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# Analysis of Spatio-temporal variations in water quality of middle section of Shatt Al-Arab River, southern Iraq

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**Abstract**
The current study aimed to use various multivariate statistical techniques (principal component analysis and cluster analysis) to evaluate Spatio-temporal changes in water quality in the middle section of the Shatt Al-Arab River and identify the most serious problems and their sources. Five stations (Abu-Flous, Mhela, Baradeyea, Maqal, and Mohammadiyat) were chosen along the axis of the middle section of the Shatt Al-Arab River, and one station (Karmat Ali) on the Karmat Ali canal for monthly analysis of 19 water quality variables from December 2020 to November 2021. The principal component analysis reveals that five principal components account for 85.694% of the total variations in the original data. Four major sources were identified as being responsible for changes in water quality over time in the middle section 1- Minerals and dissolved salts 2- organic pollution and nutrient water content (from point and non-point sources of pollutants) 3- natural factors and climatic characteristics of the region 4- The transparency of the water. Cluster analysis classified the study stations into three groups based on their degree of similarity and source of pollution. According to the findings, the middle section of the Shatt Al-Arab River can be divided into three sub-sections (Southern, middle and northern). This sub-division aids in the selection of suitable monitoring stations for the middle section of the Shatt Al-Arab River. Overall, the multivariate statistical techniques used in this study were an excellent tool for analysing and interpreting complex data sets, identifying pollution sources, and understanding Spatio-temporal variations in water quality for effective water quality management.

**Key word:** Shatt Al-Arab River, Water quality, principal component analysis, Cluster analysis.

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## Introduction

Shatt Al-Arab River waters are exposed to a significant rise in the concentrations of dissolved salts, which coincides with climatic changes and the recurrence of years of drought in the region, and the lack of rain. In addition to the intensity of demand and storage in Turkey, Syria, Iran, central and northern Iraq, and the interruption of most of the tributaries that used to supply the Shatt Al-Arab with water, causing severe salt surges, part of which comes from the upper course of the river from the southern part of the Tigris and Euphrates rivers, whose salinity has increased in recent decades, and what it adds the densely populated areas are in the center of the city (Moyel et al., 2023). The Arabian Gulf is another source of the Shatt Al-Arab salts. It is expected that sea salt incursion will increase in the future due to a lack of fresh water supplied to the Shatt Al-Arab River (Al-Asadi, 2022).

Furthermore, the Shatt Al-Arab River is subject to severe pollution as a result of dense populations on both banks of the river, as well as the predominance of industrial installations, electric power stations, ports, entertainment areas, and tourists on both sides of the river. These substances leave large amounts of pollutant untreated in the majority of the river (Al-Aboody et al., 2018). As a result of its significance, the study of the quality of Shatt Al-Arab water and its suitability for various uses drew the attention of freshwater researchers more than others (Moyel and Hussain, 2015; Adlan and Al-Abbawy 2022, and Jassim and Al-Amiri, 2023).

The middle section of the Shatt Al-Arab River is more polluted than the other sections because it is surrounded by a dense population and human activities on both river banks, and the water quality changes due to many interferences, the most dangerous of which are the various pollutants discharged from densely populated areas in the city center, and the arrival of the salt tide from the Arabian Gulf during the years. The latter, which began to affect the change of water properties, particularly during the summer, and the flowing water from various industrial installations, electric power stations, and shipyards have a negative impact on the river environment in that region (Moyel et al., 2023).

Application of different multivariate statistical techniques such as principal component analysis and cluster analysis has increased in recent years for analysing environmental data and drawing meaningful information, as well as, helps in the interpretation of complex data to better understand the quality of water and ecological status of the studied aquatic ecosystems (Shihab and Abdul Baqi 2010, Zumlot and Batayneh 2012; Shrestha and Muangthong, 2014). It also allows for the identification of possible factors/sources that influence water systems and offers a valuable tool for the reliable management of water resources, both quantity and quality (Alexakis 2011; Zumlot and Batayneh 2012). As a result, the current study aimed to use some multivariate statistical techniques (principal component analysis and cluster analysis) to analyse Spatio-temporal changes in the water quality of the middle section of the Shatt Al-Arab River, identify the most serious problems it faces, and identify its sources, due to the river's importance to the Basrah population and the economic, cultural, environmental, and recreational activities of the region.

