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Seasonal and Spatial Variation in Major Ion Composition and Water Quality of the Shatt Al-Arab River, Southern Iraq

Z. H. Al-Mahamid[1], D. A. Al-Abbawy[2] and H. K. H. Al-Mahmood[3]

[1,2]Department of Ecology, College of Science, University of Basrah, Basrah, Iraq.
[3]Department of Sedimentology and Marine Geology, University of Basrah, Basrah, Iraq.

[2]E-mail: dunya.hussain@uobasrah.edu.iq

Abstract. This study assessed seasonal and special variations in major Ions and physicochemical parameters of the Shatt Al-Arab River under changing climatic conditions. Surface water samples were collected seasonally from five stations between 2023 and 2024, Parameters such as EC, TDS, CL^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, pH, and HCO_3^- were analyzed following APHA (2005) standards, Statistical analyses (ANOVAm correlation) revealed significant seasonal and spatial differences ($p \leq 0.05$), with highest salinity and hardness during summer due to elevated temperature and reduced discharge. Findings indicate that climate-induced temperature rise and seawater intrusion are major drivers of water quality deterioration. The study recommends continuous monitoring and adaptive management to mitigate climatic and anthropogenic impacts.

Keywords. Water Quality, Surface Water, Shatt Al-Arab River, Climate Change, Salt.

1. Introduction

Water is an elixir of life, contributing significantly to its genesis from molecules (It is included in all ingredients in varying proportions), Human civilizations have flourished with water resources since ancient times [1, 2]. Each country's aquatic ecosystem, including lakes and rivers, represents an important resource for different human uses and agricultural and industrial activities [3,4,5]. Since 1990, the sustainability of freshwater supplies has been in danger due to significant groundwater depletion and increased pollutant emissions resulting from the steady increase in population growth and water demand, with many regions having experienced significant reductions [6,7]. Urbanization, agriculture, and logging cause irreversible environmental changes, as natural areas become farms or cities, and more pollutants are released into the water, including organic materials, nutrients, heavy metals, and hydrocarbons [8,9]. In parallel with the impacts of climate change, many countries have faced serious water scarcity, quality degradation, and spatial and temporal changes in hydrological cycle components, water balance and loss of certain aquatic species, especially in arid and semi-arid regions where water resources are limited and rainfall rates are consistently decreasing [10,11]. Climate is one of the most important determinants affecting river hydrology and the distribution of water resources, posing significant challenges to global social and economic progress [12]. Climate change and increased human activity cause persistent changes in the hydrological cycle of freshwater, as water resources and quality are constantly threatened by pollution from human activities involving

agricultural and industrial operations [13,14]. Natural and human activities affect river water quality through changes in temperature and rainfall rates, leading to different seasonal qualities [15].
The hydrological conditions of river water and salt concentration levels are closely related to river water quality [16]. Basra governorate is experiencing a faster temperature increase than the global average of 1 $^{\circ}$C at a rate greater than 4 $^{\circ}$C over 74 years from 1948-2022. This is because of population growth, industrial activities, declining vegetation, shrinking wetlands, and global warming. Land use changes outweigh the impact of global warming, leading to widespread droughts and reduced river water flow. [17]. Iraq's Shatt Al-Arab River suffers from severe shortages of fresh water and high salinity due to the intrusion of the salt tongue from the Arabian Gulf. This impasse was created by a significant reduction in the availability of fresh water and the lack of drainage for natural and human reasons, which severely affected drinking water purification and filtration systems, as well as agricultural, livestock, and industrial resources [18]. Climate change, frequent droughts, and the incursion of the salt tongue from the Arabian Gulf are among the major factors that caused the high concentrations of dissolved salts in the Shatt Al-Arab waters, especially during the hot summer months [19]. This is in addition to the lack of fresh water that fuels the river stream from its main tributaries because of the establishment of dams in Turkey, Iran, and Iraq [20]. All weather elements in Iraq and neighboring countries have been affected by climate changes resulting from global warming, as reduced rainfall coincides with increased temperatures and increased water evaporation rates [21].
The presence of dissolved salts is important for the balance of organisms' cells, as the entry of ion-free water expands the cells, while an excessive increase results in the contraction of aquatic living cells. High air temperatures, increased evaporation rates, low rainfall, and groundwater flow increase the concentration of dissolved solids in water bodies, and their increased concentration often indicates higher hardness or total alkalinity [22].
This study aims to study the distribution and concentrations of major cations and anions, especially salts, in the surface waters of Shatt Al-Arab River during four seasons. The analysis covers three main sections, the northern, central part, and southern parts, to evaluate spatial and seasonal changes in water quality. The research also explores the impact of climate change and declining freshwater flows on increased salinity and the overall deterioration of water quality in these areas.

