Mesopotamia Environmental Journal (MEJ)
2014, Vol.1, No.1:39-46.

Assessment of water quality of the Shatt Al-Arab River, using multivariate statistical technique

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To cite this article:

Moyel, S. Assessment of water quality of the Shatt Al-Arab River, using multivariate statistical technique. *Mesopotamia Environment Journal,* 2014, Vol. 1, No. 1, pp. 39-46.

Abstract

This paper presents the results of statistical analysis of a set of physico-chemical water quality parameters, monthly collected from December 2012 to November 2013 at seven sampling stations spread over the Shatt Al-Arab River. Seventeen parameters were treated using Multivariate statistical technique; principal component analysis (PCA) and cluster analysis (CA) were applied for the evaluation and interpretation of a water quality data set for the Shatt Al-Arab River. The results of PCA identified four latent factors, which are responsible for the data structure explaining 78.64% of the total variance of the dataset these factors are: Water mineralization, Seasonal effect of temperature and organic pollution, Nutrients content and water visibility. CA showed four different groups of similarity between the sampling stations reflecting the different physicochemical characteristics features and natural background sources types. This study suggests that PCA and CA techniques are useful tools for identification of important surface water quality monitoring stations and parameters.

Keywords; water quality assessment, multivariate statistical technique, Shatt Al-Arab River, Iraq.

Introduction

Shatt Al-Arab River is one of the most important main rivers in Iraq, because of its economic and social values. It is the main source of surface water in Basrah governorate. Water of Shatt Al-Arab has been used for various purposes including potable water supply, irrigation, fisheries, navigation, and industrial uses [1]. Moreover, Shatt Al-Arab River is the conjunction link of freshwater from Iraq into the Arabian Gulf. This river has been subjected to several pollution activities, mostly from domestic waste discharge, industrial waste and agricultural and as put this waste directly into the river without any handle them and this waste be loaded mostly pollutants may pose serious health and can adversely affect the use beneficial to the river [2]. Because rivers constitute the main inland water resource for domestic, industrial and irrigation purposes, it is imperative to prevent and control river pollution and to have reliable information on the quality of river water. In view of the spatial and temporal variations in the hydrochemistry of rivers, regular monitoring programmes are required for reliable estimates of the water quality [3]. The quality of water is identified by its physical, chemical and biological properties. The particulate problem in case of water quality monitoring is the complexity associated with analysis of a large number of measured variables [4]. The data sets contain rich information about the behavior of the water body. The classification, modeling and interpretations of monitoring data are the most important steps in the assessment of water quality. The application of different multivariate approaches, such as principal component analysis (PCA) and cluster analysis (CA) for the interpretation of these complex data matrices offers a better understanding of water quality and ecological status of the studied systems. It also allows the identification of possible factors/sources that influence water system and offer a valuable tool for the reliable management of water resources as well as rapid solutions to pollution problems [5, 6]. In the present paper, the data matrix obtained during one year monitoring program at seven different stations spread over the Shatt Al-Arab River, subjected to different multivariate statistical approaches in order to extract information about the similarities or dissimilarities among monitoring stations, and to determine the influence of possible sources (natural and anthropogenic) on the physico-chemical variables of the Shatt Al- Arab River.

Materials and Methods

Study area and sampling sites

The confluence of the Tigris and Euphrates rivers at the town of Qurna, north of Basra city forms the Shatt Al- Arab River, which flows to the south west to the Arabian Gulf. The Shatt Al-Arab River has a length of 200 km, a width range between 400 m at Basra and up to more than 2 km at the estuary and a depth of between 8-15 m, considering tides [7]. The hydrological condition of the Shatt Al-Arab River basin is affected by several factors including conditions at the upper reaches of the Tigris and Euphrates rivers, the status of advancing flood tides from the Arabian Gulf, seepage of saline ground water into the basin, as well as the impact of climate conditions prevailing in the region on discharge rates and the payload of the river [8]. The discharge of moderately saline water from the East Hammar marsh and limited precipitation exacerbates water quality and the hydrology of the region [9]. Seven sampling stations were established along the river course in order to obtain a good knowledge to detect spatial similarity for grouping sampling stations located within the monitoring area, and determine the factors or sources responsible for water quality variations in quality of the river (Table1, Fig.1).