## Materials and methods

### Study area

The Shatt Al-Arab River is a tidal river and originates from the convergence of the two major Iraqi rivers Tigris and Euphrates at Qurna town, north of 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 Qurna is about 330 meters, about 400 meters in the middle section, and the width at the estuary is about 1250 meters (Al-Asadi, 2016 and Moyel, 2023).

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 subjected to Semi-diurnal tide type, which are 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 Basrah province and closing the Karkheh River, which was feeding the Shatt Al-Suwaib River East and turning the Karoon River into the Bahminsher River a canal within Iranian territory. The Shatt Al-Arab River became 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 (Table 1, Figure 1).

**Field sampling and analytical procedures**

Water samples were collected monthly at six monitoring stations from December 2021 to November 2022, with the first five stations located in the middle of the Shatt Al-Arab River and the sixth station located along the course of the Garmat Ali canal (Figure 1 and Table 1). The stabilization and storage of samples, as well as their transportation to the laboratory, were carried out in accordance with the guidelines of standard methods (APHA, 2005). The samples were collected (in sterile and cleaned polyethylene bottles of 1 L capacity) at least 30 cm below the surface water in the middle of the river channel. Water samples were filtered using Sartorius filter paper (0.45 µm) to determine the concentrations of major ions and nutrients ($NO_3$ and $PO_4$).

Water temperature (WT), electrical conductivity (EC), and pH were all measured *in situ* using portable EC meters Model 3110 (WTW company) and portable pH meters Model 3110 (WTW company), respectively. Sens Direct turbidity (Lovibond Company) meter was used to measure the turbidity. The gravimetric method was used to measure the concentrations of total dissolved solids (TDS) and total suspension solids (TSS). The Azid-modified Winkler method was used to determine dissolved oxygen (DO). The samples for biochemical oxygen demand ($BOD_5$) determinations were incubated at 20°C for 5 days before the remaining DO were determined using the Azid-modified Winkler method. Chemical oxygen demand (COD) was measured spectrophotometricaly with a photo Lab (S6) instrument. EDTA titration was used to determine the concentrations of total hardness (TH), calcium ($Ca^{+2}$), and magnesium ($Mg^{+2}$). Sodium ($Na^+$) and potassium ($K^+$) ion concentrations were determined using flame photometry, while chloride ($Cl^-$) concentration was determined using silver nitrate titration. Titration was used to determine the concentration of sulphate ($SO_4^{-2}$). The cadmium reduction method was used to determine nitrate ($NO_3$) concentration, and the molybdate ascorbic acid method was used to determine orthophosphate ($PO_4$) concentration.

The number of fecal coliform (FC) was determined by membrane filtration using an MFC agar base at 44.5°C.

All variables were measured using the methods described in (APHA, 2005), except for sulphate variable, which were measured using the methods described in Bartram and Ballance (1996).

