
SO_4	**0.748**	**-0.399**	**0.679**	**0.679**	**0.259**	**0.301**	**-0.627**	**0.599**	**0.369**	0.181	0.206	**0.299**	**0.492**	0.205	**0.702**	**0.612**	**0.638**	**0.559**	**1**

Note: Values in bold are different from 0 with a significance level = 0.05.

Table 6. Descriptive statistics for the water quality variables of the studied stations

Variable	Statistic	Abu-Flous	Mhela	Baradeyea	Maqal	Mohammadiyat	Karmat Ali
WT C°	Min.	14.7	14.8	14.9	14.8	13.9	14.8
	Max.	32.3	32	32	32.6	32.9	32.6
	Mean	23.51	23.58	24.1	23.73	23.91	23.93
	SD	5.99	6.05	5.92	6.2	6.56	6.31
pH	Min.	7.84	7.75	7.75	7.76	7.85	7.73
	Max.	8.27	8.34	8.38	8.23	8.37	8.32
	Mean	8.1	8.02	7.93	7.94	8.08	7.95
	SD	0.13	0.17	0.18	0.12	0.16	0.15
EC mS/cm	Min.	3.84	3.82	3.31	3.19	2.53	3.7
	Max.	29.1	24.4	18.94	12.99	8.96	12.61
	Mean	10.53	9.35	7.71	6.12	4.85	5.74
	SD	7.58	6.52	4.99	3.05	1.59	2.41
TDS mg/L	Min.	2441	2429	2101	2026	1607	2352
	Max.	18501	15513	12041	8259	5696	8017
	Mean	6680.75	5924.58	4867.08	3899.17	3100.75	3706.25
	SD	4818.23	4147.64	3184.66	1939.34	1000.45	1543.34
TSS mg/L	Min.	15	12	10	12	9	10
	Max.	72	59	57	32	48	43
	Mean	37.75	32.17	31.42	23.83	29.92	27.83
	SD	18.48	13.47	11.52	5.91	13.8	11.08
Turbidity NTU	Min.	9.8	8	6.16	8.02	5.96	6.58
	Max.	46.6	38.1	36.4	23.7	30.7	27.5
	Mean	23.64	20.98	20.73	15.78	19.18	17.71
	SD	11.54	8.73	8.03	4.26	8.8	6.93
DO mg/L	Min.	2.8	3.2	3.1	3.9	4.7	3.6
	Max.	8.3	7.9	7.4	7.5	8.6	8
	Mean	6	5.79	5.28	5.57	6.25	5.51
	SD	1.68	1.61	1.5	1.44	1.39	1.51

Table 6. Cont. Descriptive statistics for the water quality variables of the studied stations

