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EVALUATION OF SPATIAL AND TEMPORAL VARIATIONS OF SURFACE WATER QUALITY IN THE NILE RIVER DAMIETTA BRANCH

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Abstract: The objective of this study is to reveal the spatial and temporal variations of surface water quality in this part of the River Nile with respect to heavy metals pollution. Seventeen parameters in total were monitored at seven sites on a monthly basis from October 2013 to September 2014. The dataset was treated using the tools of univariate and multivariate statistical analyses. Cluster analysis showed three different groups of similarity between the sampling sites reflecting the variability in physicochemical characteristics and pollution levels of the study area. Six PCs factors were identified as responsible for the data structure explaining 91 % of the total variance. These were eutrophication factor (23.2 %), physicochemical factor (20.6 %), nutrients (16.3 %) and three additional factors, affected by alkalinity and heavy metals, recorded variance less than 15 % each. Also, the heavy metals pollution index (*HPI*) revealed that most of the calculated values were below the critical index limit of 100. However, two higher values (124.89 and 133.11) were calculated at sites V and VI during summer due to the temperature and increased run-off in the river system.

Keywords: Nile River, physicochemical parameters of river water, multivariate statistical techniques, heavy metals pollution index

Introduction

Rivers play an essential role in the growth of a country's economy. The benefits of streams are not limited to the supply of drinking water but also include serving other purposes such as irrigation, fishing, navigation, industry, generation of hydropower, and the waste disposal [1]. As such, the increased human riverside activities certainly impacts river water quality.

Domestic, industrial and agricultural wastes are the main sources of river water pollution [2, 3]. Also, there are different types of wastes such as motor parts, a scrap of

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cars, engines, cans types, etc. These residues are often dumped in areas where heavy metals and other components are accessible to leaching and causing an impact on environmental values. On the other hand, the natural processes as precipitation and surface runoff are a seasonal phenomenon, largely affected by several factors including, but not limited to, climate changes [4, 5] and agriculture [6]. Due to spatial and temporal variations in water characteristics, a monitoring program that can provide a representative and reliable estimation of the parameters of surface water quality is necessary. Thus, monitoring programs including regular water sampling at different sites and determination of various physicochemical parameters are usually conducted resulting in a large data matrix, which is often difficult to interpret and needs a complicated data interpretation using multivariate methods [7].

Different multivariate statistical methods such as cluster analysis (CA), principal components analysis (PCA), and factor analysis help in the interpretation of complex data matrices for characterizing and evaluating the temporal and spatial variations of surface water quality parameters caused by natural and anthropogenic factors. This allows the identification of possible factors that affect the water systems and offers a valuable tool for reliable assessment and management of water resources in order to help find reasonable solutions to pollution problems [7-10]. In recent years with urbanization and industrial development, much attention has been given to the evaluation of heavy metals pollution in different water resources by heavy metal pollution index (*HPI*) [11, 12]. *HPI* is a method that assesses the cumulative impact of heavy metals on the overall water quality [11].

The Damietta branch of Nile River extends for 220 km from the Delta barrage to the Mediterranean Sea. It is the primary source of urban and agricultural water supply to many governorates such as El-Qalubia, El-Gharbyia, El-Dakahlyia, and Damietta [13]. It receives a significant amount of land-based effluents of untreated or partially treated sewage water [14]. Considering the above facts, the present study was taken up to assess the quality status of the Damietta branch of Nile River using multivariate statistical techniques with emphasis on the following: (i) examine the similarities or dissimilarities between sampling sites and seasons, (ii) identify water quality variables responsible for spatial and temporal variations in river water quality and (iii) explore the degree of heavy metals contamination in the river using the heavy metals pollution index (*HPI*).

Materials and methods

Study area

The study area (Fig. 1) extended about 78 km in Damietta branch. The depth varied between 1 and 7.5 m, with an average of 3.5 m. The field data used in this paper were collected at seven key points on a monthly basis from October 2013 to September 2014. The site I was located at the water inlet of water planet station was slightly stressed by pollutants. Sites II and VI near the hot water outlet of thermal power generations plants. Site III near the drainage canal of inorganic fertilizer factory receiving industrial sewage. Sites IV, V, and VII near some villages receiving domestic sewage.