2. Materials and Methods

2.1. Study Area
The Shatt Al-Arab River, formed at the confluence of the Euphrates and Tigris Rivers in Qurnah, southern Iraq, serves as an international border between Iran and Iraq. The Shatt Al-Arab River is one of Iraq's most important rivers because it is a vital navigational channel for goods, transport, and fisheries; it is also used in the activities of various populations, and is the main source of surface freshwater in Basra governorate and is described as a tidal river [23,24]. The Shatt Al-Arab River is about 204 km long and flows from the city of Al-Qurna downstream towards the Arabian Gulf in Al-Fao City. The Tigris, Euphrates, and Karun rivers are the main tributaries of the Shatt Al-Arab River [25]. The hydrological conditions of the river watershed are affected by upstream tributary reaches, tidal movements of the Arabian Gulf, mixing of salty groundwater with river water, and climatic elements such as precipitation, temperature, evapotranspiration, and runoff, which influence the discharge rates and sediment load [26, 27,18]. The terrain in the countries surrounding Iraq has a clear impact on determining the quality of its climate in terms of the trajectories, trends, and high and low pressures of air masses. Iraq's climate is described as a subtropical continental climate between the Mediterranean climate and the hot desert climate [28,29]. The climate of the study area is characterized by dry and winter rainfall. This affects the volume and quality of surface water flow, as water quality is affected by discharge levels depending on the climate of the region. Seasonal fluctuations in river flow have significantly affected the water characteristics of the Shatt Al-Arab River [30].

2.2. Study Stations

Five water sampling sites were selected along the Shatt Al-Arab River (from Al- Qurna in the north to Al-Fao in the south), including Al-Qurna, Al-Maqal, Abu al-Khasib, Al-Seebah, and Al-Fao from July 2023 to May 2024 Figure1. A GPS device was used to identify the coordinates (Table 1).

Table 1. Geographical coordinates of the study stations using a GPS device.

Number station	Station name	Longitude	Latitude
St.1	Al-Qurna	47° 44° 44″	31° 01° 37″
St.2	Al-Maqal	47° 77° 34″	30° 58° 30″
St.3	Abu al-Khasib	47° 98°56″	30° 46° 53″
St.4	Al-Seebah	48° 15° 05″	30° 19° 31″
St.5	Al-Fao	48° 46° 04″	29° 98° 99″

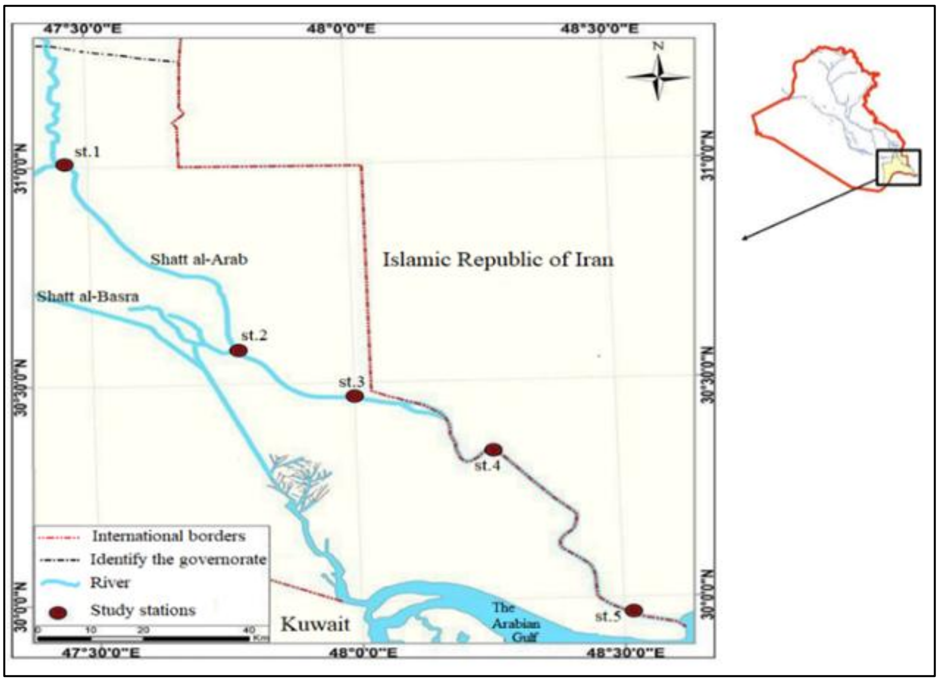

Figure 1. Map of the study stations in the SAAR.

2.3. Sampling Procedure

The Water samples were collected at each of the selected stations in the four seasons, with samples taken from the surface. The samples were collected during the lowest tide based on lunar calculations and using an application called high tide (tides and weather) to schedule tides in the Shatt Al-Arab River. Water samples were collected in 3 L surface-layer plastic bottles. The plastic bottles were sanitized and rinsed again with water collected from the sampling sites, and the water samples were collected and sealed tightly with appropriate marks while avoiding ventilation during sampling. The samples were then carefully transferred to the laboratory and kept in a cooling box for physical and chemical analyses.

