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Effect of Pollution and Seasonal Variability on The Water Quality in Different Sites of The River Nile, Aswan, Egypt

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SURFACE water quality and the seasonal dynamics of the Nile River in the Aswan district were analyzed using multivariate data analysis and overall pollution index (OPI) analysis. Water samples were collected from four sampling sites, including a reference site (site 1) and three sites receiving effluents from different pollution sources, e.g., domestic-like pollutants (site 2), industrial (site 3), and agricultural effluents (site 4). Different water quality parameters, such as physicochemical characteristics and nutrient minerals, were analyzed in the selected sites.

The average OPI values were calculated by classifying the surface water quality of each siteas follows:at site 1 (1.65: excellent), site 2 (2.70:acceptable), site 3 (11.75:polluted), and site 4 (5.08:slightly polluted). In each site, the OPI values varied seasonally within the range of water quality class, except, in autumn at site 4, the OPI value was 10.00, and hence the water quality class was changed to (polluted).

Generally, it was concluded that the industrial effluents had an adverse effect on the surface water quality of the Nile River, Aswan. Consequently, special concerns should be assumed to maintain environmental sustainability.

Keywords: Aswan, Nile River, Overall pollution index, Principal component analysis, Seasonal dynamics, Water quality.

Introduction

The term water quality is defined as the suitability of water for various uses or processes. The water quality is also expressed in terms of the state and concentration of the organic and inorganic nutrients present in the water, with certain physical and chemical characteristics of the water (Mapfumo et al., 2002).

Efforts to improve or maintain a certain water quality often compromise between the quality and quantity demands of different users. Water quality is affected by various natural and human influences (Raphael et al., 2018). The level of water quality depends on the measured physical, biological, and chemical parameters besides the purposes of water used, such as drinking water, water used in agriculture, or water used in industry (Sargaonkar & Deshpande, 2003).

The water quality of the Nile River is influenced by the agricultural, industrial, and touristic activity along the banks of the river (Ali & Soltan, 1996; Ali et al., 2011). It has been steadily deteriorating over several decades due to dumping untreated effluent sand anthropogenic inputs (Goher et al., 2014; Abdel-Satar et al., 2017).

Water quality cannot be stated as a single parameter. Rather, it is a combination of parameters that must be interpreted and assessed to determine

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the conditions that promote or degrade water quality. The important physical and chemical parameters influencing the aquatic environment are temperatures, rainfall, pH, salinity, and dissolved oxygen (Toufeek & Korium, 2009). Others include total suspended and dissolved solids, total alkalinity, and heavy metal pollutants. These parameters are the limiting factors for the survival of aquatic organisms (flora and fauna). Industrial effluents, municipal wastes, and low water flow could imitate poor water quality (Chitmana & Traichaiyaporn, 2010).

Monitoring and assessing the physio-chemical attributes provide and describe the chemical pollution of any aquatic system. Studying the biological communities reflects the integration of environmental effects of all water quality attributes, i.e., water chemistry and the system's physical and geo-morphological characteristics (Stevenson & Pan, 1999).

In this study, different water quality parameters, such as physico-chemical characteristics and nutrient minerals, were analyzed at different sites in the Nile River, As wan district, during different seasons. One site is subjected to non-polluted conditions, where others are subjected to domestic-like, industrial, and agricultural pollution. Also, comparative analyses were manipulated to study the effect of different types of pollution and seasonal variability on water quality. Then, the water quality status adjudicated by calculation of overall pollution index (OPI) was assessed for each site during different seasons.

Materials and Methods

Study area and sampling regime

Water samples (triplicates) were collected from four sites in the Nile River, Aswan district. The descriptions and locations of the sites are depicted in Table 1, Fig. 1. The samples were seasonally collected.

General physico-chemical analysis of water

Field measurements

Water temperature, pH, flow rate, transparency, conductivity, total dissolved salts, and dissolved oxygen (DO) were immediately measured in the field.

Water temperature: (expressed as ºC) was measured using a glass mercurial thermometer calibrated to tens of a degree centigrade.

A pH: pH meter A-1 Electro (EG) was used for measuring pH values.

The flow rate was determined using a wood rod of 1m length. The rod was laid on the surface of the water and left to move freely with the current for 1min. The distance was measured, and the flow rate was calculated after Slingsby & Cook (1986) (Equation 1):

Flow rate (m/s)= Distance (m)/time (s) .... (1)

Transparency/turbidity: Transparency is a measure of water clarity. Transparency was estimated by measuring Secchi depth (Holdren, 2002). The Secchi depth (m) is the depth of water beyond which a high-contrast pattern on a submerged disk is no longer visible. Turbidity can be estimated based on measured transparency data, and the relation between transparency and turbidity is expressed in Equation (2) [modified from Davies-Colley & Smith (2001)]:

Turbidity (NTU)= (11.123/Secchi depth (feet)) ^ (1.56) ....(2)

where NTU is the nephelometric turbidity unit.