**Table 1.** GPS of 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" |

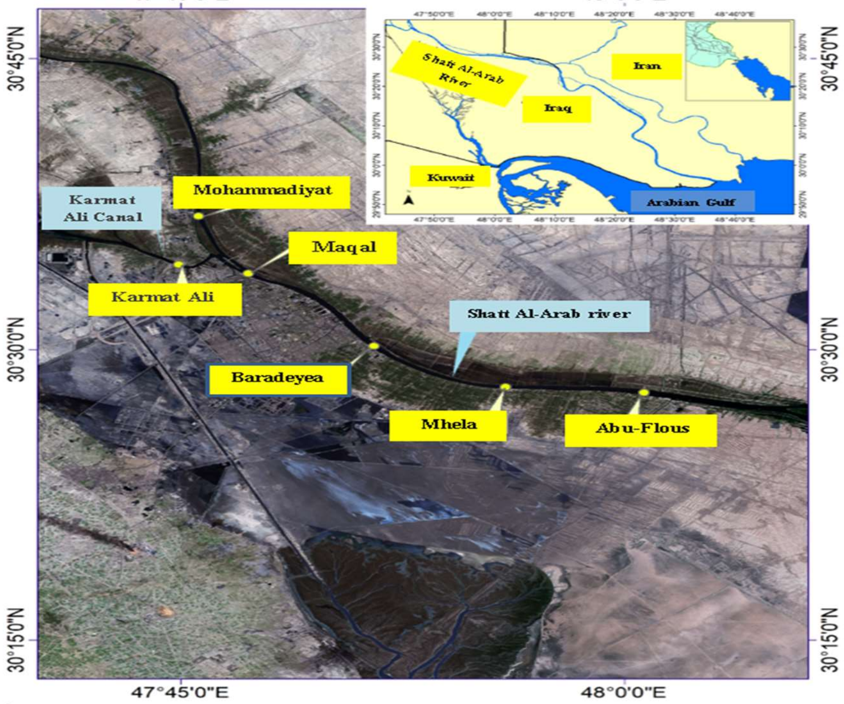

**Figure 1.** Map for the study area showing the sampling stations

## Multivariate Statistical Technique (MST)

### Principal component analysis (PCA)

PCA was used to obtain the best interpretation of the water quality data. In order to obtain more reliable results, the Kaiser-Meyer-Olkin scale (KMO) was used to determine the adequacy of the data for PCA (Abuzaid and Jahin, 2022).

KMO is a metric that compares the size of observed correlation coefficients to the size of partial correlation coefficients for various variables. A number close to 1 for KMO indicates that there are enough data for PCA analysis (0.8 and above is significant, 0.7 is acceptable, 0.6 is median, and less than 0.5 is not acceptable).

As a result, in order for the PCA analysis results to be more acceptable, a relatively high value of KMO must be obtained in order to be more reliable in the analysis results (Zhou et al., 2007). The KMO test was performed on the current study's data, and a high value (0.803) was recorded, indicating its adequacy for the PCA. To obtain the greatest variation within the axes, the Varimax Rotation method was used in conjunction with the Kaiser Criterion. To complete the PCA calculations, the original data were converted to standardization (Z-scale) data, which reduced the effect of variable value variation and eliminated the need for different units (Fan et al., 2010).

## Cluster analysis (CA)

The Hierarchical Agglomerative Cluster Analysis (HAC) method was adopted to calculate the amount of similarity between the different study stations using Ward's method after converting the original data into standard (Z-scale) data (Ukpatu et al., 2015). XLSTAT Software v. 2018 was used in the PCA and CA calculation, as well as the box plots for all variables.

## Results and discussion

### Principal component analysis

The PCA is one of the most important methods of multivariate statistics, which aims to interpret the correlation coefficients that have positive statistical significance between the various variables, or it is a mathematical process aimed at simplifying the correlations between the various variables included in the analysis, down to the common factors that describe the relationship between these variables and their interpretation (Vega et al., 1998). The importance of analysing the PCA in water resources management of has emerged due to its ability to diagnose the variables or factors that lead to the deterioration of water quality, and thus the possibility of accurately identifying their sources and working on them to improve water quality (Finkler et al., 2016; Abuzaid and Jahin, 2022)

Figure (2) and Table (2) show the eigenvalue for each principal component, which enabled us to determine the number of acceptable principal components for describing and interpreting the original data structure involved in the statistical analysis process. It extracted five principal components that have eigenvalues greater or equal to 1 (Eigenvalue ≥1) that explain 85.694% of the total variance of the original data. Table (2) and Figures (3-a), (3-b), (3-c), and (3-d) factor loading show the five principal components of the nineteen variables.

