Spatial and Temporal Distribution of Organic Pollution in the Shatt Al-Arab Waterway Using Remote Sensing Techniques and Geographic Information Systems

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ABSTRACT

This study was conducted to assess the environmental characteristics and pollution levels of the Shatt al-Arab waterway, extending from Al-Qurna district in the north to Al-Faw district in the south. Based on repeated field surveys, 29 study stations were selected along a 121.723 km stretch of the river, from Al-Sharsh sub-district in the north to Al-Wasiliya port in the south. The geographical locations of the stations were precisely determined using the Global Positioning System (GPS) and plotted on a map according to the Universal Transverse Mercator (UTM) coordinate system. Water samples were collected monthly for a full year (from October 30, 2024, to October 17, 2025), coinciding with the dates of satellite imagery acquisition by Landsat 8, to determine the spatial and temporal distribution of both the biochemical oxygen demand (BOD5) and the chemical oxygen demand (COD). The lowest values for biochemical oxygen demand (BOD5) were recorded at the central stations (Al-Fayhaa, Teaching Hospital, Al-Sankar, and Mahijran), with Al-Fayhaa station recording the lowest concentration at approximately 0.19 mg L^{-1} during September. In contrast, the highest values were recorded at the northern stations (Al-Sharsh, Al-Shafi, Nahr Omar, Jisr Saad, and the Basra Water Project), peaking at Jisr Saad and Nahr Omar stations at 7.7 mg L^{-1} and 7.22 mg L^{-1}, respectively, during April. Elevated BOD5 values were also observed in the central regions during the spring and winter seasons. As for chemical oxygen demand (COD), the lowest value was recorded in the northern region at Sayed Ali Noor station at 76 mg L^{-1} in January, while it reached its highest level in the central region at Al-Sankar station during November, reaching 1497 mg L^{-1}. The study also indicated a continuous increase in COD values in the southern regions throughout the year.

Keywords: Shatt al-Arab; biochemical oxygen demand (BOD5); chemical oxygen demand (COD); Landsat 8; chemical pollution; geographic information systems (GIS)

Introduction

Freshwater and its surface sources are the cornerstone of life and sustainable development. Their chemical and physical quality is directly linked to their suitability for civil, agricultural, and industrial uses. The Shatt al-Arab River is the vital water artery of southern Iraq, particularly Basra Governorate. However, in recent decades, it has faced serious environmental challenges resulting from climate change and declining freshwater inflows from the Tigris and Euphrates rivers. This, in turn, has led to an increase in saltwater intrusion and the salt tongue from the Arabian Gulf, as well as exacerbating human pressures through the direct discharge of untreated sewage and industrial pollutants into the river and its tributaries. This deterioration in water quality directly impacts the biological and chemical indicators of the aquatic ecosystem, most notably dissolved oxygen (DO) concentration, a critical indicator of the environmental condition of water bodies, the activity and abundance of

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aquatic organisms, and the river's self-purification capacity through microorganisms. Dissolved oxygen is closely related to the biochemical oxygen demand (BOD), which is a measure of the amount of oxygen in water consumed by microorganisms to decompose easily biodegradable organic matter under aerobic conditions and is measured by a five-day incubation period [9]. Dissolved oxygen concentration is an important indicator of water pollution due to its importance in the respiration of fish and other aquatic organisms and its role in the natural self-purification process of water carried out by microorganisms. It also has a direct impact on the activity, abundance, and survival of aquatic organisms. Dissolved oxygen is one of the most important factors affecting water quality due to its fundamental role in maintaining the natural balance [3,6,7].

The chemical oxygen demand (COD) is a measure of the amount of oxygen required for the chemical oxidation of oxidizable organic and inorganic materials present in water using a strong oxidizing agent ($K_2 Cr_2 O_7$) under specific laboratory conditions. COD is used as an important indicator for assessing the degree of organic pollution in surface water, groundwater, and wastewater. Its value is usually higher than that of BOD5. COD is subject to several influences, including various environmental, temporal, and social factors; therefore, there are no specific rules governing it [1,5].

In an evaluation study of the water quality index of the Shatt al-Arab River and its tributaries in Iraq, conducted by Hamdan et al. [8], 37 sites were selected. The results showed that all of the studied sites exceeded their respective water quality standards. Within the range of WHO and Iraqi standards, the highest value for the biochemical oxygen demand was 4 mg L^{-1} at the Al-Baradhiya station in April, and the lowest value was 0.6 mg L^{-1} at the Abu Al-Khasib station in October. The highest COD value was recorded at Al-Khora, reaching 546 mg L^{-1}, and the lowest value was recorded at the Al-Siraji site, at 12.9 mg L^{-1}.

In a study of the central part of the Shatt al-Arab River conducted by Moyel et al. [13] at six stations, results showed significant temporal and spatial variation. The colder months recorded relatively low BOD values, ranging between 3 and 4.2 mg L^{-1}, while the warmer months recorded the highest BOD5 values, reaching 16.3 mg L^{-1} at the Abu Flous station. The Al-Baradhiya station recorded the highest COD value at 146 mg L^{-1} in September, while the Karma Ali station recorded the lowest value at 17 mg L^{-1} in February.

Al-Zubaidi [4] indicated significant differences between the studied stations and across the study months in BOD5 and COD values. The Al-Najibiya station recorded the highest BOD5 value at 7.1 mg L^{-1} in May, while the lowest COD value was recorded at Al-Faw, reaching 2.0 mg L^{-1} during September. The lowest COD concentration was recorded at Al-Qurna station, reaching 15 mg L^{-1} in August, while the highest concentration was recorded at the southernmost station of the Shatt al-Arab (Al-Naq'a), reaching 225 mg L^{-1}, also in August. Geographic Information Systems (GIS) were used to compare water quality data and related information collected on the Tigris River, and to display the pollution distribution in the river on easily viewable maps that can be used by specialists and decision-makers [11]. In a study conducted by Mohamed et al. [12], the spatial and temporal distribution of some water characteristics of the Shatt al-Arab was classified and predicted using GIS and spatial analysis techniques at three stations (Al-Deir, Al-Shalah, and Abu Al-Khasib); the results showed that GIS and spatial analysis techniques were effective in assessing the water quality of the Shatt al-Arab. Seth and Dholakia [14] showed that remote sensing and geographic information systems technologies provide an integrated platform for continuous and systematic monitoring of commonly monitored water quality parameters such as turbidity, chlorophyll-a, BOD, COD, and DO.