Physicochemical analysis

Temperature (*T*), water transparency (*WT*), pH, electrical conductivity (*EC*), total dissolved solids (*TDS*), and dissolved oxygen (*DO*) were measured in-situ using portable water quality analyzers. In the lab, the analysis of physicochemical parameters namely

nephelometric turbidity units (*NTU*), chloride (Cl^-), alkalinity (CaCO_3), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), and inorganic dissolved phosphorus (PO_4^{3-}) were done by standard methods [15]. The phytoplankton biomass (Chlorophyll-*a*) was determined according to the methods described by Wetzel and Likens [16]. Four metals (Pb, Cu, Cd, and Ni) were determined by graphite furnace atomic absorption spectrophotometry. Briefly, 300 cm^3 aliquot of the water sample is taken in a 500 cm^3 conical flask and boiled over a hot plate until the volume is reduced to 100 cm^3 . The digestion of the water samples was then achieved by the method described by APHA [15]. The analysis was performed by atomic absorption spectrometer (Agilent 240FS), and the detection limits for Pb, Cu, Cd, and Ni were 0.1-30, 0.2-60, 0.02-3, and 0.1-20 $\mu\text{g dm}^{-3}$, respectively. The instrument was calibrated with standard solutions prepared from commercially available respective standards (Chemlab-Belgium). Analytical blank was used before the estimation of every metal. The analysis was performed in duplicates, and the results were represented as averages of the duplicates [17].

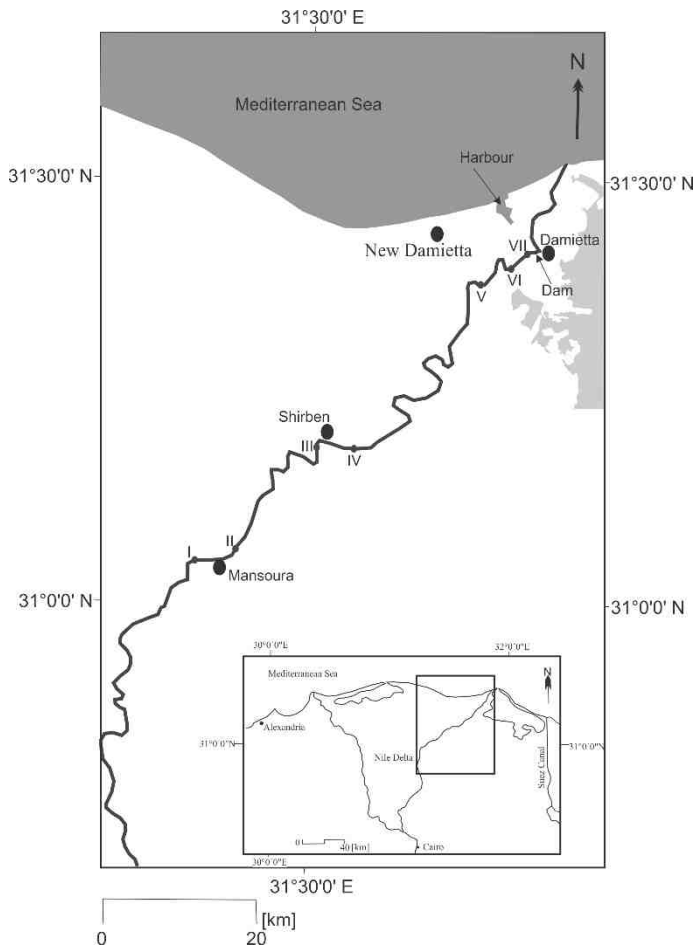


Fig. 1. Map of the study area showing the location of water sampling stations

Statistical analysis

Descriptive statistics were calculated for the monitored parameters in the water samples. The Pearson correlation coefficient was used to define the relationship between each two parameters. Multivariate analysis of variance was used (MANOVA) where the several variables were tested together spatially or temporally instead of one variable [7].