Physical and chemical parameters, including water temperature (WT), potential of hydrogen (pH), and electrical conductivity (EC), were measured using a factory field device water multimeter (HANA, Hl 9813-6). The weight method was followed by [31] to measure total suspended solids (TSS) by filtering a specific size of the water sample using Millipore filter paper 0.45μm the standard procedure of [31] was employed to analyze the cations and anions Total hardness (TH), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Bicarbonate (HCO_3^-), Chloride (Cl^-), Sodium (Na^+), Potassium (K^+), and Sulfate (SO_4^{2-}).

2.4. Statistical Analysis

All data were statistically analyzed using IBM SPSS v 27.0. descriptive statistics (mean ± SD) were computed for each variable. One-way ANOVA tested seasonal and spatial variations among stations at

$p \leq 0.05$. Pearsons's correlation analysis determined relationships among physicochemical parameters and climatic variables (temperature, rainfall).

3. Results and Discussion

3.1. Physicochemical Parameters of Water

The highest temperature rate during the summer was 36.4°C at Al-Fao Station, and the lowest rate during winter was 15.8°C at Al-Maqal Station Figure 3. The results of the statistical analysis of the water temperature values showed that there were significant differences between seasons and stations at a significance level of $p \leq 0.05$. Water temperature changes depending on the season, geographical location, and extent of river pollution from the effluents of power plants and others. Water warming during winter may be caused by rising water levels and lower solar radiation, but in summer, it is higher due to lower water levels and increased solar radiation [32,33]. Spatial differences in water temperature are due, among other factors, to the time of sample collection, water movement, the impact of depth, tidal movement, the speed of water runoff and its impact on solar radiation (clear atmosphere or clouds), geographical location, and the nature of human activities close to the study stations [18].

Electrical conductivity (EC) refers to the ability of water to conduct electricity, as well as the presence of solvents and mineral acids in water [34]. Statistical analysis showed that there were significant differences in electrical conductivity values between seasons and stations $p \leq 0.05$. Figure 4 shows that the EC rates near the downstream increased with the impact of the Arabian Gulf water mixing with freshwater masses in the waters of the Shatt Al-Arab River, gradually decreasing northward to the lowest values at the Al-Qurna station, as the Shatt Al-Arab water in the north of Basra is affected by water flowing from the Tigris River with low salt concentration. This led to a significant increase in summer electrical conductivity values, particularly in Al-Fao (St.5), compared to other stations close to marine water sources. Higher evaporation rates, lower discharge from the Tigris River and lower rainfall rates and urban runoff, agricultural and industrial wastewater in Basra governorate also contribute to this increase [35]. During spring, electrical conductivity values increased for most stations due to the increased solubility of salts and minerals in water, increased rainfall, dissolved substances drained into rivers, biological activity of organisms, and other environmental impacts, which may affect sample collection and the concentration of dissolved substances in the river. Similar trends of elevated EC in summer due to reduced river inflow and marine intrusion were reported for Shatt Al-Arab River by [30,18].

Total dissolved solids (TDS) are an important characteristic of natural water, defined as the total concentration of organic and inorganic substances in water that can be in ionic or non-ionic forms, including mostly inorganic constituents of sodium ions, potassium, calcium, magnesium, and chloride [36]. TDS originates from natural sources, such as the release of certain ions from rock minerals, through the flow of water above them and seawater and the dissolution of soil minerals, sediment, and ions, or from human activities such as household and industrial waste as well as agricultural runoff [37, 38]. The distribution and spread of aquatic biology and determination of the size of the biological community depend on the salt concentration in the water body. The results of the study showed that there were clear changes during the four seasons, as rates in the northern and central locations were in approximately the same range, and the highest rates were recorded at 20,058 mg/L for surface water during the spring season at Al-Fao station and the lowest at 997 mg/L at Al-Qurna station during the summer season. Salinity was high in Al-Fao in all seasons except autumn, with the lowest rate recorded at 4604 mg/L in surface water. The lowest salinity rate was recorded at the Al-Qurna site during summer, reaching 997 mg/L in the surface water. The results also showed that Al-Qurna was characterized by a noticeable decrease in salinity levels compared to other sites studied and across all seasons of the year. Statistical analysis showed that there were significant differences in TDS values between the seasons and stations ($p \leq 0.05$).

The rise in salinity levels during the summer season is attributed to a group of environmental and climatic factors, most notably the effects of climate change, the increase in heat waves, and extreme climate, which lead to higher evaporation rates as a result of rising temperatures, as well as a decrease in the discharge of water from the Tigris and Euphrates Rivers(Figure 2). The penetration of the salt front coming from the Arabian Gulf also contributes to the increasing consumption of Shatt Al-Arab River water for human and industrial uses, such as injecting oil wells with large quantities of water, which exacerbates salt concentrations in Shatt Al-Arab water [39, 40]. The noticeable decrease in water salinity at the Al-Qurna station, which continues across all seasons, may be attributed to the direct effect of the Tigris River water, which has a low salt concentration and contributes to reducing water salinity in the northern parts of Shatt Al-Arab River.