In a study on the impact of the water quality of the Diyala River on the water quality of the

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Tigris River using GIS, conducted by Al-Moussawi and Al-Rubaie [2], samples were collected monthly from November 2017 to April 2018 from four selected locations in the Tigris and Diyala rivers. Fourteen water properties were analyzed, including pH, electrical conductivity, total dissolved solids, turbidity, dissolved oxygen, BOD, total solids, calcium, magnesium, chloride, sulfates, phosphates, sodium, and total alkalinity; the GIS maps showed that the water quality of the Tigris River is affected by the water quality of the Diyala River at the selected locations, with sudden changes in March and Maysan in 2018 compared to other months. In an integrated assessment of surface water pollution using GIS, the water quality index, and machine learning in urban-industrial confluence areas surrounding the Indian capital, Shukla et al. [15] demonstrated that combining GIS and machine learning frameworks presents a transformative approach to understanding the fate and transport of organic and inorganic pollutants in water, particularly in urban and industrial contexts, especially in assessing water quality according to international standards. Given the spatial and temporal complexity associated with the movement and distribution of pollutants in hydraulic water systems, there is an urgent need to adopt modern technologies that transcend traditional monitoring methods. This study aims to shed light on the environmental reality of the Shatt al-Arab River by employing geoinformatics techniques and laboratory analyses of environmental indicators (BOD5 and COD), with the goal of building a clear and comprehensive picture that supports decision-makers in developing sustainable management strategies.

Materials and Methods

Study area

The study area lies within the Shatt al-Arab waterway, which extends from Al-Qurna district in the north to Al-Faw district in the south. Twenty-nine sampling stations were selected along the waterway, starting from the Al-Sharsh area near Shallah al-Hassan in the north and extending to the port of Al-Wasiliya in the south, covering a distance of 121.723 km. The study area lies between longitudes 47°28′21″ and 48°16′50″ East and latitudes 30°19′29″ and 30°57′24″ North. Figure 1 illustrates the study area.

Multiple field surveys and reconnaissance tours were conducted along the Shatt al-Arab River, resulting in the identification of 29 environmental and strategic sites for water sampling. The precise geographic coordinates of each site were determined using a GPS device (Table 1) and then digitally plotted on a map of the region according to the UTM (Universal Transverse Mercator) system. A specialized team was formed to monitor the timing of measurements; a sampling interval of every 32 days was adopted to ensure precise synchronization with the period of satellite imagery acquisition by the Landsat 8 satellite, thus supporting modelling and remote sensing operations. Field monitoring continued for a full year, starting on October 30, 2024, and ending on October 17, 2025. Water was collected in clean, sterilized 1-litre plastic containers and transported directly in refrigerated boxes containing ice to preserve sample characteristics until arrival at the laboratory.

Office work

Satellite imagery was downloaded from the official website of the United States Geological Survey (USGS) for the Landsat 8 satellite. The first image covering the study area was captured on October 30, 2024. Subsequent imagery was downloaded according to its capture date, every 32 days for a full year; the last image was captured on October 2, 2025. The compressed image file contained eleven spectral bands with spatial resolutions of 30 m × 30 m for bands 1, 2, 3, 4, 5, and 7; 100 m × 100 m for thermal bands 10 and 11; and 15 m × 15 m for band 8. The sensor's OLI spectral bands were merged after correction using ArcMap 10.4.1 to obtain a single image of the second, fourth, and seventh spectral bands. This image was prepared for digital processing and the differentiation of ground fea-

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tures and landmarks, as well as for use in guided and unguided classification. The spatial resolution of the resulting satellite image was enhanced using the Pan Sharpening tool with the eighth spectral band in ArcMap 10.4.1, resulting in a multi-spectral image with a resolution of 15 m × 15 m. The resulting satellite image was cropped using ArcMap 10.4.1 to cover the study area and a shape file was created. Work within the Geographic Information System (GIS) environment included georeferencing, numbering, and database creation for water quality maps and sample locations, carried out using ArcGIS 10.4.1, with data entry, storage, retrieval, spatial analysis, and output in the form of maps and shapefiles.

Studied traits

The biochemical oxygen demand (BOD5) and chemical oxygen demand (COD) of water samples were determined according to the methods described in APHA (2017) [5]. Biochemical oxygen demand was determined after incubating the samples in an incubator at 20°C for five days. The BOD5 value was calculated using the following equation and expressed in mg L^{-1}:

$$BOD5\ (mg\ L^{-1}) = Dissolved\ oxygen\ before\ incubation - Dissolved\ oxygen\ after\ incubation$$

The chemical oxygen demand (COD) of the water was determined after digesting the sample for two hours using potassium dichromate and concentrated sulfuric acid with a Lovibond COD analyzer, and was also expressed in mg L^{-1}.

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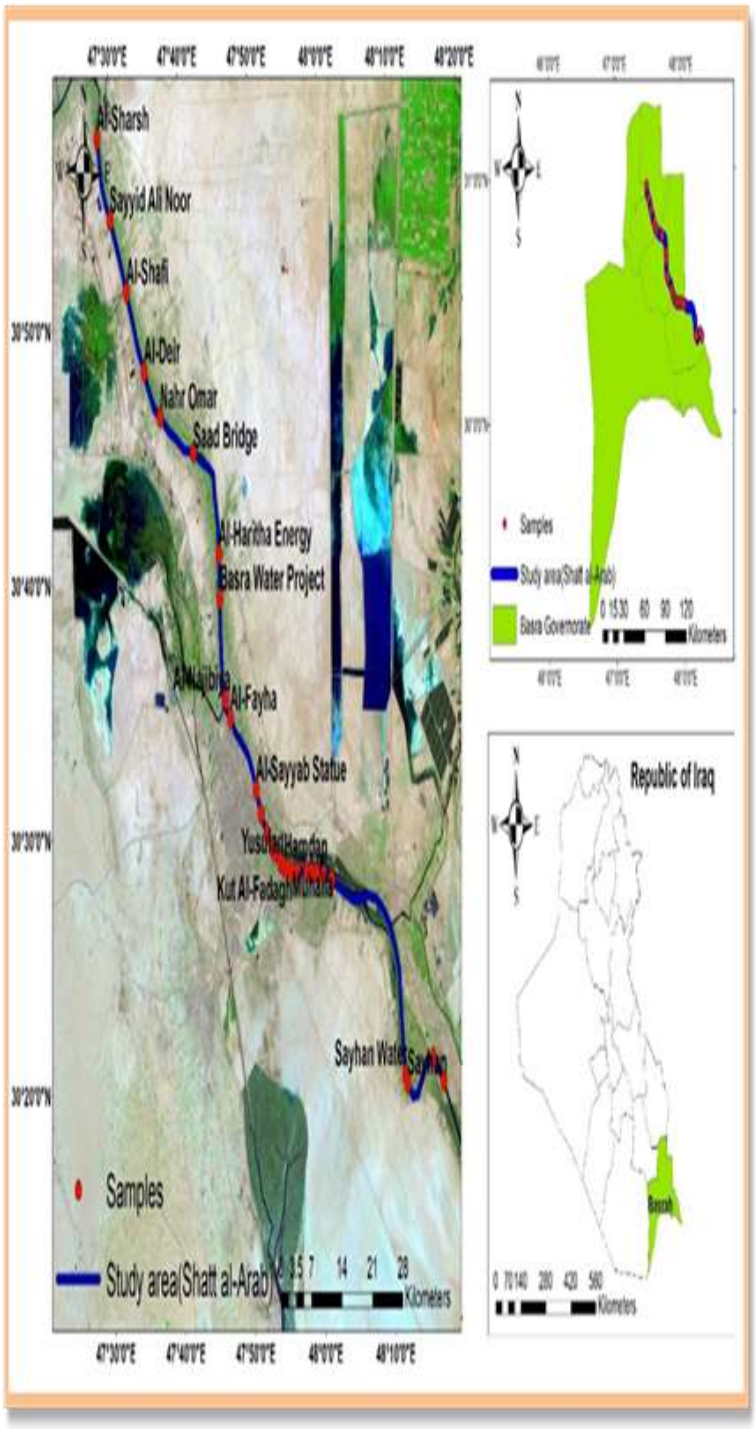