BOD_5 mg/L	Min.	4.2	4.7	3.7	3.5	3	3
	Max.	16.3	14.9	13.1	9.4	7.1	8.3
	Mean	7.02	7.48	8.34	6.9	4.99	5.51
	SD	3.43	3.38	2.87	1.52	1.23	1.74
COD mg/L	Min.	22	26	26	21	18	17
	Max.	111	103	146	65	66	61
	Mean	42.08	50.58	59.92	41.83	31	35.75
	SD	26.09	27.31	35.08	10.58	15.01	14.79
NO_3 mg/L	Min.	6.66	7.97	9.2	6.39	4.19	5.06
	Max.	14.16	15.81	17.84	13.73	15.06	12.91
	Mean	9.54	10.34	11.99	10.55	7.99	9.06
	SD	1.86	2.56	2.9	1.98	2.9	2.79
PO_4 mg/L	Min.	0.18	0.11	0.48	0.08	0.25	0.21
	Max.	4.09	2.28	3.54	5.18	1.93	2.01
	Mean	1.08	0.84	1.49	1.44	0.7	0.87
	SD	1.07	0.63	1.1	1.62	0.51	0.59
FC cfu/100 ml	Min.	1600	2300	9400	2800	1100	1700
	Max.	47000	61000	82000	72000	14000	24400
	Mean	16850	15300	34875	19516.67	4591.67	7575
	SD	11770.34	16597.81	23357.7	18746.29	3723.99	6759.66
TH mg/L	Min.	880	960	980	900	720	780
	Max.	2500	2000	1650	1350	1340	1500
	Mean	1404.17	1312.92	1240.5	1143.33	1069.75	1122.08
	SD	418.84	286.11	194.1	134.72	171.97	193.96
Ca^{+2} mg/L	Min.	180	204	186	152	140	156
	Max.	311	302	272	256	240	264
	Mean	240.17	232	228	218.25	205.67	211.33
	SD	38.06	27.62	25.52	27.95	30.01	31.45
Mg^{+2} mg/L	Min.	96	101	105	103	77	116
	Max.	2388	1832	1504	1227	1088	1099
	Mean	743.42	648.92	537.17	443.25	384.17	386.42
	SD	736.31	623.61	505.1	407.4	346.71	312.91
Na^{+1} mg/L	Min.	582	568	525	497	411	468
	Max.	3398	2544	1974	1644	834	1262
	Mean	1181.25	1056.83	877.08	745.67	642.67	702.92
	SD	776.1	588.72	398.55	301.82	103.3	202.05
K^{+1} mg/L	Min.	15.2	14.8	13.8	13	10.8	12.3
	Max.	99.2	96.7	71.7	63.1	38.2	43.1
	Mean	38.92	32.88	25.35	21.9	19.1	19.67
	SD	38.92	32.88	25.35	21.9	19.1	19.67
Cl^{-1} mg/L	Min.	929	699	680	540	424	589
	Max.	5748	4499	3449	2200	1949	1379
	Mean	1869.25	1624.67	1290.5	1027.67	881	906.08
	SD	1323.6	1057.59	735.97	430.61	385.08	223.73
SO_4^{-2} mg/L	Min.	574	548	376	416	488	468
	Max.	1580	1464	1594	1246	1192	1528
	Mean	1010.75	968.25	941	895.58	824.42	887.25
	SD	265.63	251.28	287.7	215.29	235.48	256.04

public health have set strict limits to prevent the presence of these bacteria in natural waters, especially water used as a source of drinking water (WHO, 1996). The numbers of FC bacteria showed a clear fluctuation in the water of the studied stations throughout the study period. The water of Baradeyea station recorded the highest values, followed by the rest of the stations (Table, 6), and the reason for this can be attributed to the location of that station surrounded by various sources of pollutants that present different types of pollutants, especially domestic wastewater and sewage water from residential areas, markets, restaurants, and ship and boat berths, in addition to the waste from Al-Sadr Teaching Hospital, which is close to that station, which contributes to the high numbers of FC bacteria. These results are consistent with the findings of Al-Enazi (2016) that this station is the most affected by pollutants laden with waste and sewage when compared to other sites. It is noted through Table (6) that the water of Baradeyea, Mhela, Abu-Flous and Maqal stations recorded a great fluctuation in the numbers of FC bacteria, especially during July, when those stations recorded high values compared to the rest of the study months. This can be attributed to the very low water discharge of the river and the high amount of sewage discharged into the river laden with excrement containing large numbers of FC bacteria. There was a significant positive correlation ($r = 0.524$; $p < 0.05$) between FC bacteria and the concentrations of the BOD_5. As for the Mohammadiyat station, it recorded a lower number of FC bacteria, followed by the Karmat Ali station, compared to the rest of the stations throughout the study period, Table (6), as it is relatively farthest from the areas of overpopulation and large human activities that increase the levels of pollutants (Al-Kanaani, 2017).

Water quality index

The results of the WQI for the water of the studied stations did not show significant temporal and spatial differences in quality, which witnessed a clear deterioration throughout the study period. The water quality did not exceed the poor category on the index scale (Table 7). On the basis of the dry and wet seasons of the study, the lowest water quality was recorded during the dry season, which was represented by the summer and autumn months, which witnessed a significant increase in most of the values of the variables, especially the variables that represent dissolved salts and organic pollutants as a result of the significant decrease in the water discharges of the river, the increase in the concentrations of pollutants, and the progression of the salt wedge front. In addition to the decrease in dissolved oxygen values during that period due to high temperatures and concentrations of dissolved salts and their consumption in the oxidation of organic pollutants, which negatively affected the value of the measured WQI. Water quality witnessed a relative improvement during the wet season compared to its values during the dry season (Table 7). The reason for this can be attributed to the relative improvement in the values of most of the variables, the values