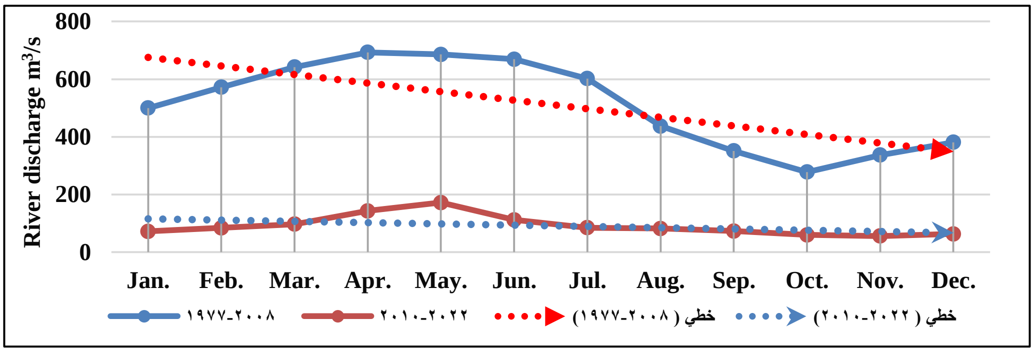

Figure 2. Change in discharge into the Shatt Al-Arab River (MOWR).

pH is an important factor that directly affects the water ecosystem because each organism lives within a certain pH range in the water environment [20]. The pH values ranged from 7.3 to 8.8 during the spring and summer, respectively (Figure 6). Statistical analysis revealed significant differences in pH values between seasons ($p \leq 0.05$). There were no significant differences between the stations with the $p > 0.05$ error probability value. The pH values of all stations trended toward the baseline and ranged from 7.3 to 8.9, a feature of the Shatt Al-Arab River water as a result of the geology of the area characterized by its high carbonate ion and bicarbonate content. The elevated pH during the summer was due to high temperatures, evaporation, low water levels, and seawater intrusion from the Arabian Gulf [18]. In conjunction with the shortage of river flow in the Shatt Al-Arab River Figure 2, the relative decrease in pH values at the Al-Seebah station is due to the high organic content of water as a result of human and agricultural activities on both sides of the Shatt al-Arab and the mixing of wastewater with river water [2,41]. The decrease in pH rates during spring is due to an increase in carbon dioxide concentrations as a result of an increase in the amount of organic material from degraded plants, causing values below normal pH levels [42].

Chloride ions (Cl^-) are widespread in all surface waters and are found in multiple forms, including sodium and potassium ions. Chloride ion values freshwater range from about 10-20 mg/L, and in marine waters, they are approximately 19,000 mg/L [43]. Chloride ions are essential for all organisms to maintain osmotic pressure and are vital to human health and nutrition [44].

Figure 7 shows the values of chloride ions in the surface water of the study stations, with the highest rate of 21,836 mg/L at Al-Fao station during the summer and the lowest rate of 383 mg/L at Al-Qurna station during the spring.

The results of the study showed an increase in chloride ion values during the summer season for surface water with the impact of marine water filling the southern riverbed of Shatt Al-Arab River, particularly at Al-Fao station during the drought months and seasonal discharge shortages[43]The entry of 1% of seawater may raise the freshwater chloride content to 190 mg/L and may cause soil to leak into rivers in agricultural areas on chloride values, as water flows through the soil layer containing chloride, leading to the dissolution of salt deposits and other sediments into river water. The closure of the Euphrates River from the Shatt Al-Arab River side, the low level of water discharge from the Tigris River, and the incursion of the Salt Front are causes of the high levels of chloride ions in the Shatt Al-Arab River water [45]. The reduced chloride ion concentrations at the Al-Qurna station can be explained during the four seasons beyond the source of marine water and stabilize the quality of the water mass coming from the Tigris River. The lower rates of chloride ions in surface water during autumn may be due to the impact of nearby stations on the Karun River water coming from the Iranian territory, which is sometimes opened, as its freshwater mitigates salinity levels [46].

Figure 8 shows the change of Sulphates (SO_4^{2-}) in the study stations, the highest rate of 27876.5 mg/L during the summer at Al-Fao station, and the lowest value of 2307.6 mg/L during the summer at Al-Qurna station. The statistical analysis results showed seasonal and spatial moral differences at $p < 0.05$ morale level. In this study, sulfate ion rates showed variability during the seasons and between the selected stations, with the highest rates recorded during the summer at the Al-Fao station. The significant rise during the summer can be attributed to the mixing of marine waters from the Arabian Gulf in conjunction with the lack of river discharge of Shatt Al-Arab River and the high evaporation rates of surface water due to high temperatures in the summer. This is consistent with the results of several previous studies [47]. The reason why sulfate ion concentrations differ during seasons and between plants can be traced, inter alia, to increased fossil fuel burning resulting from increased sulfur-rich industrial activities that are subject to complex chemical reactions that lead to oxidation (SO_3); thus, the formation of sulfuric acid (H_2SO_4), which is the main component of sulfate in the atmosphere and thus increases sulfate concentrations in the aquatic environment [48, 49].