Figure 1. Location of the study area.

Results and Discussion

1. Biochemical Oxygen Demand (BOD5)

The results in Table 2, collected from 29 monitoring stations along the Shatt al-Arab waterway over four seasons, show a clear gradient in pollution from north to south. However, the results also reveal a significant decrease in the biological oxygen demand (BOD) values, despite the quantity of pollutants from various sources — industrial, agricultural, and sewage — discharged into the Shatt al-Arab. This is attributed to the high salinity levels, which reduce the activity of mi-

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croorganisms that decompose organic matter, in addition to the increase in the water level of the Tigris River, which helps to reduce pollution. The lowest value was recorded in the northern region at the Sayed Ali Noor station, which reached 0.76 mg L^{-1} in January, while the highest concentration value was recorded in the central region at the Al-Sankar station in November, which reached 1.497 mg L^{-1}, and it was recorded at the Mahijran and Mahila stations in June, which reached 1.495 mg L^{-1}. These results are consistent with what Moyel et al. [13] concluded.

Table 1. Geographic coordinates and locations of water sampling stations along the Shatt al-Arab River.

Station number	Station name	Geographic coordinates (UTM)	
		Longitude	Latitude
S1	Al-Sharsh	736156.614	3427494.352
S2	Sayyid Ali Noor	739253.784	3421511.238
S3	Al-Shafi	742741.377	3416230.709
S4	Al-Deir	747012.936	3410594.887
S5	Nahr Omar	750757.16	3407218.06
S6	Saad Bridge	758465.469	3404716.441
S7	Al-Haritha Energy	764116.621	3397296.782
S8	Basra Water Project	764443.914	3394106.992
S9	Al-Najibiya	765244.345	3386447.145
S10	Al-Fayha	766995	3385602.544
S11	Al-Sayyab Statue	772687	3380045.756
S12	Al-Ta'leemi Hospital	773866.457	3378415.193
S13	Awaisiyan	775237.042	3376944.287
S14	Fajjat Al-Arab	776607.216	3375917.894
S15	Mahjaran	777078.648	3375594.373
S16	Yusufan	778349.174	3374921.609
S17	Hamdan	779322.835	3374540.005
S18	Kut Al-Fadagh	780089	3374311.346
S19	Muhaila	781126.733	3374163.16
S20	Al-Sankar	782383.477	3374120.083
S21	Abu Mughira	784412.02	3374075.832
S22	Nahr Khuz	785449.774	3374048.935
S23	Al-Labani	786692.511	3374042.547
S24	Al-Sahel	212283.717	3373823.469
S25	Abu Flous Port	214004.767	3373424
S26	Sayhan Water	230127.399	3358542.453
S27	Sayhan	230508.443	3357831.47
S28	Al-Siba	236610.792	3359302.866
S29	Al-Wasiliya	238828.425	3357499.221

2. Spatial distribution of BOD5 concentrations during the seasons

Figure 2 shows the BOD5 (mg L^{-1}) for the studied stations across the four seasons.

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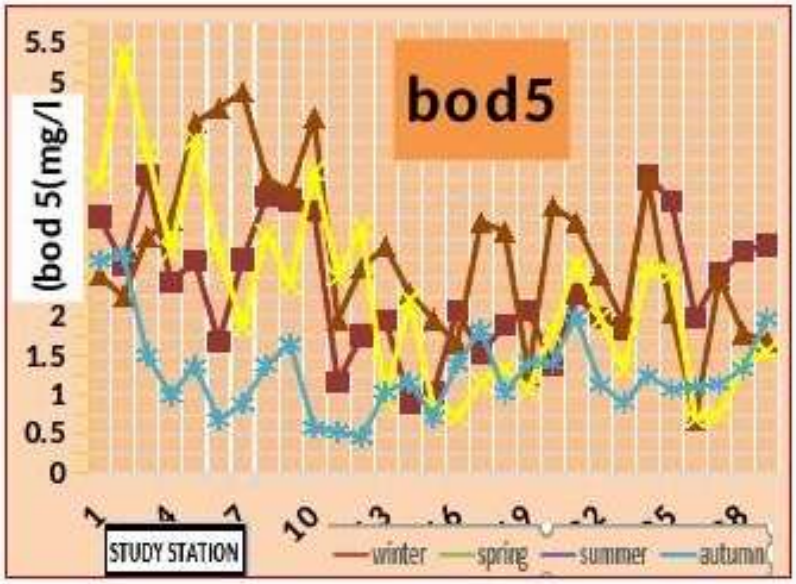


Figure 2. BOD5 (mg L^{-1}) for the studied stations across the four seasons.