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Table 1.*Sampling locations and coordinates of sampling stations at Shatt Al-Arab River*

Station number	Station name	Longitude	Latitude
St. 1	**Garma**	47° 45 32. 39	30° 37 29.85
St. 2	**Maqal**	47° 47 15.01	30° 33 59.12
St. 3	**Ashar**	47° 51 29.10	30° 30 12.43
St. 4	**Mohela**	47° 55 34.73	30° 28 .5.53
St. 5	**Abuflouse**	48° 11 16.94	30° 27 37.77
St. 6	**Seba**	48° 16 36.48	30° 19 52.41
St. 7	**Fao**	48° 27 52.75	29° 59 23.73

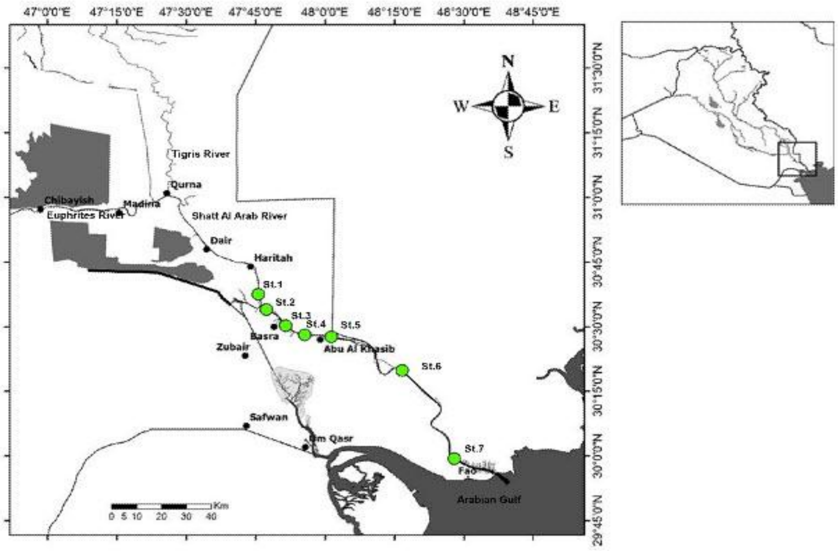

Figure. 1.*Map of Shatt Al-Arab River showing the seven sampling stations*

Field Sampling and procedures

Monthly water samples were collected from selected seven stations in Shatt Al-Arab River from December 2012 to November 2013. Water samples collected for analysis of nutrient, major ions were filtered using Millipore filter paper (0.45µm) and preserved and analyzed according to the standard methods described in [10]. Water physical and chemical parameters including water temperature (WT), electrical conductivity (EC), salinity and pH were measured *insitu* using the WTW Multi-meter model 4430. Turbidity was determined *insitu* by WTW turbidity-meter type Terb 550. Dissolved oxygen (DO) and Biochemical oxygen demand (BOD_5) were determined by the Winkler azide method. Alkalinity was determined by acid titration using methyl-orange as endpoint. Calcium (Ca^{+2}) and magnesium (Mg^{+2}) concentrations were measured by ethylene- diamine tetra acetic acid (EDTA) complexometricy titration. Sodium (Na^{+}) and potassium (K^{+}) concentrations were measured by flame photometry and chloride (Cl^{-}) concentration by silver nitrate ($AgNO_3$) titration using potassium chromate (K_2CrO_4) solution as an indicator. Sulphate (SO_4^{-2}) concentration was determined specrophotometrically by barium sulphate turbidity method. Nitrite nitrogen (NO_2-N) was determined according to colorimetric method. Nitrate nitrogen (NO_3-N) and orthophosphate phosphorus (PO_4-P) concentrations were measured by ultraviolet (UV) and molybdate ascorbic acid methods, respectively. Statistical computations were executed using the statistical software package, XL STAT pro v.4. In order to minimize the influence of different variables and their respective units of measurements, each water quality parameter was standardized (z-scale) before PCA and CA analysis [11].