Indexing approach: Heavy metals pollution index (*HPI*) is a technique of rating that shows the aggregate influence of individual heavy metals on the total water quality. The rating is a value between zero and one, and its selection depends upon the relative importance of individual water quality considerations or it can be defined as inversely proportional to the recommended standard (S_i) for each parameter [18-20]. The calculation of *HPI* involves the following steps:

1. The calculation of weightage of i^{th} parameters.
2. The calculation of the quality rating for each of the heavy metal.
3. The summation of these sub-indices in the overall index.

The weightage of i^{th} parameter is given by

$$W_i = K/S_i$$

where W_i is the unit weightage and S_i the recommended standard for i^{th} parameter ($i = 1-4$), while k is the constant of proportionality.

Individual quality rating is given by the expression below

$$Q_i = 100 V_i/S_i$$

where Q_i is the sub-index of i^{th} parameter, V_i is the monitored value of the i^{th} parameter in [$\mu\text{g dm}^{-3}$] and S_i the standard or permissible limit for the i^{th} parameter.

The heavy metal index is then calculated as follows:

$$HPI = \frac{\sum_{i=1}^n (Q_i W_i)}{\sum_{i=1}^n W_i}$$

where Q_i is the sub-index of i^{th} parameter. W_i is the unit weightage for i^{th} parameter, n is the number of parameters considered. Generally, the critical pollution index value is 100.

All the previous analysis were performed by SPSS 18. Cluster analysis (CA) and the principal component analysis (PCA) are employed in the data set by using StatSoft Statistica 8.0 software package.

Results and discussion

General water quality

Descriptive statistics including the maximum, minimum, mean and standard deviation are summarized in Table 1. In all sampling sites, the water was slightly alkaline, the range of pH was 7.60-8.72. This pH range may indicate the presence of carbonates of calcium and magnesium in water [21]. The water transparency ranged between 30 and 545 cm with an average of 180 ± 156 cm. The observed high standard deviation around the mean may be attributed to the seasonal variations in the intensity of solar radiations penetrating the surface water [22]. In the case of total dissolved solids (*TDS*), there was a considerable amount of dissolved ions in the study area. It was in the range of 268-686 $\text{mg}\cdot\text{dm}^{-3}$ with an average of 435 ± 117 $\text{mg}\cdot\text{dm}^{-3}$. The effluents from urban, agricultural and industrialized

zones are directed into the river course which almost increases the concentrations of *TDS* in the water body [23, 24]. The conductivity (*EC*) values are sensitive to the variations of dissolved salts [25]. Throughout this study, the *EC* values ranged from 398 to 1434 $\mu\text{S}\cdot\text{cm}^{-1}$ with an average 830 $\mu\text{S}\cdot\text{cm}^{-1}$. These high values may indicate the high impact of land runoff where wastewater could increase the conductivity due to the presence of chloride, and nutrient salts [26]. Moreover, they also suggest a potential irrigation problem in Damietta branch due to salinity hazards where the *EC* values exceed on an average the level set by national guidelines [27] for agricultural use and other purposes. Chlorinity (Cl^-) concentrations ranged from 144 to 210 $\text{mg}\cdot\text{dm}^{-3}$ with an average of 163 $\text{mg}\cdot\text{dm}^{-3}$. These recorded high levels of chloride indicating that the sampling sites are receiving sewage water and industrial effluents that rich in chloride (Cl^- should be $< 50 \text{ mg}\cdot\text{dm}^{-3}$) as adopted by Ravindra and Kaushik [28]. Dissolved oxygen (*DO*) concentrations showed variable results according to site nature. The values ranged from 3.7 to 7.8 $\text{mg}\cdot\text{dm}^{-3}$ which better than the values (1.7 to 6.8 $\text{mg}\cdot\text{dm}^{-3}$) that recorded by El Shakour and Mostafa [25] in Rosetta branch. Nutrient concentrations were considerably high most of the year: nitrite (0.017 to 0.095 $\text{mg}\cdot\text{dm}^{-3}$), nitrate (0.03 to 0.20 $\text{mg}\cdot\text{dm}^{-3}$), ammonium (0.003 to 0.55 $\text{mg}\cdot\text{dm}^{-3}$), and phosphate (undetected level 0.093 $\text{mg}\cdot\text{dm}^{-3}$).