Figures 3, 4, 5, and 6 illustrate the spatial distribution of the biological oxygen demand (BOD) values for the four seasons at the studied stations along the Shatt al-Arab. In winter (Figure 3), we observe a difference in the spatial distribution of the studied stations due to the decrease and increase in BOD5 values. The northern stations (Al-Sharsh, Sayyid Ali Noor, Al-Shafi, Al-Deir, and Nahr Omar) and the central stations (Al-Haritha, Basra Water Project, Al-Najibiya, Al-Fayha, Muhaila, Al-Sahel, and Abu Flous Port), which constituted 41.3% of the total stations, recorded the highest concentrations, ranging between 2.08 and 3.81 mg L^{-1}. The central stations from the statue of Al-Sayyab to Al-Sankar, which constituted 41.2%, recorded concentrations ranging between 0.9 and 2.07 mg L^{-1}. The southern stations (Sihan Water Project, Sihan, Al-Siba, and Al-Wasiliya Port), which constituted 17.5%, recorded values ranging between 3.23-2.08 mg L^{-1}. Figure 4 illustrates the spatial distribution of BOD5 values in the spring. Stations from Al-Sharsh to Awaisian recorded values ranging from 2.38 to 4.87 mg/L, representing 41.4% of the total. Stations (Sayyid Ali Noor, Statue of Al-Sayyab, Hamdan, Al-Sankar, Al-Sahel, Abu Flous Port, Seihan Water Project, Seihan, Al-Siba, and Al-Wasiliya Port), representing 37.9%, recorded lower values ranging from 0.7 to 2.37 mg/L. The remaining stations, representing 20.7%, recorded values ranging from 2.38 to 3.2 mg/L. Figure 5 illustrates the spatial distribution of BOD5 values in the summer, showing a significant increase compared to other seasons. The northern stations (Al-Sharsh, Sayyid Ali Noor, Al-Shafi, Al-Deir, Nahr Amr, and Jisr Saad), representing 20.7%, recorded the highest values. The values for the spatial distribution ranged between 5.34-2.59 mg L^{-1}, while the southern stations (Seihan Water Project, Seihan, Al-Seeb and Al-Wasiliya Port), which constituted 17.5%, recorded low values that fell within the spatial distribution that ranged between 1.65-0.711 mg L^{-1}. As for the central stations, which constituted 61.8%, they were within the spatial distribution in which the BOD5 values ranged between 3.52-1.66 mg L^{-1}. Figure 6 shows the spatial distribution of BOD5 values for the autumn season, as the stations recorded a rise and a fall in BOD5 values, and they were different in the spatial distribution, and their values ranged between 3.31-0.2 mg L^{-1}.

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Table 2. Monthly BOD5 concentration (mg L^{-1}) for the studied stations of the Shatt al-Arab waterway.

station	BOD /11	BOD /12	BOD /1	BOD /2	BOD /3	BOD /4	BOD /5	BOD /6	BOD /7	BOD /8	BOD /9	BOD /10	average
S1	3.27	6.40	0.57	2.88	2.97	0.40	4.22	2.94	3.60	4.70	2.90	1.98	3.07
S2	3.25	3.35	2.98	1.68	3.75	0.70	2.29	6.10	5.40	4.68	3.36	1.74	3.27
S3	2.11	6.60	1.95	2.89	3.67	1.18	4.22	5.30	4.20	2.86	1.38	1.03	3.12
S4	0.87	2.00	2.90	2.43	3.54	4.86	1.30	3.60	2.80	2.15	0.35	1.75	2.38
S5	0.73	1.87	4.00	2.28	4.12	7.22	2.10	6.00	4.70	2.10	0.27	3.10	3.21
S6	0.50	1.25	2.22	1.56	4.17	7.70	2.15	3.87	2.76	1.86	0.41	1.12	2.46
S7	1.30	3.75	2.30	2.15	4.13	4.67	5.82	2.23	1.97	1.46	0.38	0.96	2.59
S8	1.87	1.56	6.76	2.29	3.71	3.87	3.70	5.20	2.70	1.28	1.03	1.23	2.93
S9	3.23	4.35	1.54	4.58	3.23	5.98	1.59	3.90	1.97	1.39	0.61	1.10	2.79
S10	0.55	0.60	5.56	3.90	5.75	4.10	3.80	5.65	3.98	1.97	0.19	1.00	3.09
S11	0.95	0.77	0.35	2.37	2.51	1.48	1.88	3.35	2.21	2.00	0.32	0.31	1.54
S12	0.75	1.75	0.71	2.82	3.14	2.35	2.40	5.40	3.15	0.86	0.42	0.21	2.00
S13	1.53	1.85	1.88	2.15	3.95	2.11	2.60	1.20	0.95	0.65	0.31	1.29	1.71
S14	0.70	0.79	0.98	0.94	2.10	2.35	2.45	3.86	1.86	0.97	1.30	1.48	1.65
S15	1.00	0.50	0.25	2.30	1.87	2.42	1.63	0.95	0.85	0.77	0.85	0.29	1.14
S16	2.62	1.97	2.14	2.10	2.33	1.60	1.02	0.56	0.75	0.90	1.25	0.34	1.47
S17	2.88	1.45	0.54	2.62	3.87	2.65	3.10	1.22	1.15	1.12	1.26	1.34	1.93
S18	1.45	0.45	1.85	3.38	4.14	1.23	3.9	1.54	1.35	1.13	1.23	0.37	1.84
S19	1.25	1.10	2.25	2.90	1.26	1.13	1.43	1.12	1.15	0.98	1.25	1.72	1.46
S20	2.62	0.50	2.42	1.22	3.19	4.68	2.36	1.65	2.10	1.67	1.34	0.27	2.00
S21	3.96	1.50	1.70	3.64	3.13	2.16	4.35	3.81	2.69	1.57	1.47	0.59	2.55
S22	0.55	1.28	1.15	3.50	3.23	1.42	2.96	2.25	2.10	1.62	1.39	1.45	1.91
S23	0.87	1.60	1.63	2.31	0.67	1.23	3.84	1.55	1.35	1.13	1.06	0.78	1.50
S24	0.54	2.94	4.52	4.00	3.24	3.12	4.95	3.40	2.73	1.78	1.65	1.57	2.87
S25	0.59	0.80	4.90	4.7	2.89	2.10	1.16	3.10	2.69	1.89	1.58	1.05	2.29
S26	1.56	2.45	0.85	2.67	1.06	0.40	0.60	0.67	0.65	0.79	1.28	0.45	1.12
S27	1.48	2.76	1.59	3.34	1.88	1.15	4.43	0.65	0.79	0.82	0.60	1.33	1.74
S28	1.21	4.65	1.88	1.98	1.64	0.50	3.23	2.20	1.15	0.72	0.50	2.29	1.83
S29	3.66	3.12	1.23	1.39	1.78	1.04	2.25	2.90	1.13	0.67	1.14	1.15	1.79
aver	1.65	2.21	2.19	2.65	3.00	2.61	2.82	2.97	2.24	1.60	1.07	1.15	2.18

Table 3. Seasonal values of COD and BOD5 (mg L^{-1}) during the four seasons for the studied stations of the Shatt al-Arab.