Results and Discussion

Principal component analysis

It is difficult to draw a clear conclusion directly because the complexity of relationships between parameters of water quality. However, PCA can explain the structure of the data in detail by extracting the latent information [11]. PCA is designed to transform the original variables (parameters in this study) in to new, uncorrelated variables (axes), called the principal components (PCs), which are linear combinations of the original variables [12]. In this study, the scree plot was used to identify the number of PCs to be retained in order to comprehend the underlying data structure [3, 5]. According to eigenvalue-one criterion [13], only four PCs (with eigenvalue >1) were considered which explaining 78.64% of the total variance in the water quality datasets, the rest PCs were eliminated (Table 2; Fig. 3, 4). In order to make easier interpretation for the PCA results, the first four PCs were rotated according to varimax method with Kaiser Normalization [14]. Results of the PCs from the Varimax rotations are displayed in Table 2 and Fig. 3, 4. The first rotated component (PC_1) which explains 32.80% of total variance in the datasets and has strong positive loading on EC, salinity, Cl^-, Mg^{+2}, K^+, SO_4^{-2} and Na^+, respectively, whereas, it has moderate positive loading on Ca^{+2} (Table 2) (Table 2; Fig. 3). This component can be related to mineral component of the river water. The parameters on this component indicate fluctuation and reduction in water flow and increase in soluble salts from Arabian Gulf [2, 15]. The PC_2 explained 21.41% of total variance in datasets and consists of a strong positive loading of WT, alkalinity and BOD_5, while strong and moderate negative loading with DO and pH respectively (Table 2). This component was mainly associated with the seasonal effect of temperature and anthropogenic pollution sources and can be explained as high levels of dissolved organic matters consumes large amount of oxygen, which results in formation of ammonia, CO_2 and organic acids leading to a decrease in water pH values (Volga *et al.*, 1998; Shrestha and Kazama, 2007). The PC_3 explained 14.85% of the total variance and was positively and largely contributed by inorganic nutrients-related parameters (NO_3-N, NO_2-N and PO_4-P) (Table 2; Fig. 4). This component distinguishes the importance of anthropogenic inputs mainly from non-point pollution sources (such as agricultural runoff and atmospheric deposition) [6], and point pollution sources (such as domestic and industrial wastewater effluents) [16]. According to [17], high levels of both dissolved inorganic nitrogen and phosphorus in Shatt Al-Arab water, resulted from both point and non-point pollution sources. PC_4 explains 9.57% of total variance has strong positive loading on turbidity. This component can be attributed to the water visibility. In summary, four extracted factors (PCs) representing four different processes responsible for water quality variations in Shatt Al-Arab River: (1) Water mineralization, (2) Seasonal effect of temperature and organic pollution, (3) Nutrients content and (4) water visibility.

Table 2. *The principal components After Varimax Rotation*

	PC_1	PC_2	PC_3	PC_4
WT	0.006	**0.926**	-0.027	0.030
pH	-0.045	**-0.691**	-0.452	0.104
Salinity	**0.934**	0.168	-0.125	0.091
EC	**0.941**	0.142	-0.132	0.076
Turbidity	0.274	-0.049	-0.149	**0.851**
DO	0.036	**-0.814**	-0.414	-0.015
BOD_5	-0.030	**0.731**	0.492	-0.024
Alkalinity	0.326	**0.818**	-0.064	-0.175
Ca^{+2}	**0.580**	-0.175	0.031	0.510
Mg^{+2}	**0.808**	-0.086	0.053	0.270
Na^+	**0.784**	0.008	-0.097	0.471
K^+	**0.803**	0.298	-0.107	0.249
Cl^-	**0.816**	0.030	-0.138	0.001
SO_4^{-2}	**0.796**	-0.076	-0.044	0.029
NO_3-N	-0.264	-0.051	**0.804**	0.158
NO_2-N	0.031	0.376	**0.723**	-0.185
PO_4-P	-0.149	0.334	**0.796**	-0.228
Eigenvalue	5.576	3.641	2.525	1.628
Variability (%)	32.798	21.416	14.853	9.574
Cumulative %	32.798	54.215	69.068	78.642