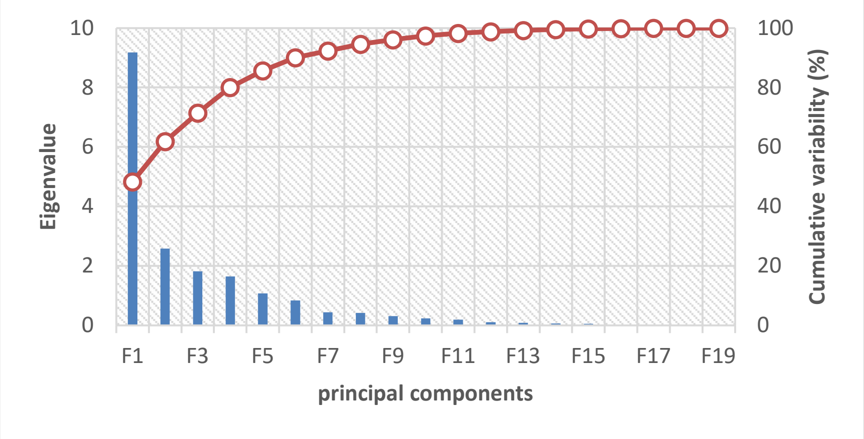

Figure (2) Eigenvalues for the principal components

The first principal component (PC1) contributed 38.564% of the total variance of the data, It included, with large positive loadings (0.914), (0.914), (0.891), (0.713), (0.812), (0.937), (0.924) and (0.933) the variables that indicate the mineral and salt content of water EC, TDS, and TH, Ca, Mg, Na, K, and Cl, respectively (Table, 2) and (Figure, 3). According to the findings, the water salinity factor had the greatest impact on the water quality of the Shatt Al-Arab River in the study area. The water coming with salty tidal currents is the most important source of salts in the Shatt Al-Arab River, especially when the discharge of fresh water from the Tigris River is reduced. The return water from draining agricultural land, as well as the disposal of untreated domestic and industrial waste, contributes to the increase in dissolved salts (Lafta, 2022).

The second principal component (PC2) explained 17.675% of the total variance, related to a group of variables that recorded positive loads (0.894) and (0.697) represented by the variables WT and $SO_4$, and negative loads (-0.720) and (-0.811) represented by the variables pH and DO, respectively (Table, 2) and (Figure, 3). These variables clearly represent the impact of natural factors such as climatic changes, which was evident through seasonal changes in temperature, as well as the impact of human pollution sources and the natural interaction processes of different water components on the water quality of the studied stations (Shrestha and Kazama, 2007).

The third principal component (PC3) explained 11.785% of the total variance, as it was closely associated with total suspended solids (TSS) and turbidity (Turb.), which recorded significant positive loading values (0.973) and (0.963), respectively (Table, 2) and (Figure, 3). This component represents the effect of suspended load and turbidity on the water quality of the studied stations, as the presence of suspended matter and turbidity in the river water depends on the presence of inorganic solids such as clay particles, sand and silt resulting from weathering and sculpting of soil and rocks in the riverbed, as well as the presence of naturally occurring organic materials in the riverbed as organic crumbs, microorganisms and algae, or entering the riverbed through the excretion of various pollutants.

The fourth principal component (PC4) explained 11.764% of the total variance, which was associated with positive loadings (0.576), (0.619), (0.799), and (0.773) for the $BOD_5$, COD, $NO_3$, and FC variants, respectively (Table, 2) and (Figure, 3). This component was clearly associated with organic pollution such as biodegradable organic pollutants represented by $BOD_5$, which come from natural sources usually as a result of the decomposition of the bodies of dead organisms, or through human pollution with sewage water containing large numbers of fecal coliform bacteria as well. That component of biodegradable and non-biodegradable total organic pollutants, represented by COD that comes from a variety of natural and human sources particularly pollutants derived from industrial waste. This component also explains the relationship of nitrates with organic pollutants, which are a major source of them in aquatic environments, as the oxidation of nitrogenous organic compounds results in the release of large amounts of nitrates in the event of organic pollution containing these compounds (Moyel, 2014).

While the fifth principal component (PC5) explained 5.906% of the total variance related to orthophosphate ($PO_4$), which had a high positive loading value (0.942) in that component (Table, 2) and (Figure, 3). This component was associated with phosphate plant nutrients that enter river water from a variety of sources, including natural weathering processes of rocks and soils containing these compounds, as well as various pollutants that enter the river course, particularly domestic and industrial wastewater and wastewater containing high levels of detergents, as well as water used to drain agricultural lands fertilised with phosphate fertilisers.

Through the results of the principal components analysis, four factors responsible for water quality changes in the study area can be identified 1- dissolved salts and minerals 2- organic pollution and water content of nutrients (from point and non-point sources of pollutants) 3- natural factors and climatic characteristics of the region 4- Water transparency.