	Winter		Spring		Summer		Autumn	
station	BOD5	COD	BOD	COD	BOD	COD	BOD	COD
S1	3.28	137	2.53	176.3	3.75	109	2.72	141
S2	2.67	91.7	2.25	154.7	5.39	212	2.78	195
S3	3.81	180	3.02	176	4.12	143	1.51	392
S4	2.44	107	3.23	180	2.85	198	0.99	333
S5	2.72	215.7	4.48	227	4.27	287	1.37	452
S6	1.68	169.3	4.67	125.7	2.83	280	0.68	733
S7	2.73	202.3	4.87	242	1.89	843	0.88	903
S8	3.54	204.3	3.76	187.7	3.06	982	1.38	1000
S9	3.49	167	3.6	199	2.42	744	1.65	969
S10	3.35	178.7	4.55	194	3.87	1304	0.58	704
S11	1.16	149.7	1.96	224.7	2.52	1325	0.53	877
S12	1.76	214	2.63	224	3.14	1331	0.46	922
S13	1.96	227.7	2.89	176.3	0.93	1356	1.04	852
S14	0.9	155	2.3	483.3	2.23	1319	1.16	951
S15	1.02	140	1.97	261.7	0.86	1414	0.71	907

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S16	2.07	150.3	1.65	213.3	0.74	1324	1.4	939
S17	1.54	141.7	3.21	192.3	1.16	1242	1.83	829
S18	1.89	150.7	3.09	203.3	1.34	1276	1.02	870
S19	2.08	194.7	1.27	222.3	1.08	1464	1.41	942
S20	1.38	211.7	3.41	221	1.81	1427	1.41	1035
S21	2.28	179	3.21	242.3	2.69	1389	2.01	1033
S22	1.98	251.7	2.54	221	1.99	1426	1.13	1059
S23	1.85	255.7	1.91	237.7	1.34	1378	0.9	1017
S24	3.82	188.7	3.77	232.3	2.64	1346	1.25	958
S25	3.47	224.3	2.05	240.7	2.56	1237	1.07	980
S26	1.99	177.7	0.69	344.3	0.7	1227	1.1	1020
S27	2.56	197.3	2.49	428.3	0.75	1247	1.14	1021
S28	2.84	202.3	1.79	519.3	1.36	1273	1.33	1009
S29	2.91	250.3	1.69	490.7	1.57	1359	1.98	1000

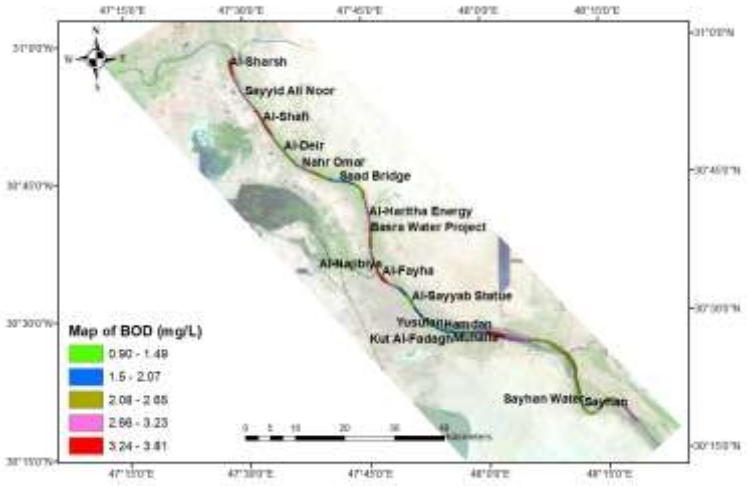


Figure 3. Spatial distribution of BOD5 (mg L^{-1}) for the winter season.

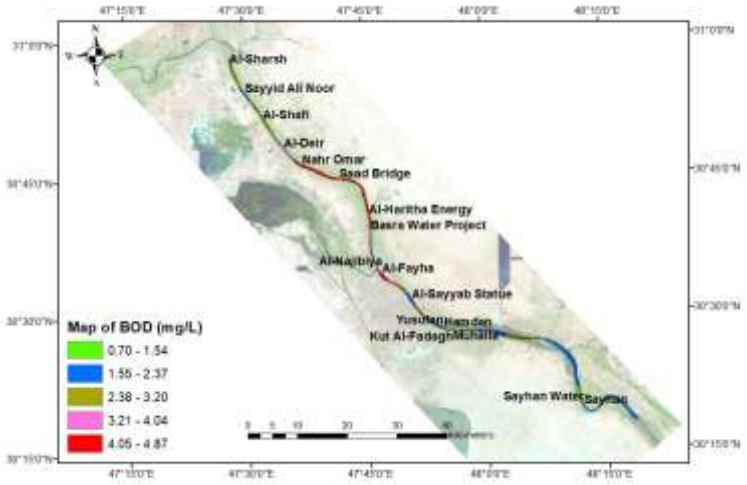


Figure 4. Spatial distribution of BOD5 (mg L^{-1}) for the spring season.

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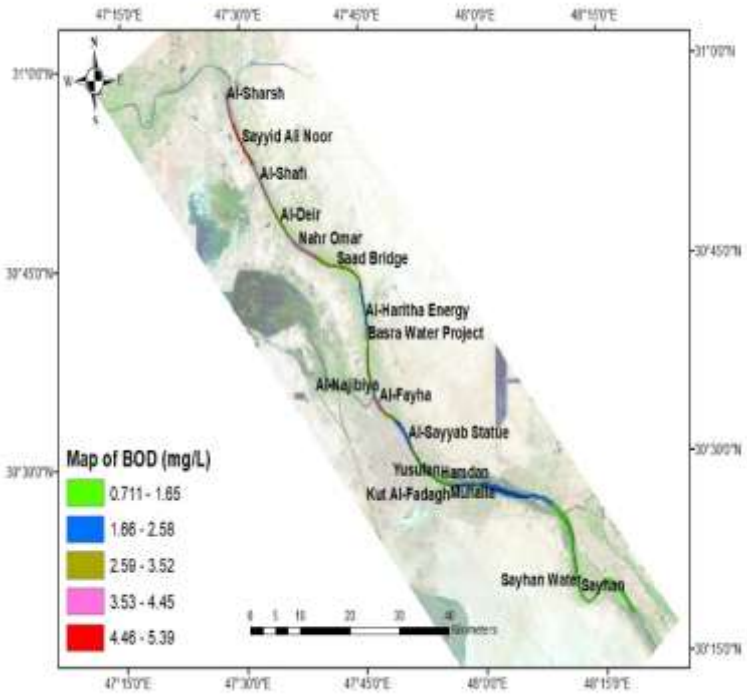


Figure 5. Spatial distribution of BOD5 (mg L^{-1}) for the summer season.