[50] noted that increasing sulfate ions in the atmosphere as a result of increased human activities are soluble in water and may affect water quality and the availability of toxic nutrients, thus affecting biodiversity in the aquatic environment. Atmospheric chemistry and the presence of these ions in aerosols significantly affect the biogeochemical processes of water.

Figure 9 shows that the total hardness (TH) rates varied during the seasons and locations with the highest surface water rate of 5,339 mg/L at Al-Fao station during the summer and the lowest rate of 550 mg/L at Al-Qurna station. Fig 10 shows quarterly changes in calcium ion rates for the study stations; surface water recorded the highest value during spring at 331 mg/L at Al-Fao station and the lowest during autumn at 104 mg/L at Al-Qurna station. Magnesium rates in the surface waters of the Shatt Al-Arab River ranged from to 92-1243 mg/L during the summer at Al-Qurna and Al-Fao stations.

Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are natural elements present in freshwater. The presence and abundance of these elements depend on a number of different factors, including the geology of the region, the type of soil adjacent to the water surface, vegetation, seasonal changes such as precipitation, and increased evaporation and runoff rates. These elements are the major ions that cause the total hardness [51]. The Shatt Al-Arab River water was classified by [52] as high-hardship water (hardship > 300), and calcium concentrations may be as high as 25 mg/L. The results showed an increase in total hardness rates and calcium and magnesium ions, and the highest rates were recorded at Al-Fao station (St.5) during most seasons, particularly in the summer. This may be due to the significant impact of the southern section of the Shatt Al-Arab River on water coming from the Arabian Gulf during the movement of the tide, the incursion of the salt tongue and other factors, including high temperatures and increased evaporation rates, resulting in a decrease in water levels and accumulation of these ions, In addition to the low water releases received by the Shatt Al-Arab River from the Tigris River [53,54, 55].

[56] stated that the levels of total hardness and calcium and magnesium ions may rise at some stations during winter as a result of increased human activities, domestic wastewater supply, and industrial activities such as power plants. The low levels of both the total hardship and the ions causing them at the Al-Qurna station during the study period may be explained by a number of factors, including the type of soil surrounding this area and the nutritious water. water from the Tigris River, which contains low concentrations of mineral salts. Depth of 4 m [57, 54].

The results of the study show that magnesium ion rates are higher than those of calcium ion Figure 11. This indicates that this element is enriched in river water and that magnesium hardship increases more than calcium hardship during summer when salt concentrations increase. This is consistent with several previous studies [18, 20, 56].

Sodium ion ($Na^{+)}$ values along the Shatt Al-Arab riverbed with the highest surface water value during the summer of 3425.3 mg/L at Al-Fao station and the lowest value of 146.9 mg/L at Al-Qurna station during the spring (Figure 12).

Potassium ion (K^+) rates, as shown in Fig 13, rose to a maximum of 199.3 mg/L at Al-Fao station during the summer, while the lowest rates were recorded at 6.64 mg/L at Al-Qurna station during the spring of surface water. Statistical analysis of sodium and magnesium ions showed that there were significant differences between seasons and all study stations at $p \leq 0.05$.
The results of the current study showed that the rates of sodium ions (Na^+) and Potassium (K^+) recorded the highest values during the summer for surface water with a higher rise at Al-Fao station, to begin with a decrease with moderate temperatures reaching the lowest in the spring at Qurna station, and recorded a strong positive correlation between sodium ions and potassium (r = 0.970; $p \leq 0.01$), and the abundance and presence of sodium ions exceeded that of potassium ions during the study. [58] showed that potassium ions exist in a lower proportion of sodium ions, and sodium ion solubility is higher than that of potassium ions in aquatic environments.
The highest rate of bicarbonate (HCO_3^-) during summer was 348.92 mg/L, and the lowest value during winter was 102.48 mg/L Fig 14.
The results of the statistical analysis revealed a positive and strong correlation between the concentration of HCO3- ions and water temperature (r = 0.665; $p \leq 0.01$), electrical conductivity (r = 0.310; $p \leq 0.01$), and CO_2 (r = 0.510). [59] The high bicarbonate rate indicates that there is no or no carbonate ion concentration High water bases are also associated with the presence of bicarbonate ion during the dry season, as HCO_3^- values are affected by salt ion concentrations, river water flow rates and increased evaporation rates and that the marked rise in spring indicates river water pollution, Contamination persists even after rainfall, i.e. the river is unable to mitigate pollutants, especially in locations near which power plants produce untreated discharge water and contain high amounts of bicarbonate ions [60]. It has been added to agricultural discharge sites, contributing to an increased concentration of carbon dioxide and the release of bicarbonate from the sediment to the water column [61,62].
[63] noted that the withdrawal of carbon dioxide from bicarbonate ions for use in photosynthesis by aquatic plants leads to higher total basal values in the water body. Lower bicarbonate levels during winter can be attributed to lower temperatures, lower evaporation rates, higher aquatic expenses, degradation of bicarbonate ions into carbon, or free carbon dioxide absorption by aquatic biota, including plants for use in photosynthesis or the result of degradation of organic matter at some stations that reduce pH values [64]. The results of the current study showed that bicarbonate rates are high compared to natural water values of 20-200 mg/L [31]. The rise in bicarbonate is caused by the rise in pH values and their baseline direction in the waters of the Shatt Al-Arab River [59].
Figure 15 shows seasonal changes in free carbon dioxide (FCO_2) rates for all study stations, with the highest rate of 1.1 mg/L during spring, while the lowest rate was 0.16 mg/L in winter for surface water. Free carbon dioxide concentrations dissolved in water rose during the spring and summer seasons at the central and southern stations of Shatt Al-Arab River. This may be due to the high temperatures resulting in increased oxidation of compounds or organic and inorganic materials and accelerated respiratory activities of organisms [65]. The statistical analysis results showed a strong positive correlation (r = 0.567; $p \leq 0.01$)) between the free carbon dioxide concentrations and temperatures. Free CO_2 rates were also associated with pH values, with a reverse correlation (r = -0.252; $p \leq 0.05$). [66] noted that there is an inverse relationship between free dioxide and pH because FCO_2 causes higher concentrations of bicarbonate ions and hydrogen, and lower concentrations of carbonate ions and hydroxyl (OH).
Lower rates of FCO_2 in autumn and winter, particularly at the Al-Qurnah station north of the Shatt Al-Arab River, may be attributable to lower temperatures, increased water expenditure, and rapid runoff, reducing pollution and the vital potential of plants, algae, and biodegradation processes [55, 66,67,68].