Table 2. The principal components After Varimax Rotation

| | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| **WT** | 0.322 | **0.894** | -0.033 | -0.084 | 0.052 |
| **pH** | 0.21 | **-0.72** | 0.032 | -0.252 | -0.073 |
| **EC** | **0.914** | 0.316 | 0.139 | 0.079 | 0.049 |
| **TDS** | **0.914** | 0.315 | 0.143 | 0.076 | 0.046 |
| **TSS** | 0.137 | -0.036 | **0.973** | 0.001 | -0.015 |
| **Turbidity** | 0.199 | -0.008 | **0.963** | 0.029 | 0.004 |
| **DO** | -0.345 | **-0.811** | 0.134 | -0.123 | -0.03 |
| **BOD$_5$** | 0.565 | 0.439 | -0.097 | **0.576** | -0.22 |
| **COD** | 0.422 | 0.324 | -0.187 | **0.619** | -0.188 |
| **NO$_3$** | 0.073 | 0.066 | -0.112 | **0.799** | 0.343 |
| **PO$_4$** | 0.098 | 0.127 | -0.006 | 0.103 | **0.942** |
| **FC** | 0.197 | 0.023 | 0.33 | **0.773** | -0.002 |
| **TH** | **0.891** | -0.007 | 0.135 | 0.205 | -0.004 |
| **Ca** | **0.713** | -0.237 | -0.02 | 0.232 | 0.01 |
| **Mg** | **0.812** | 0.455 | 0.137 | -0.024 | 0.098 |
| **Na** | **0.937** | 0.189 | 0.087 | 0.163 | 0.031 |
| **K** | **0.924** | 0.258 | 0.085 | 0.089 | 0.023 |
| **Cl** | **0.933** | 0.11 | 0.136 | 0.181 | 0.029 |
| **SO$_4$** | 0.466 | **0.697** | 0.262 | 0.112 | 0.088 |
| **Eigenvalue** | **9.181** | **2.574** | **1.81** | **1.643** | **1.074** |
| **Variability (%)** | **38.564** | **17.675** | **11.785** | **11.764** | **5.906** |
| **Cumulative %** | **38.564** | **56.239** | **68.024** | **79.788** | **85.694** |

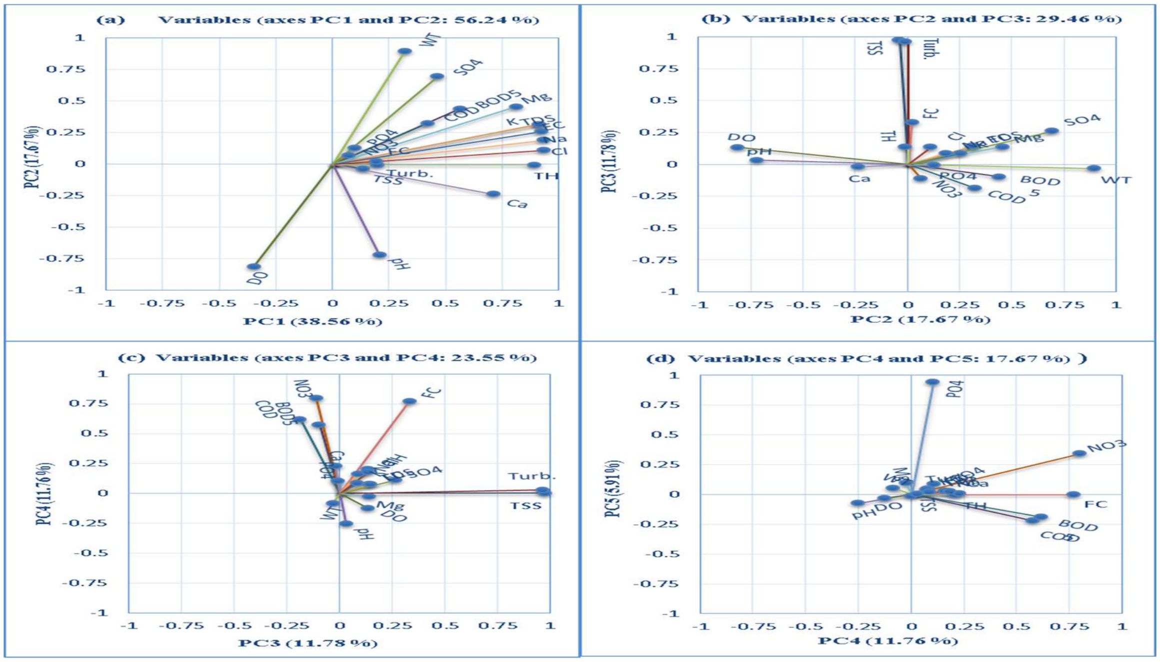

**Figure 3.** Component loadings for the (a) with PC1 and PC2, and (b) with PC2 and PC3, and (c) with PC3 and PC4, and (d) with PC4 and PC5 after varimax rotation.