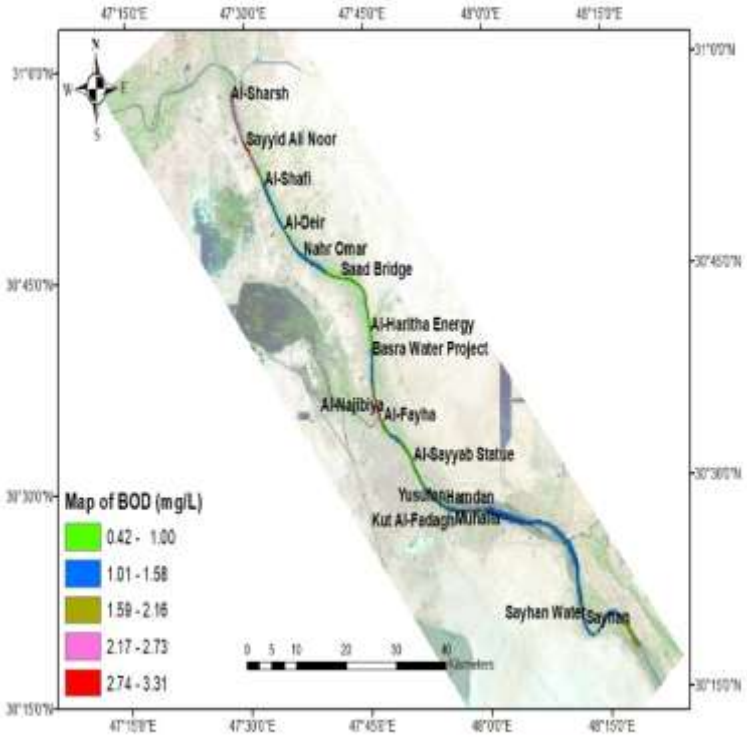


Figure 6. Spatial distribution of BOD5 (mg L^{-1}) for the autumn season.

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3. Chemical Oxygen Demand (COD)

Table 4 shows the results of the monthly chemical oxygen demand (COD) for the studied stations. We note that there is a spatial and temporal variation in the values of the chemical oxygen demand (COD). The northern stations recorded the lowest value compared to the central and southern stations, as the concentration increases towards the central and southern stations towards the estuary. The hot months recorded a significant increase compared to the cold months as a result of increased activity of organisms to oxidize organic materials, which increases the rate of reactions and the increase in the amount of organic materials dumped into the Shatt al-Arab from waste from cities, industrial centers, health centers and other sources of pollution, and a decrease in the level of the river's fluidity as a result of the lack of fresh water releases from the Tigris River which helps to reduce pollution. The lowest value was recorded in the northern region at the Sayed Ali Noor station, which reached 76 mg L^{-1} in January, while the highest concentration value was recorded in the central region at the Al-Sankar station in November, which reached 1497 mg L^{-1}, and it was recorded at the Mahijran and Mahila stations in June, which reached 1495 mg L^{-1}. These results are consistent with what Moyel et al. [13] concluded.

Table 4. Monthly COD concentration (mg L^{-1}) for the studied stations of the Shatt al-Arab waterway.

Station	COD/11	COD/12	COD/1	COD/2	COD/3	COD/4	COD/5	COD/6	COD/7	COD/8	COD/9	COD/10	average
S1	86	112	120	179	160	197	172	134	118	76	142	196	141.
S2	90	96	76	103	119	185	160	188	172	277	80	416	163.
S3	138	144	120	276	218	169	141	128	126	174	168	871	223
S4	96	100	86	135	160	165	215	125	109	359	134	769	204.
S5	120	178	184	285	213	219	249	146	139	576	409	827	295.
S6	146	182	166	160	129	135	113	105	102	633	879	1174	327.
S7	120	146	96	365	310	237	179	829	768	932	1265	1323	547.
S8	128	176	168	269	160	197	206	1389	589	969	1494	1378	593.
S9	110	146	180	275	217	228	152	542	521	1169	1320	1476	528.
S10	120	132	96	308	175	207	200	1242	1395	1274	1262	730	595.
S11	95	120	164	265	179	216	279	1289	1427	1260	1327	1209	652.
S12	200	168	148	326	245	219	208	1325	1289	1379	1468	1097	672.
S13	125	160	148	375	169	172	188	1305	1286	1477	1420	1012	653.
S14	120	108	112	245	153	239	1058	1351	1274	1332	1465	1268	727.
S15	110	142	92	186	165	265	355	1495	1359	1389	1421	1189	680.
S16	180	168	96	187	154	219	267	1346	1328	1298	1358	1279	656.
S17	146	138	94	223	179	186	212	1438	1354	934	1189	1153	604.
S18	120	176	94	212	156	185	269	1451	1410	967	1182	1307	627.
S19	150	192	166	226	203	219	245	1495	1429	1467	1398	1279	706
S20	160	216	200	219	195	217	251	1467	1381	1432	1448	1497	723.
S21	186	212	80	245	221	241	265	1423	1353	1392	1460	1454	711.
S22	216	240	218	297	155	229	279	1471	1382	1426	1471	1490	739.
S23	190	224	198	345	178	238	297	1410	1333	1391	1426	1436	722.
S24	166	192	180	294	165	243	289	1358	1312	1368	1387	1322	689.
S25	187	210	196	367	189	228	305	1136	1086	1489	1439	1313	679.
S26	178	190	182	261	159	267	607	1296	1107	1279	1389	1492	700.
S27	180	194	128	270	202	298	785	1197	1158	1385	1429	1455	723.
S28	190	240	164	203	189	287	1082	1105	1384	1329	1408	1429	751
S29	220	256	216	279	165	247	1060	1124	1487	1465	1308	1471	774
Aver	147.3	171.	143.7	254.5	182.1	219.1	347.9	1045.	1006.	1100	1157	1183.	579.

4. Spatial distribution of COD concentration during the seasons

Figure 7 and Table 3 illustrate the chemical oxygen demand (COD) during the four sea-