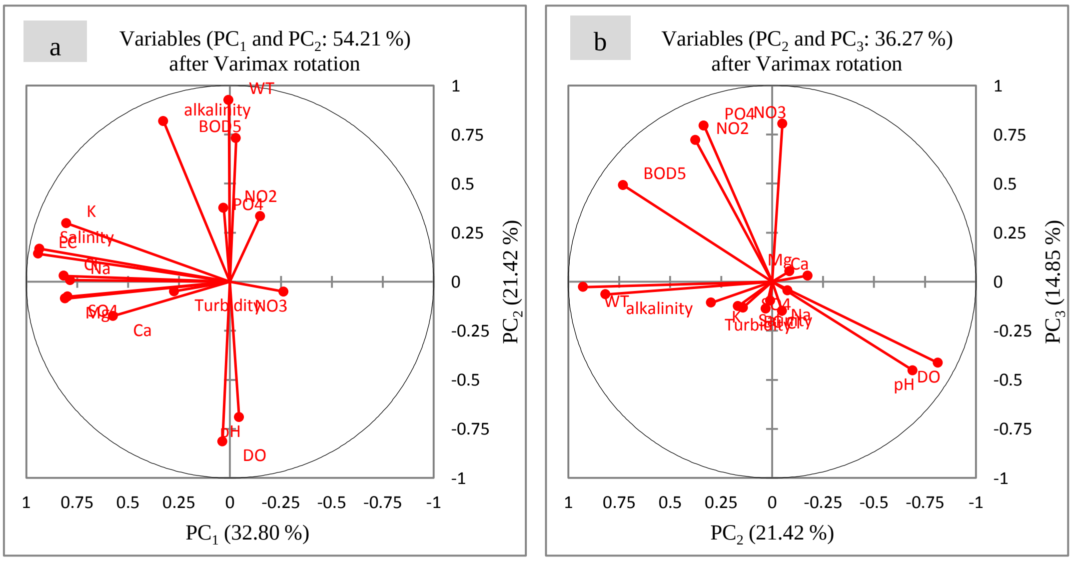

Figure 3. *Component loadings for the (a) with PC_1 and PC_2, and (b) with PC_2 and PC_3 after varimax rotation*

Spatial similarity and sample station grouping using cluster analysis

The purpose of cluster analysis is to identify groups or clusters of similar stations on the basis of similarities within a class and dissimilarities between different classes [18]. Hierarchical agglomerative clustering is the most common approach, which provides instinctive similarity relationships between any one sample and the entire dataset, is typically illustrated by a dendrogram (tree diagram) [19]. The dendrogram presents a picture of the groups and their proximity to one another, with a dramatic reduction in the dimensionality of the original data [20]. To detect spatial similarity among groups, CA was applied to the seven sampling stations. Hierarchical agglomerative CA was performed on the normalized data set by means of the Ward's method, using Euclidean distances as a measure of similarity. The clustering procedure generated four groups of stations in a convincing way, indicating relatively high independency for each group (Fig. 4). In the other word, the stations in these groups have similar characteristic features and natural background sources types. Cluster 1 (X1) consisted St.1 and St.2, which were located at the upper reach of the river, were population density is considerably moderate and it's characterized by a large number of farmland and orchards especially on the left bank of the river. The common feature of these stations was well oxygenated and lower soluble salts content compared to the other stations (Fig. 5). Cluster 2 (X2) consisted St. 3 and St. 4, which were located at the middle part of the River, they both represent heavily populated areas of Basra City and it is likely that high values of BOD_5 and nutrient concentrations, as well as, depletion in DO concentration with lower pH in these stations indicate water pollution resulting from, sewage effluents discharged from Basrah city, as well as industrial and agricultural activities (Fig. 5). The cluster 3 (X3), including St.5 and St.6 which located at the river downstream. The common feature of these stations was relatively higher turbidity, Na^+, Cl^- and SO_4^{-2} compared to other stations in clusters 1 and 2 (Fig. 5). The cluster 4 (X4), consisted St.7, which is located close the mouth of the river, and it is negatively affected by the high level of salty water intrusion from the Arabian Gulf (Fig. 5). The common feature of this station was high salinity, EC, major ions, alkalinity concentrations and turbidity, whereas, it was low in nutrient content compared to the other stations (Fig. 5).

In summary, hierarchical CA helped to group the seven sampling stations into four clusters of similar characteristics reflecting the different water quality characteristics and pollution (natural and anthropogenic) sources. It is evident that the CA technique is useful in offering reliable classification of surface waters throughout a whole region, and will make it possible to accurately perform spatial assessment in an optimal manner. Thus, it could be employed to design a future spatial sampling strategy in an optimal manner by reducing the number of sampling stations without losing any significance of the outcome [11].

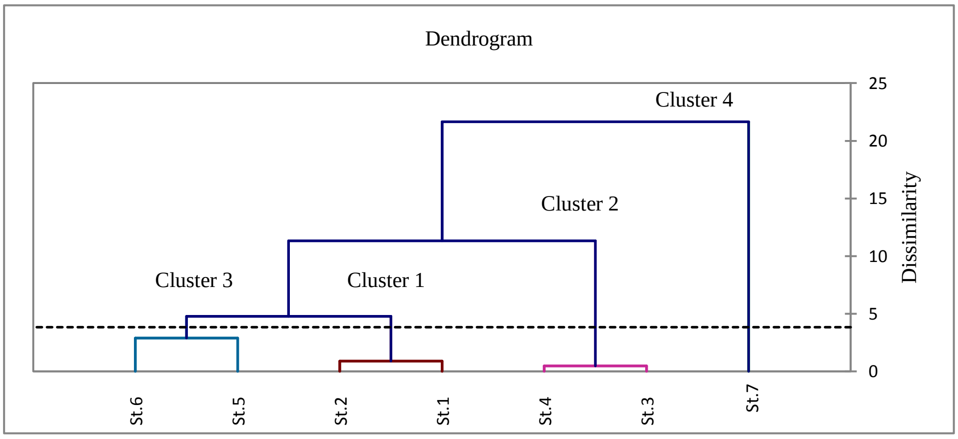

Figure 4. *Dendrogram obtained by agglomerative hierarchal clustering analysis for sampling stations*