Table 7. WQI categorization and variance (F1, F2, and F3) in the six stations during December 2020 to November 2021

Season	WQI	Abu-Flous	Mhela	Baradeyea	Maqal	Mohammadiyat	Karmat Ali
Wet	WQI value	23	24	16	24	31	29
	Category	Poor	Poor	Poor	Poor	Poor	Poor
	F1	75	75	88	75	75	75
	F2	62	62	67	56	50	54
	F3	91	89	96	92	78	80
Dry	WQI value	22	17	15	21	27	24
	Category	Poor	Poor	Poor	Poor	Poor	Poor
	F1	75	88	88	75	88	75
	F2	62	67	71	65	56	67
	F3	93	93	95	94	71	86
Annual	WQI value	23	18	15	23	27	26
	Category	Poor	Poor	Poor	Poor	Poor	Poor
	F1	75	88	88	75	88	75
	F2	62	65	69	60	53	60
	F3	92	91	96	93	75	83

of which began to decline due to the mitigation that occurred as a result of the relative increase in the amount of freshwater entering the course of the river and the decline of the influence of the salt edge front, in addition to the gradual rise in the dissolved oxygen values and the decrease in temperatures. With regard to the spatial changes, the Baradeyea station recorded the lowest values, followed by the Mhela and Abu-Flous stations, then Al-Maqal, Karmat Ali, and Mohammadiyat stations, respectively (Table 7). The decrease in the values of the WQI in the stations of Baradeyea, Mhela, then Abu-Flous and Maqal is due to the large deviation of the values of the variables (F3 = 96), F3 = 91, F3 = 92, and (F3 = 93) from their standard specifications due to the increase in the concentrations of most of the variables in the water of those stations compared to the two stations of Mohammadiyat, and Karma Ali. In addition to the increased frequency of variables deviating from their standard specifications in the waters of the four stations above (F2 = 69, F2 = 65, F2 = 62, and F2 = 60), respectively (Table 7). This may be due to the location of these stations near dense population centers and industrial and service facilities in the city center. Consequently, it receives large quantities of pollutants from the disposal of domestic, agricultural, and industrial waste from neighboring areas, in addition to being affected by the salt wedge front Arabian Gulf, especially the downstream stations. At the same time, the Mohammadiyat station recorded the highest values, followed by the Karmat Ali station (Table 7) because it is located upstream of the river and receives fewer pollutants. In addition, it is less affected by the salt wedge front compared to the rest of the stations.

CONCLUSIONS

It is clear from the results of the current study that there is a visible deterioration in the water quality of the middle section of the Shatt al-Arab River. The water quality did not exceed the poor category on the WQI scale in all stations throughout the study period. Several factors combined to deteriorate the river ecosystem. The most important of which is the state of drought and the irregularity of the freshwater inflow from the Tigris River, which led to a decrease in the discharge of freshwater entering the course of the river, which was accompanied by a noticeable rise in the concentrations of dissolved salts coming with the salt wedge front from the Arabian Gulf. In addition to discharge of domestic sewage and industrial waste and drainage water from agricultural lands directly into the river, causing high concentrations of pollutants, especially organic and bacterial pollutants, significantly in the stations located near the high population centers, represented by the Baradeyea station, followed by two stations of Maqal and Mhela, which recorded high levels of organic and bacterial pollutants. It can be postulated that the reason for the deterioration of the waters of the middle section of the Shatt al-Arab river is due to two main factors: increase salinity and organic pollution. Moreover, a clear effect of the East Hammar Marsh on the water quality of the middle section of the Shatt al-Arab river was not recorded through the results of the monitoring station in the Karmat Ali canal.

The Shatt al-Arab River, in general, the middle section in particular, needs comprehensive management that includes the development of a clear and rapid plan to identify the most important factors leading to the deterioration of the Shatt Al-Arab environment and work to address them, due that the river is of great importance to the population of the Basrah Province, which exceeds four million people.

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