Table 2. Morale level of water quality variables for the current study year 2023-2024.

Dependent Variable	Source	Corrected Model	Intercept	Stations	Seasons
WT	F	32.75 **	21076.29 **	15.66 **	387 **
pH	F	2.45 *	37538.28 **	1.53 N.S	13.60 **
EC	F	44.27 **	1253.89 **	282.38 **	39.47 **
TDS	F	95.71**	3217.19**	593.533**	66.39 **
Cl^-	F	18.69 **	243.14 **	123.84 **	14.28 **
Ca^{2+}	F	7.86 **	2932.31 **	52.08 **	5.87 **
Mg^{2+}	F	141.01 **	4152.03 **	1221.52 **	13.64 **
TH	F	142.84**	5164.71**	1242.28**	13.82**
HCO_3^-	F	7.21 **	2216.69 **	1.99 N.S	66.26 **
SO_4^{2-}	F	243085.25**	2908398.17**	411032.39**	815512.24**
CO_2	F	2.35 **	328.39 **	0.94 N.S	15.87 **
Na^+	F	92.66**	1631.90**	459.26**	29.15**
K^+	F	**26.89	**218.56	**115.47	**11.38

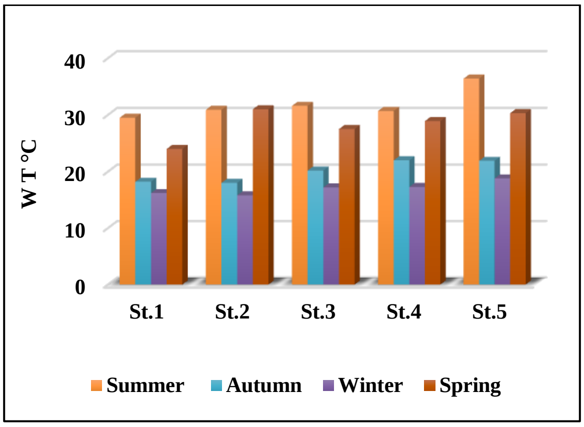

Figure 3. Water Temperature °C.

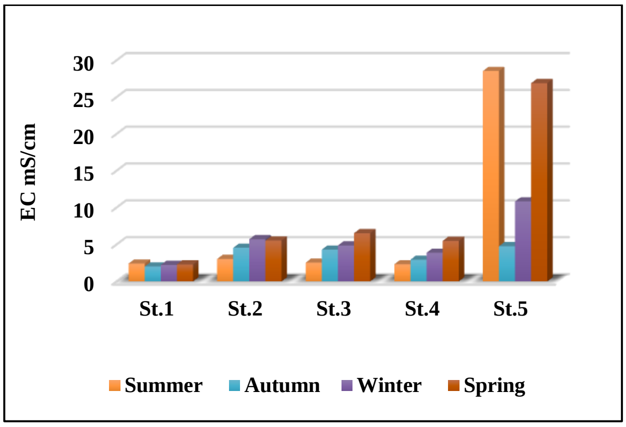

Figure 4. Electrical conductivity mS/cm.