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sons. There are differences between seasons and stations. Winter recorded lower COD values due to lower temperatures and reduced activity of organisms that oxidize organic matter. The northern stations (Al-Sharsh, Sayyid Ali Noor, and Al-Deir) recorded the lowest values due to lower organic pollution from sewage and increased discharge from the Tigris River, which helps to mitigate pollution. Values ranged between 91.7 and 137 mg L^{-1}, while the Al-Labani, Nahr Khuz, and Al-Wasiliya port stations recorded the highest values, ranging between 251.7 and 255.7 mg L^{-1}, representing an increase of 90.8%. The highest values were recorded during the summer due to the high temperatures, which lead to increased biological activity and a faster oxidation of organic matter. The reduced flow of water in the Shatt al-Arab also contributes to the lower dilution rates. Additionally, there is an increase in sewage, domestic, industrial, and agricultural waste. There is a clear increase in the concentration of the chemical oxygen demand (COD) at the central stations compared to the northern and southern stations. This is because the central stations are located within the city, which is characterized by high population density and various industrial activities that generate large quantities of wastewater pollutants originating from tributaries flowing into the Shatt al-Arab. The Mahila, Al-Sankar, and Al-Labani stations recorded the highest concentrations, ranging between 1426 and 1464 mg L^{-1}. While the northern stations (Al-Sharsh, Sayed Ali Nour, Al-Shafi, Al-Deir, Nahr Amr, Jisr Saad) recorded the lowest concentration ranging between 109-287 mg L^{-1}, the central stations recorded a 410% increase compared to the northern stations. In the spring, the northern stations (Al-Sharsh, Sayyid Ali Noor, Al-Shafi, Al-Deir, Nahr Amr, Jisr Saad) recorded the lowest values, ranging from 125.7-227 mg L^{-1}, while the southern stations (Sayhan Water Project, Sayhan, Al-Siba, and Al-Wasiliya Port) recorded the highest concentration, ranging between 344.3-519.3 mg L^{-1}, and recorded an increase of 128.7% compared to the northern stations. In the autumn, the northern stations (Al-Sharsh, Sayyid Ali Noor, Al-Shafi, Al-Deir, Nahr Amr, Jisr Saad) recorded the lowest values, ranging between 141-452 mg L^{-1}, while the central stations (Al-Sankar, Abu Mughira, Nahr Khuz, and Al-Labani) recorded the highest concentration, ranging between 1017-1059 mg L^{-1}, and recorded an increase of 133.7% compared to the northern stations. These results are consistent with Al-Zubaidi [4].

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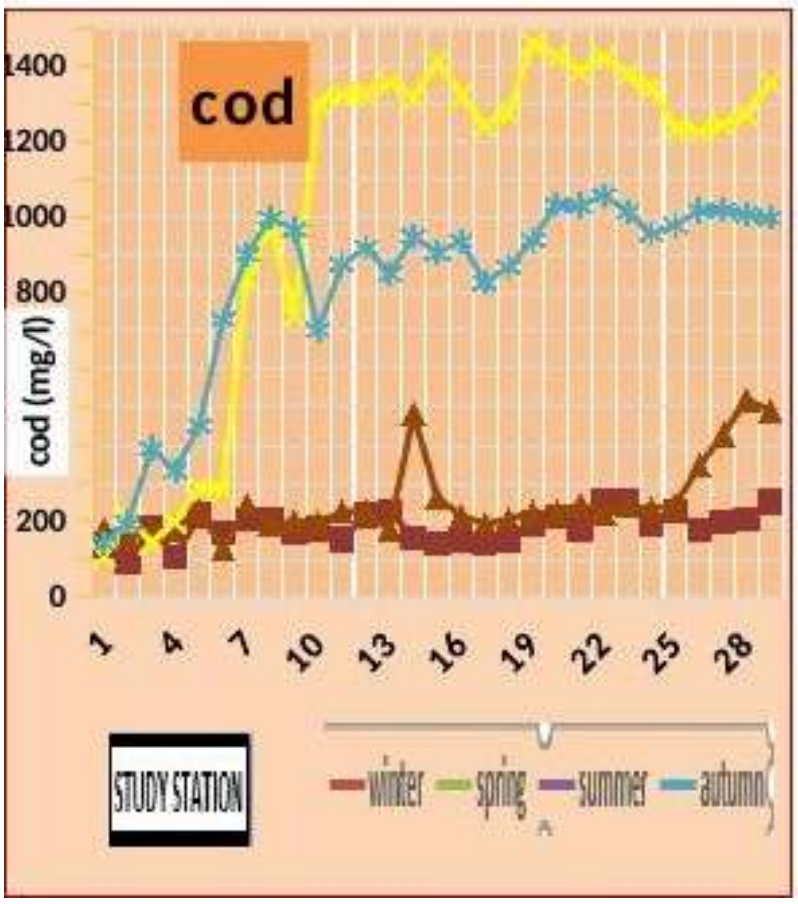


Figure 7. COD (mg L^{-1}) for the studied stations across the four seasons.

Figures 8, 9, 10, and 11 illustrate the spatial distribution of COD values at the stations throughout the year. Figure 8 shows the highest COD values recorded during the summer. The spatial distribution of the northern stations (Al-Sharsh, Sayyid Ali Noor, Al-Shafi, Al-Deir, Nahr Amr, and Jisr Saad), representing 20.7% of the total stations, fell within a range of 109-380 mg L^{-1}. The remaining stations, including those in the central and southern regions (69.0% of the total), recorded the highest COD values. This is attributed to the high temperatures, which accelerate the decomposition of organic matter, and the low water level in the river during the summer, coupled with the accumulation of pollutants from urban wastewater and tributaries flowing into the main river. These values ranged from 1191-1460 mg L^{-1}. Meanwhile, the central stations (Al-Haritha Power Plant, Basra Water Project, and Al-Najibiya), representing 10.3%, recorded values ranging from 651-1190 mg L^{-1}. In autumn (Figure 9), the northern stations (Al-Sharsh, Sayed Ali Noor, Al-Shafi, Al-Deir, and Nahr Omar), which constituted 17.3% of the total stations, recorded the lowest values within a spatial distribution where COD values ranged between 141-508 mg L^{-1}. Meanwhile, most of the central and southern stations, which constituted 72.4% of the total stations, recorded values ranging between 875-1060 mg L^{-1}. Figure 10 shows the spatial distribution of COD values in winter, the lowest of all seasons; the northern stations (Al-Sharsh, Sayed Ali Noor, and Al-Deir) recorded the lowest values, ranging between 91.7 and 137 mg L^{-1}, while the Al-Labani, Nahr Khuz, and Al-Wasiliya port stations recorded the highest values, ranging between 223 and 256 mg L^{-1}. Figure 11 shows the spatial distribution of COD values in spring; the northern stations recorded the lowest values, ranging between 128 and 204 mg L^{-1}, while the southern stations (Sayhan Water Project, Sayhan, Al-Siba, and Al-Wasiliya Port) rec-

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orded the highest concentration, ranging be- tween 441 and 519 mg L^{-1}.



Figure 8. Spatial distribution of COD (mg L^{-1}) for the summer season.