## Cluster Analysis

Cluster analysis has been widely used in data analysis for environmental research and studies, as this method divides monitoring stations into separate groups based on specific levels of similarities and differences, or in other words, the cluster analysis technique classifies the studied stations or sites within groups of each group. It has distinct characteristics that set it apart from the stations or sites in other groups (Shrestha and Muangthong, 2014; Xiao et al., 2016). Cluster analysis was used to reveal the spatial differences in water quality between the stations of the current study by looking at the similarities and differences in their chemical, physical and biological properties. In general, the results of the cluster analysis classified the six study stations into three groups; each group includes stations with a common relative similarity in quality (Figure, 4). The first group (CA1) included the Abu-Flous and Mhela stations, as both stations recorded high concentrations of dissolved salts compared to the rest of the stations (Figure, 5). The proximity of the two stations, as well as their location in the lower course of the river in the south, made them vulnerable to the salty water mass coming from the Arabian Gulf, as well as the increased impact of sewage waste draining the river and water from agricultural lands containing high concentrations of dissolved salts. These findings were consistent with many studies on the waters of the Shatt Al-Arab, which indicated an increase in the concentration of dissolved salts in the waters of the Shatt Al-Arab as we moved south (Hameed et al., 2013 and Lafta, 2021).

The second group (CA2) was unique to Baradeyea station, which showed a different pattern of variance in most of the measured variables, particularly those indicating organic pollution and bacterial content, when compared to the other stations (Figure, 5). The reason for this can be attributed to the station's location, which is surrounded by various sources of pollutants that present various types of pollutants, particularly domestic waste water and sewage water from residential areas, markets, restaurants, and ship and boat berths, as well as waste from Al-Sadr Teaching Hospital, which contributes to the rise in pollution. Pollutants, particularly organic pollutants and fecal coliform bacteria, and these findings are consistent with the findings of Al-Ankush (2013) and Moyel et al., (2023) that this station is more affected by pollutants loaded with waste and sewage than other stations.

The third group (CA3) included the Maqal, Mohammadiyat, and Karmat Ali stations, which appear to have relatively better water quality than the other stations (Figure, 5). This can be explained by its being far from densely populated areas, which means it receives fewer quantities from stations located downstream. It is also worth noting that the concentrations of dissolved salts in the water at these stations are low in comparison to other stations (Figure, 5). The relative difference between the Mohammadiyat station and the Maqal and Karmat Ali stations may explain why it is relatively better in terms of quality due to its location upstream of the river, which receives the least number of pollutants, as well as the spread of a number of aquatic plant species on both banks of the river in that station that works to improve water quality.