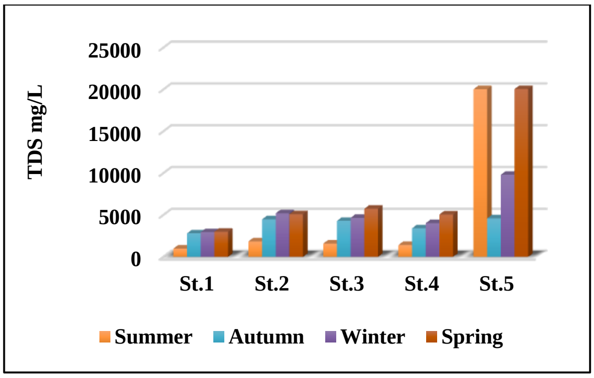

Figure 5. Total dissolved solids mg/L.

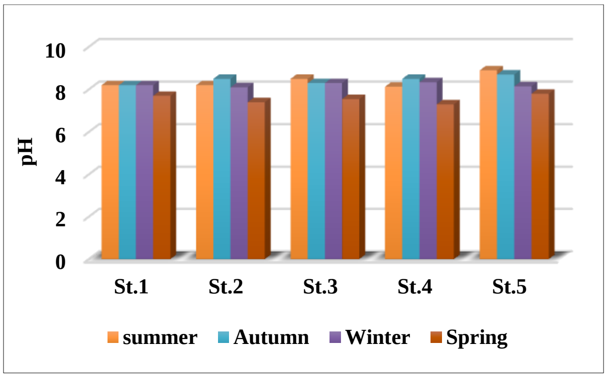

Figure 6. Potential of Hydrogen.

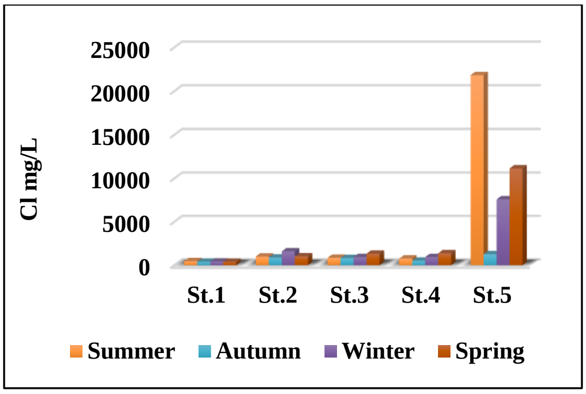

Figure 7. Chloride ion mg/L.

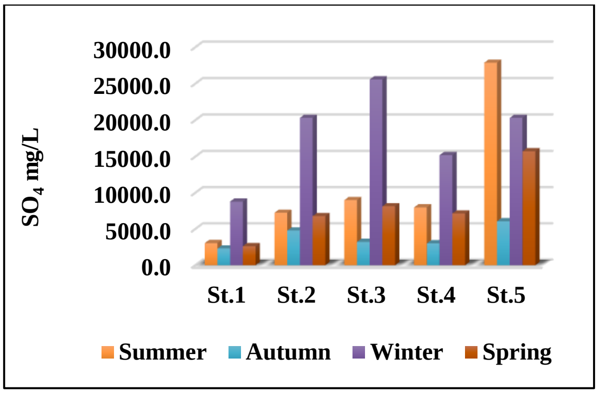

Figure 8. Sulphates ion mg/L.

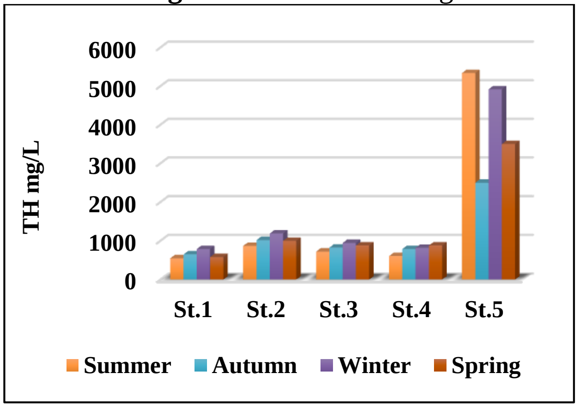

Figure 9. Total Hardness mg/L.

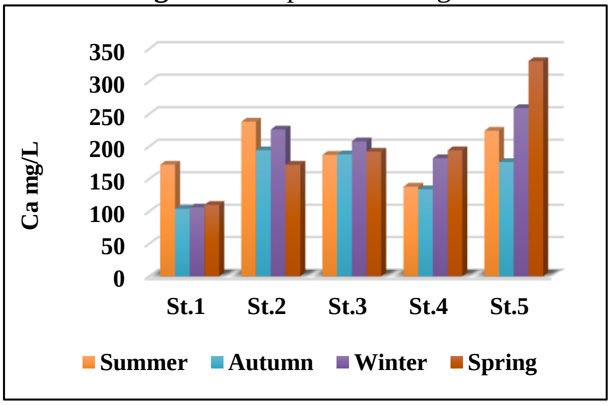

Figure 10. Calcium ion mg/L.