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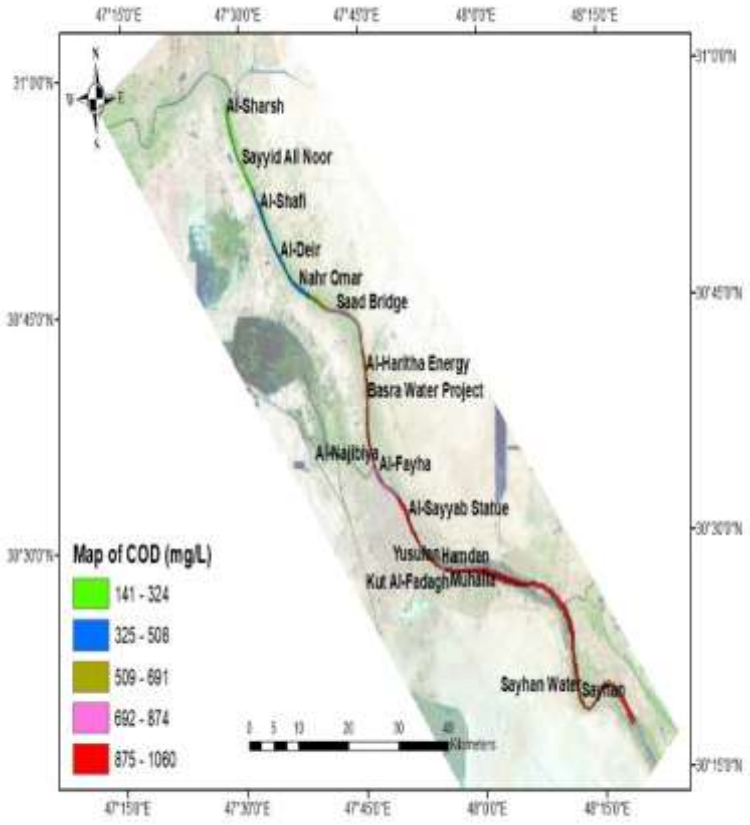


Figure 9. Spatial distribution of COD (mg L^{-1}) for the autumn season.

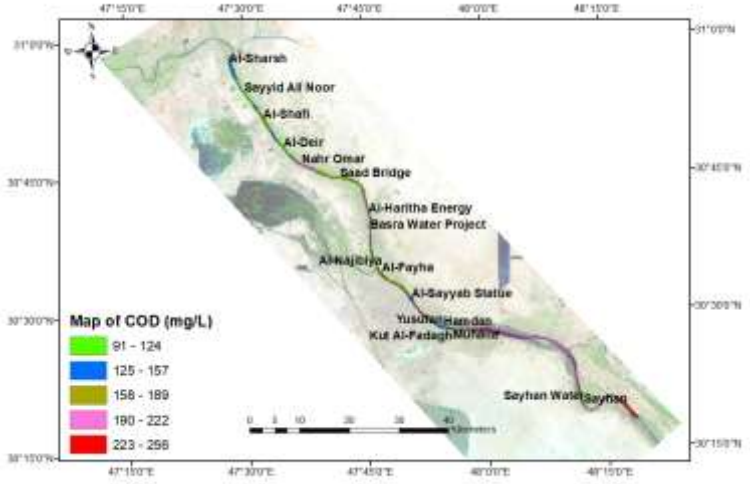


Figure 10. Spatial distribution of COD (mg L^{-1}) for the winter season.

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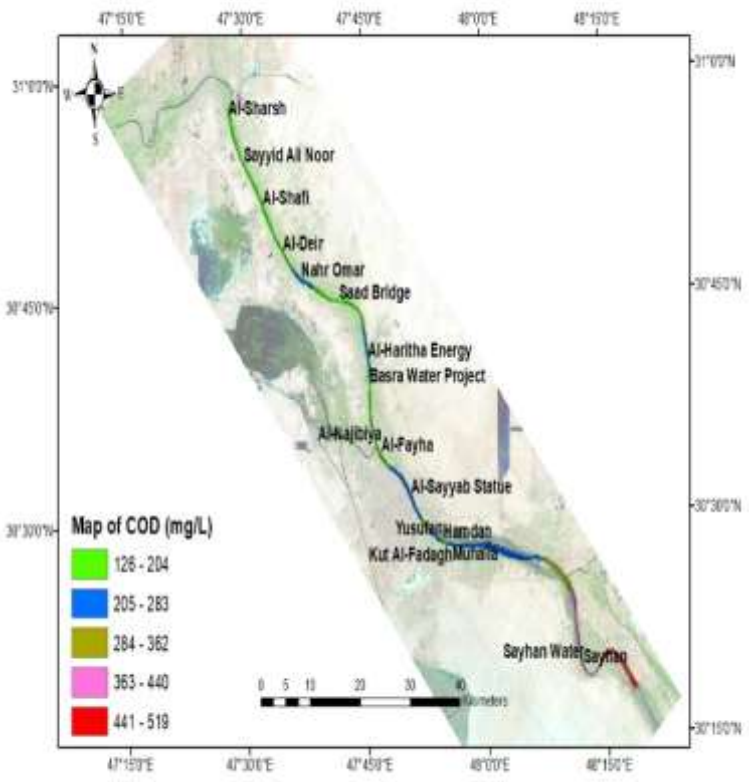


Figure 11. Spatial distribution of COD (mg L^{-1}) for the spring season.

Conclusions

1. The study revealed the ability of Geographic Information Systems (GIS) to build a database of the qualitative characteristics of the Shatt al-Arab waters. This database aids in studying and evaluating the water situation and producing accurate maps for monitoring water quality and pollutant transport.

2. The Shatt al-Arab waters suffer from spatially and temporally varying organic and chemical pollution, with a clear predominance of non-biodegradable chemical pollution (represented by a sharp increase in COD values and a decrease in BOD5 values). The main sources of this pollution are attributed to the flow of untreated sewage and industrial wastewater into the river.

3. These results underscore the urgent need to adopt advanced treatment technologies and pre-treatment of sewage and industrial wastewater before its discharge into the Shatt al-Arab, with the aim of restoring the river's ecological condition.

Recommendations

1. The use of Geographic Information Systems (GIS) and remote sensing in research and studies on the Shatt al-Arab waterway is a rapid, modern, cost-effective, and effective method for understanding temporal and spatial environmental changes in the Shatt al-Arab.

2. The urgent need to adopt advanced treatment technologies and implement primary treatment for sewage and industrial wastewater before discharging it into the Shatt al-Arab, with the aim of restoring the river's environmental condition.

3. The need for future research focusing on measuring the concentrations of heavy metals and hydrocarbon pollutants in the central region (near the Al-Sankar station and the teach-

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ing hospital) to pinpoint the exact source of the sudden spikes in chemical pollution.

4. Making industrial facilities, hospitals, and municipalities located along the banks of the Shatt al-Arab (especially in the central and southern regions) treat their wastewater before discharging it into the river, to reduce the clear dominance of non-biodegradable chemical pollution and the sharp rise in COD values, and designating the 29 stations identified in this study as permanent monitoring stations and reference stations under the Basra Environment Directorate to continuously monitor the chemical and physical changes in the river.

5. Expansion of future pollution-management research: future studies should expand their scope to investigate heavy metals and other industrial pollutants, with particular emphasis on developing and evaluating effective remediation approaches and providing practical recommendations for mitigating severe chemical pollution in the central region.

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