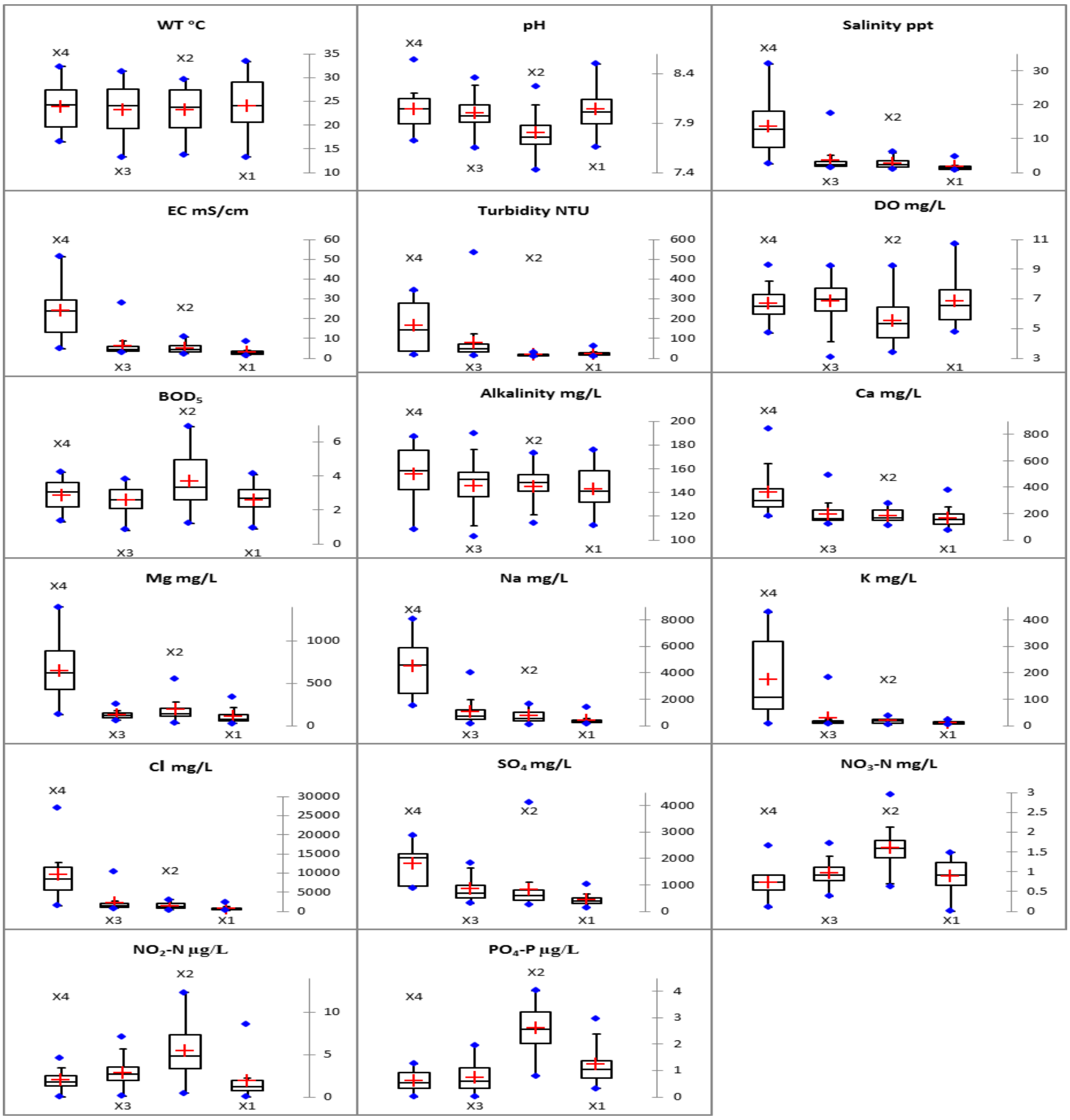

Figure 5. Box plots represent spatial variation of the water quality parameters between clusters in Shatt Al- Arab River

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