Table 1

Summary of basic descriptive statistics

Component	Units	Mean	Stand. dev.	Minimum	Maximum
Temperature	[°C]	28.0	4.7	19.0	36.3
Transparency	[cm]	180	156	30	545
pH	[-]	8.21	0.35	7.60	8.72
<i>DO</i>	[$\text{mg}\cdot\text{dm}^{-3}$]	5.90	0.78	3.68	7.83
Alkalinity (<i>ALK</i>)	[$\text{mg}\cdot\text{dm}^{-3}$]	825	183	673	1438
<i>EC</i>	[$\mu\text{S}\cdot\text{cm}^{-1}$]	830	342	398	1434
<i>TDS</i>	[$\text{mg}\cdot\text{dm}^{-3}$]	435	117	277	686
Cl^-	[$\text{mg}\cdot\text{dm}^{-3}$]	163	15	144	210
NO_2^-	[$\text{mg}\cdot\text{dm}^{-3}$]	0.04	0.02	0.02	0.10
NO_3^-	[$\text{mg}\cdot\text{dm}^{-3}$]	0.10	0.05	0.04	0.20
NH_4^+	[$\text{mg}\cdot\text{dm}^{-3}$]	0.27	0.13	0.003	0.55
PO_4^{3-}	[$\text{mg}\cdot\text{dm}^{-3}$]	0.02	0.02	0	0.09
Cu	[$\mu\text{g}\cdot\text{dm}^{-3}$]	22.5	9.8	3.2	40.4
Ni	[$\mu\text{g}\cdot\text{dm}^{-3}$]	3.2	2.8	0.08	7.7
Pb	[$\mu\text{g}\cdot\text{dm}^{-3}$]	0.76	0.84	0.08	2.86
Cd	[$\mu\text{g}\cdot\text{dm}^{-3}$]	0.10	0.06	0.01	0.23
Chlorophyll-a	[$\mu\text{g}\cdot\text{dm}^{-3}$]	11.0	4.3	3.3	19.6

According to the environmental management engineers [29], the presence of elevated levels of ammonia in water is considered indicative of freshly polluted water by discharged wastes. These high nutrient levels promoted the intensive growth of phytoplankton where chlorophyll-a values ranged between 3.2 and 19.6 $\mu\text{g}\cdot\text{dm}^{-3}$. The high chlorophyll-a concentrations indicate poor water quality and the values between 4 and 10 $\mu\text{g}\cdot\text{dm}^{-3}$ are considered as levels of eutrophication [30, 31]. The data of the water quality parameters show significant correlations between most of the parameters (Table 2). This indicates that the monitored parameters; except nickel metal which did not show a significant correlation with any parameter, may share a common origin source. For example, ammonia has significant positive correlations with phosphate, lead, and cadmium, indicating a probably

common source of organic contamination such as untreated wastewater [32, 33]. The obtained data were further analyzed by using an additional multivariate statistical technique (MANOVA) to explore temporal and spatial variations (Table 3). According to the data obtained, the seven sites and the four seasons are significantly different regarding selected water quality parameters.