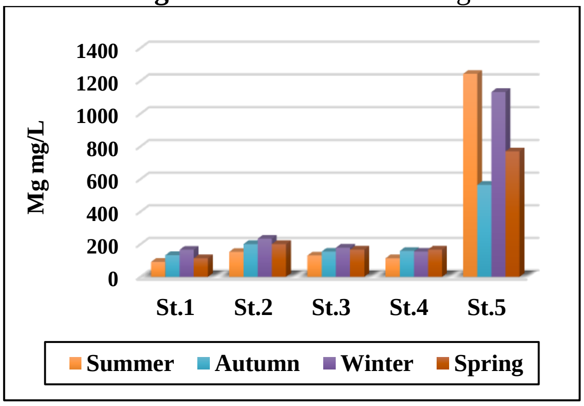

Figure 11. Magnesium ion mg/L.

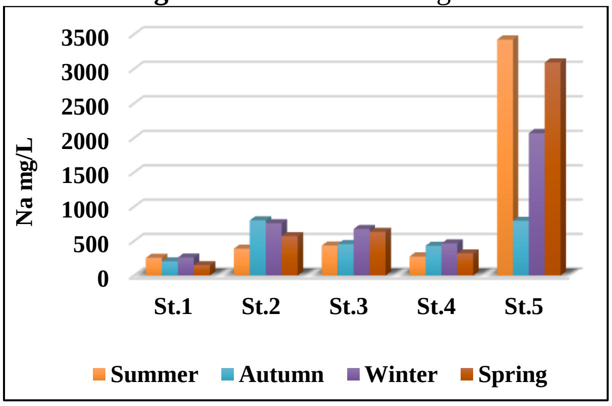

Figure 12. Sodium ion mg/L.

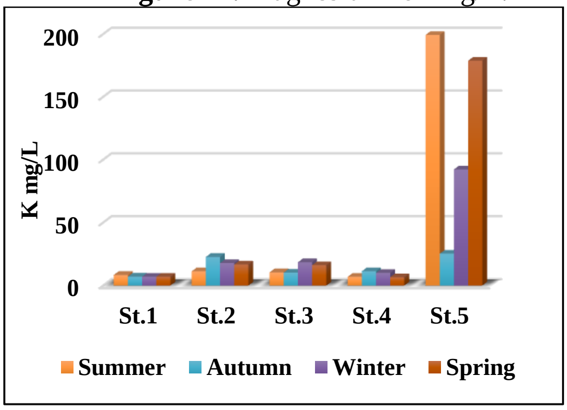

Figure 13. Potassium ion mg/L.

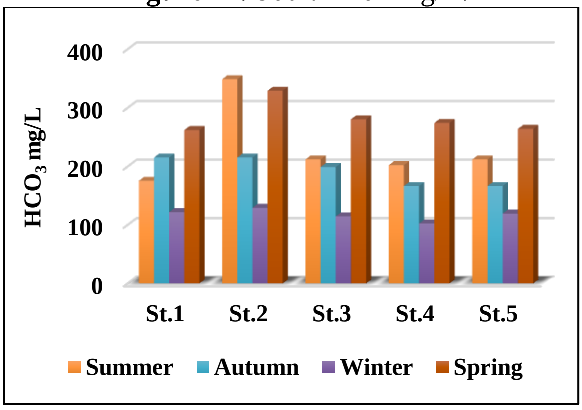

Figure 14. Bicarbonate ion mg/L.

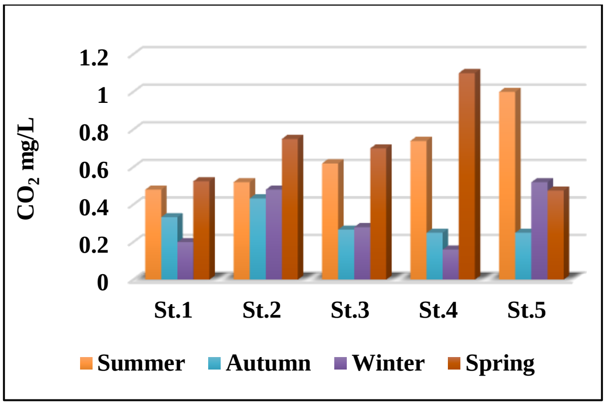

Figure 15. Free Carbon Dioxide mg/L.

Conclusions

The study suggests that both climate changes including increased temperatures, lower rainfall, and intensified evaporation and anthropogenic activities like as dam construction, industrial discharge, and freshwater depletion have simultaneously impaired the water quality of the Shatt Al-Arab River. These stresses have made salinity, ionic imbalance, and seawater intrusion worse, especially in the southern parts near Al-Fao. This threatens the health of the ecosystem and the ability to use the water. To protect the river's long-term health for southern Iraq, we need to take immediate steps to manage and adapt to these climate and human effects.

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