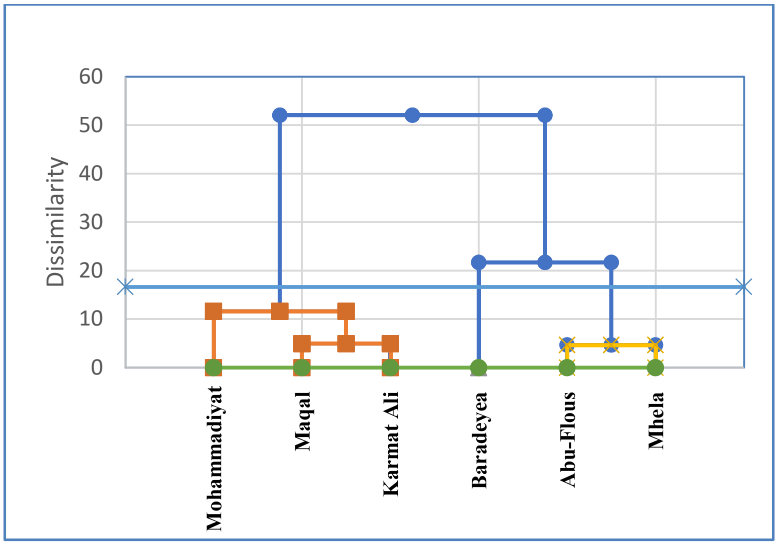

**Figure 4.** Dendrogram obtained by agglomerative hierarchal clustering analysis for sampling stations

## Conclusions

Water quality monitoring programmes generate multidimensional data that must be statistically processed using multivariate statistical techniques in order to be analysed, interpreted, and converted into useful information. The current study used principal component analysis and cluster analysis to assess the Spatio-temporal changes in the water quality of the Shatt al-Arab River's middle section. The principal components analysis gave an accurate diagnosis of the main sources responsible for the Spatio-temporal changes in the water quality of the study area, as the sources of these changes cannot be easily discovered in percentages without using such a statistical technique. This clearly indicates the importance of using principal component analysis in water quality management. The results of the principal components analysis revealed four major factors responsible for Spatio-temporal changes in the water quality of the study area: 1- Minerals and dissolved salts 2- organic pollution and nutrient water content (from point and non-point sources of pollutants) 3- natural factors and climatic characteristics of the region 4- The transparency of the water. The cluster analysis divided the six study stations into three groups based on the degree of similarity in water characteristics and pollution sources. Based on these findings, the middle section of the Shatt Al-Arab River can be divided into three sections (southern, central, and northern) based on their qualitative characteristics. This division can help with the process of reducing the number of stations and selecting ideal monitoring station sites that are sufficient to monitor and evaluate the study area with minimal effort and cost. Finally, the middle section of the Shatt Al-Arab River suffers from pollution and continuous deterioration in water quality. Additionally, the river lacks an administrative monitor for changes in water criteria, and the river requires efficient monitoring to track the rapid changes in the Shatt Al-Arab's environment.

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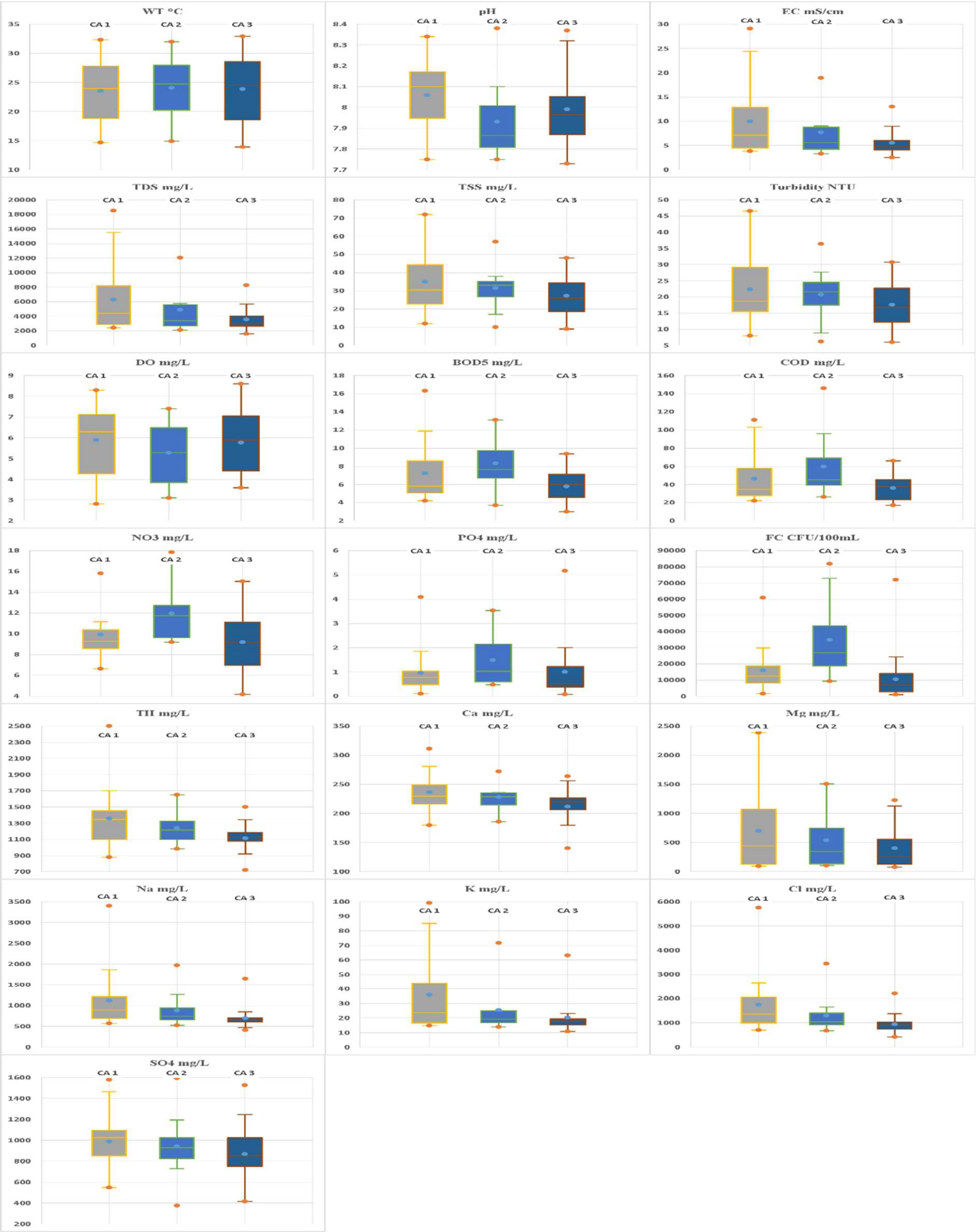