Table 2

Correlation coefficient between the selected water quality parameters

	<i>T</i>	<i>WT</i>	<i>pH</i>	<i>DO</i>	<i>ALK</i>	<i>EC</i>	<i>TDS</i>	<i>Cl⁻</i>	<i>NO₂⁻</i>	<i>NO₃⁻</i>	<i>NH₄⁺</i>	<i>PO₄³⁻</i>	<i>Cu</i>	<i>Ni</i>	<i>Pb</i>	<i>Cd</i>
<i>T</i>	1															
<i>WT</i>	0.2	1														
<i>pH</i>	-0.6**	-0.1	1													
<i>DO</i>	-0.6**	-0.1	-0.5**	1												
<i>ALK</i>	0.4*	0.4*	-0.13	-0.2	1											
<i>EC</i>	0.5*	-0.8**	0.07	0.14	-0.44*	1										
<i>TDS</i>	0.5*	-0.8**	0.22	-0.2	-0.47*	0.9**	1									
<i>Cl⁻</i>	0.2	0.5*	0.2	-0.46*	-0.03	-0.3	-0.3	1								
<i>NO₂⁻</i>	-0.1	-0.01	0.3	0.1	0.24	0.01	0.1	0.1	1							
<i>NO₃⁻</i>	-0.4*	-0.14	-0.6**	-0.1	0.1	0.01	0.1	0.02	0.4*	1						
<i>NH₄⁺</i>	-0.5**	0.1	-0.4*	-0.47*	0.03	-0.2	-0.1	0.3	0.3	0.1	1					
<i>PO₄³⁻</i>	-0.4*	0.1	-0.5**	0.2	-0.017	-0.3	-0.2	0.1	0.3	0.1	0.5**	1				
<i>Cu</i>	0.2	-0.2	-0.1	-0.3	0.1	0.2	-0.2	-0.4*	0.1	0.1	0.37	0.14	1			
<i>Ni</i>	0.1	-0.2	-0.1	0.2	0.1	0.34	0.3	0.1	0.1	0.1	0.3	0.2	0.1	1		
<i>Pb</i>	0.1	-0.04	-0.5**	-0.3	-0.021	0.01	-0.1	-0.2	0.3	0.1	0.4*	0.3	0.1	0.1	1	
<i>Cd</i>	0.2	-0.1	-0.1	-0.6**	-0.1	0.2	0.2	-0.4*	0.02	-0.03	0.5**	0.2	0.25	0.06	0.2	1
<i>Chl-a</i>	0.8**	0.4*	0.6**	-0.6**	0.4*	-0.3	-0.3	-0.4*	0.2	0.2	0.6**	-0.3	0.35	0.1	0.2	0.15

** correlation is significant at the 0.01 level, * correlation is significant at the 0.05 level, *T* - temperature, *WT* - water transparency, *ALK* - alkalinity, *EC* - electric conductivity, *Chl-a* - chlorophyll-a

Table 3

Multivariate test (MANOVA) for all sites (A) and seasons (B) of Damietta branch of Nile River

(A)			
Test	Value	<i>F</i>	Sig.
Pillai's Trace	4.5	2.4	0.05
Wilks' Lambda	0.0	4	0.001
Hotelling's Trace	803	17.342	< 0.001
Roy's Largest Root	777.3	389	< 0.001
(B)			
Test	Value	<i>F</i>	Sig.
Pillai's Trace	2.8	5.9	< 0.001
Wilks' Lambda	0.0	7.7	< 0.001
Hotelling's Trace	107	11.2	< 0.001
Roy's Largest Root	89.8	45	< 0.001

Heavy metals pollution index (HPI)

The maximum values of lead (Table 4) were found at sites III and V1 in autumn (2.2 and 2.1 $\mu\text{g dm}^{-3}$ respectively), also at sites V and V1 in summer (2.26 and 2 $\mu\text{g}\cdot\text{dm}^{-3}$ respectively), the other values were low. These low amounts of lead may be attributed to the less soluble of lead-containing minerals in natural waters [34]. The high values of copper in respective seasons may indicate the direct impact of domestic and agricultural runoff. The maximum Cu was 42.3 and 41.35 $\mu\text{g}\cdot\text{dm}^{-3}$ in spring at sites VI and II

respectively. The low values of cadmium (0.01-0.23 $\mu\text{g}\cdot\text{dm}^{-3}$) indicate there is no significant source of cadmium pollutants. According to Caruso and Bishop [35], the major source of Cd is the metal industry and waste incineration, which is absent in the monitoring area. The maximum values of nickel were 7.67 $\mu\text{g}\cdot\text{dm}^{-3}$ in summer at site II and 7.30 $\mu\text{g}\cdot\text{dm}^{-3}$ in autumn and summer at two sites I and VI. Most of the dissolved heavy metals showed slightly high concentrations during summer and fall than the other seasons. This kind of pattern may be due to the high evaporation rate of surface water followed by elevated temperature [20, 22]. It was also observed that for all metals, there was a trend of increasing concentrations at site VI which severely suffering from hot water flow throughout the year.

Table 4
The values of heavy metals and the *HPI* calculation for the surface water based on the world water standard

	Pb [$\mu\text{g}\cdot\text{dm}^{-3}$]	Cu [$\mu\text{g}\cdot\text{dm}^{-3}$]	Cd [$\mu\text{g}\cdot\text{dm}^{-3}$]	Ni [$\mu\text{g}\cdot\text{dm}^{-3}$]	HPI
I-Su	0.16	16.22	0.10	0.48	8.3
I-Sp	0.08	11.48	0.12	0.39	4.8
I-W	0.08	16.22	0.03	7.0	5.5
I-A	0.40	19.38	0.07	7.30	20.5
Average	0.18	20.30	0.08	3.79	9.8
II-Su	0.08	19.80	0.09	7.67	4.7
II-Sp	0.08	41.35	0.18	0.37	5.4
II-W	0.74	17.43	0.05	1.31	34.5
II-A	1.71	27.55	0.10	1.24	87.5
Average	0.65	26.53	0.10	2.65	33.1
III-Su	0.12	19.80	0.01	5.40	6.8
III-Sp	0.53	28.08	0.12	0.08	25.3
III-W	0.36	18.04	0.10	6.10	18.7
III-A	2.21	4.49	0.12	0.17	102
Average	0.80	17.60	0.08	2.93	38.1
IV-Su	1.95	21.03	0.14	4.31	91.1
IV-Sp	0.08	25.60	0.23	6.65	7.2
IV-W	0.60	17.77	0.16	5.28	30
IV-A	1.41	37.29	0.03	4.33	65.5
Average	1.01	25.40	0.14	5.14	48.5
V-Su	2.26	30.98	0.12	4.99	125
V-Sp	0.08	25.32	0.14	5.92	6.5
V-W	0.08	18.30	0.01	0.08	3.8
V-A	0.81	40.17	0.21	2.63	39.4
Average	0.81	28.70	0.12	3.40	43.6
VI-Su	2.86	20.25	0.18	7.30	133.1
VI-Sp	0.32	42.30	0.05	6.32	16.5
VI-W	0.08	31.80	0.02	1.61	4
VI-A	2.09	37.37	0.15	1.86	97
Average	1.30	32.93	0.10	4.27	62.6
VII-Su	0.08	12.20	0.11	0.51	4.8
VII-Sp	0.08	12.68	0.17	0.31	5.3
VII-W	0.90	3.20	0.01	0.08	41.1
VIII-A	1.37	25.79	0.04	3.24	63.54
Average	0.61	13.46	0.08	1.04	28.67

To assess the degree of surface water pollution, *HPI* was calculated (Table 4) and the results with units weightage (W_i) and standard permissible (S_i) showed that the *HPI* value

considering all the seasons and locations was 36.5. This *HPI* value is less than the critical value of 100 as suggested by several authors [18, 36]. However, considering the class proposed by Edet and Offiong [37], the general water quality in regard to heavy metals in the high class ($HPI > 30$). So it can be inferred that the impact of all the considered metals on the overall quality of the water is alarming due to the increased human activities near some of the locations that can be clearly visualized while sampling.