**Figure 5.** Box plots represent spatial variation of the water quality variables between clusters in the study area.

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# تحليل التغيرات الزمنية والمكانية في نوعية مياه المجرى الأوسط من شط العرب، جنوبي العراق.

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## الملخص

هدفت الدراسة الحالية إلى استخدام تقنيات الإحصاء المتعدد المتغيرات (تحليل المكونات الأساس والتحليل العنقودي) لتقييم التغيرات المكانية والزمانية في نوعية مياه المجرى الأوسط من شط العرب، وتحديد اهم العوامل المؤثرة على نوعية مياه المنطقة المدروسة وتحديد مصادرها. اختيرت خمس محطات لجمع العينات المائية (أبو فلوس ومحيلة والبراضعية والمعقل والمحمديات) واقعة على المجرى الأوسط من شط العرب، ومحطة واحدة (كرمة علي) واقعة على مجرى قناة كرمة علي، إذ جمعت العينات لمراقبة تسعة عشر متغيرًا من متغيرات نوعية المياه على أساس شهري خلال الفترة الممتدة من ديسمبر 2020 إلى نوفمبر 2021. أظهرت نتائج تحليل المكونات الأساس أن خمساً من المكونات الأساس كانت مسؤولة عن 85.694% من إجمالي التباين الكلي للبيانات الأصلية. كما حددت أربعة مصادر رئيسة مسؤولة عن التغيرات في نوعية مياه المنطقة المدروسة وهي: 1- المعادن والأملاح الذائبة، 2- التلوث العضوي ومحتوى المياه من المغذيات (من مصادر التلوث النقطية وغير النقطية)، 3- العوامل الطبيعية والخصائص المناخية للمنطقة، 4- شفافية المياه. صنف التحليل العنقودي محطات الدراسة إلى ثلاث مجموعات بناءً على درجة التشابه ومصادر التلوث. وبحسب النتائج، يمكن تقسيم المجرى الأوسط من شط العرب إلى ثلاث مناطق فرعية (الجنوبية والوسطى والشمالية). يُسهم هذا التصنيف في اختيار محطات مراقبة مناسبة لهذا المجرى. بشكل عام، كانت التقنيات الإحصائية متعددة المتغيرات المستخدمة في الدراسة الحالية أداة ممتازة لتحليل وتفسير مجموعات البيانات المعقدة، وتحديد مصادر التلوث، وفهم التغيرات المكانية والزمانية لنوعية المياه، مما يدعم الإدارة الفعالة لنوعية المياه.