Spatially, the *HPI* showed evident variations where its values ranged from 3.8 to 133.1. Taking into account the average *HPI* for each site, the lowest *HPI* was calculated for the site I, which is nearly far from the direct impact of human activities, while the highest was for site VI, which is close to the thermal power station. Temporally, in the summer season, the *HPI* was calculated to be 133.1 at site VI which was even higher than the critical value of 100. And during the same period, the calculated *HPI* for the sites IV and V also fall in the high class. Furthermore, high values of *HPI* were calculated at sites II and III during autumn. All of these increases are attributed to human activities.

Spatial similarity of monitoring sites (CA)

Cluster analysis was performed to find the similarity between the sampling sites. The dataset was treated (after $\log_{10}(x+1)$ transformed) by the method of complete linkage with Bray-Curtis as a measure of similarity. Three statistically significant clusters were formed (Fig. 2): cluster 1 comprised only two sampling sites (II and VI), which corresponded to the hot water outlets of thermal power stations. Cluster 2 comprised four sampling sites and subdivided into two smaller clusters, the first comprised 3 sampling sites (IV, V, and VII) where agricultural and domestic land use were predominant and the second cluster included only one sampling site (III) where urban and industrial zone was predominant. Cluster 3 was small cluster comprised only sampling site (I) which almost far from the direct impact of pollutants. The clustering technique reveals the group of a similar site in a considerable way [38]. These clusters included sampling sites with similar characteristic features and were affected by sources of similar types.

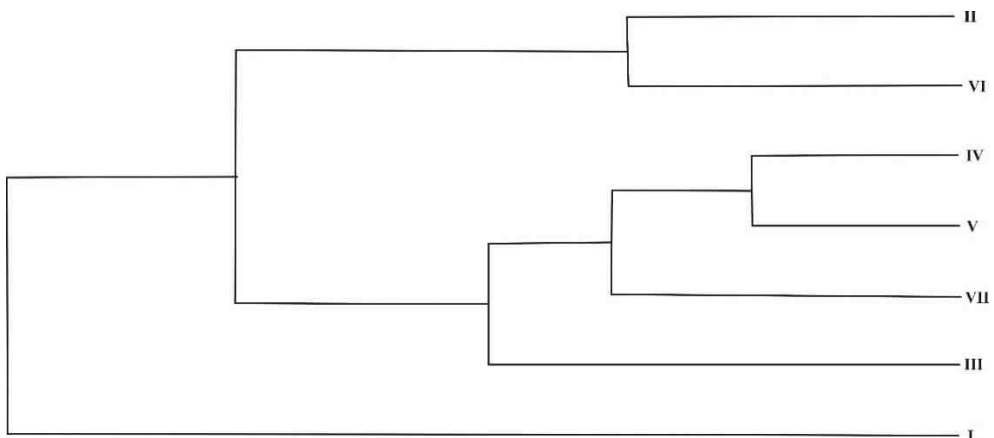


Fig. 2. Cluster analysis of spatial changes of water quality parameters on Bray-Curtis similarity

Source determination

The principal component analysis was employed on our dataset to identify the factors that influence the surface water quality. Six principal components were obtained with eigenvalues > 1 explaining about 91.03 % of the total variation. The first PC accounting for 23.2 % of the total variance was correlated with water transparency, dissolved oxygen values, phosphate concentration, and phytoplankton biomass (Table 5). This eutrophication factor may be interpreted as representing influences from domestic and agricultural effluents. The second PC was correlated with temperature, pH, conductivity, and TDS. This factor described the variability of physicochemical sources, which explains 20.6 % of the total variability. Conductivity is normally used as an indicator of natural pollutants which can be caused by soil erosion and/or weathering effects on water quality during seasonal fluctuations [39]. This component also suggests that most of the variations are due to *TDS* and conductivity. The third PC accounting for 16.29 %, was correlated mainly with water-soluble N-species, NO_2^- , NO_3^- , and NH_4^+ . This nutrient factor represented influences for agricultural and industrial runoff. The fourth PC was loaded on total alkalinity, probably represented the buffering indicator of water quality, which explains 12.58 % of the total variance. The fifth PC, accounting 10.6 % of the total variance was loaded with Pb and Cd and could be considered as representing toxic pollutants from industrial effluents. Finally, the sixth PC factor which explained only 7.76 % was correlated with Cu and Ni and represented soil leaching process and the runoff from extensively farmed areas. According to Shokr et al. [40], the concentrations of Cu and Ni in the Nile Delta soil exceeded recommended values (63 and 50 $\text{mg}\cdot\text{kg}^{-1}$ respectively) proposed by Canadian Soil Quality Guidelines [41] for agricultural and residential purposes. Flooded rice soils in the Nile Delta increase the mobility of water-soluble heavy metals [42] and thus recycling it back into the Nile river.

Table 5
Results of the principal component analysis (PCA) for water quality parameters of the study area during one year

Variables	Units	PC1	PC2	PC3	PC4	PC5	PC6
Temperature	[°C]	-0.19	0.79	-0.27	0.37	0.04	0.03
pH	[-]	0.15	0.79	0.41	0.17	0.06	0.06
Alkalinity	[$\text{mg}\cdot\text{dm}^{-3}$]	0.24	-0.22	0.16	0.75	-0.38	-0.29
Transparency	[cm]	0.75	-0.18	0.1	-0.087	-0.13	0.27
Conductivity	[$\mu\text{S}\cdot\text{cm}^{-1}$]	0.01	0.92	-0.17	-0.02	-0.1	-0.06
Cl^-	[$\text{mg}\cdot\text{dm}^{-3}$]	-0.49	0.46	-0.29	-0.11	-0.31	0.25
<i>TDS</i>	[$\text{mg}\cdot\text{dm}^{-3}$]	-0.13	0.95	-0.05	0.06	-0.04	0.02
<i>DO</i>	[$\text{mg}\cdot\text{dm}^{-3}$]	0.67	0.12	-0.21	-0.17	-0.41	-0.18
NO_2^-	[$\text{mg}\cdot\text{dm}^{-3}$]	-0.28	0.04	0.71	0.19	-0.24	0.3
NO_3^-	[$\text{mg}\cdot\text{dm}^{-3}$]	-0.34	0.11	0.64	0.14	-0.02	-0.25
NH_4^+	[$\text{mg}\cdot\text{dm}^{-3}$]	-0.15	-0.22	0.78	0.14	0.19	-0.19
PO_4^{3-}	[$\text{mg}\cdot\text{dm}^{-3}$]	0.67	-0.21	0.2	0.1	0.42	0.15
Chlorophyll-a	[$\mu\text{g}\cdot\text{dm}^{-3}$]	0.82	-0.21	-0.01	0.27	0.1	-0.2
Pb	[$\mu\text{g}\cdot\text{dm}^{-3}$]	0.37	0.02	0.09	-0.13	0.63	-0.06
Cu	[$\mu\text{g}\cdot\text{dm}^{-3}$]	0.39	0.29	-0.24	0.19	-0.08	0.54
Cd	[$\mu\text{g}\cdot\text{dm}^{-3}$]	0.44	0.31	0.39	-0.03	0.65	0.18
Ni	[$\mu\text{g}\cdot\text{dm}^{-3}$]	0.11	0.32	-0.17	0.17	0.22	0.78
Total		23.2	20.63	16.29	12.58	10.6	7.76

Conclusions

In the present study, the multivariate statistical techniques were successfully employed to evaluate the variations in water quality of the Nile River Damietta branch. Cluster analysis grouped the seven sampling sites into three clusters based on similar characters of water quality parameters and pollution sources. The principal component analysis provided meaningful information about the parameters responsible for water quality variations which are mainly related to natural conditions, pollution, and nutrients (agricultural and industrial runoffs). Also, anthropogenic activities appeared to be the main source of most elements, whereas soil leaching contributed highly to Cu and Ni concentrations. It is believed that these findings could be very useful for the local authorities to manage and control the pollution of the river water used in different human uses.

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