TABLE 1. The description and location of the sampling sites

Site no	Description	Location
1	Mainstream of the Nile River near Saluga and Ghazal Islands [non-polluted [reference site].	N 24° 04`.328``; E 032° 52`. 279``
2	Mainstream of the Nile River near Isis Island; polluted from wastes from Isis hotel. [Domestic-like pollution].	N 24°27`.644``; E 032°54`. 825``
3	Mainstream of the Nile River; polluted with industrial effluents of Kima fertilizer factory. [Industrial pollution].	N 24° 07`.023``; E 032° 54`.058``
4	El-Mansouriya drainage canal; polluted with agricultural effluents. [Agricultural pollution].	N 24°27`. 685`; E 032° 54`.299``

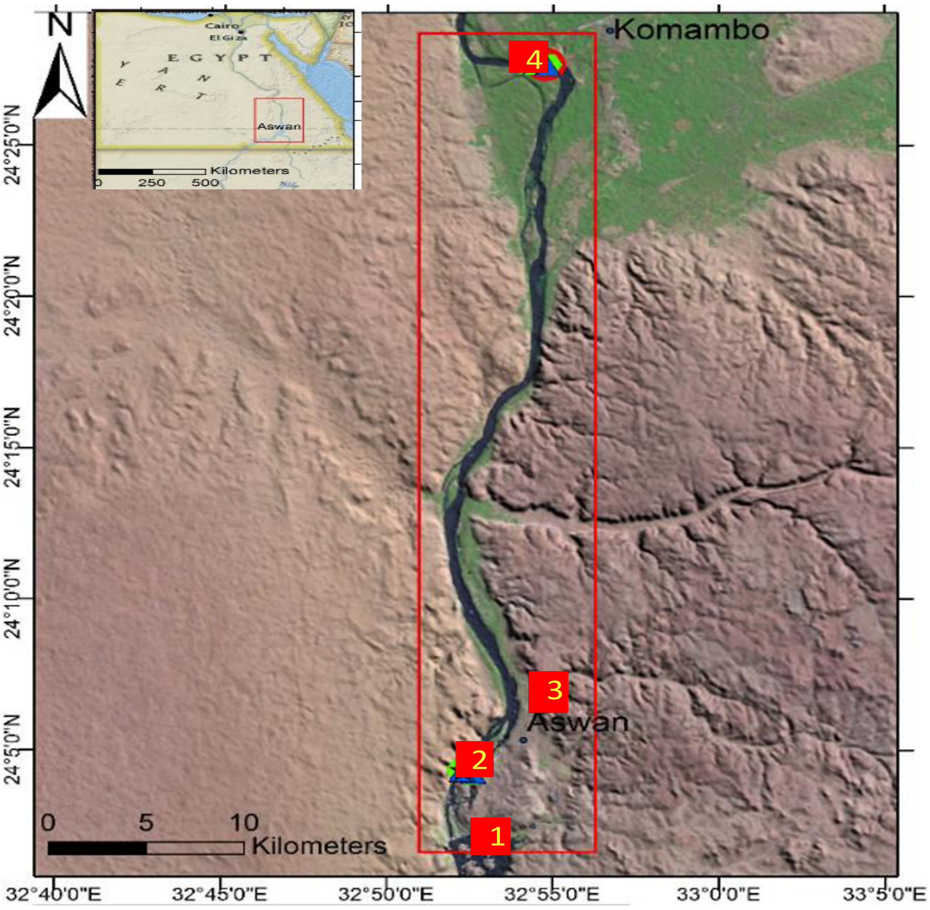

Fig. 1. A map shows the study area of the Nile River at Aswan Distinct

Conductivity: (expressed asµs/cm) was determined by the conductivity meter (model HI 8033).

Total dissolved solids (TDS): It is the sum of the silica plus the major ions in the water. TDS depends on the conductivity of the water sample (Atekwana et al., 2004), as shown in Equation (3):

TDS (mg/L)= keEC…………………………(3)

where Ke is a calibration factor, and EC is the electrical conductivity expressed in µS/cm.

Dissolved oxygen: water samples (100mL) were collected in triplicates in 100–300mL clean bottles. Then, the samples were filtered, and DO was determined using Winkler's method (Clark et al., 1985).

Laboratory measurements

Chemical oxygen demand (COD), biological oxygen demand (BOD), and nutrient minerals were measured in the laboratory.

Chemical oxygen demand: was estimated according to Graaf Bierbrauwer et al. (1967). It is expressed in (mg/L).

Biological oxygen demand: was determined according to Verma & Singh (2013). It is expressed in (mg/L).

Measurements of nutrient minerals

Calcium (Ca^{+2}) and magnesium (Mg^{+2}) were determined using the EDTA titration method (Ibraheem & Abdel-Raouf, 2001). Then, total water hardness was calculated according to Betz & Noll (1950) (Equation 4):

Total water hardness (mg/L)= $2.49\times Ca^{+2}$(mg/L) + $4.12\times Mg^{+2}$ (mg/L) ………………..……………(4)

where, 2.49 and 4.12 are the ratios of the molar masses of Ca^{+2} and Mg^{+2}, respectively.

Chloride (Cl^-): according to the method described by Tessier et al. (1979).

Sulfate (SO_4^{-2}), Nitrate (NO_3^-), and phosphate (PO_4^{-3}) were determined using atomic absorption spectroscopy (modeli CE 3000 series AA spectrophotometer) (Farrukh, 2012).

Fluoride (F^-) and bromide (Br^-) were determined using ion Chromatography (model Shimadzu) (Stefanović et al., 2001). All minerals were expressed as (mg/L).

Determination of the overall pollution index and water quality status

To determine each site's water quality status, OPI was calculated as adopted by Sargaonkar & Deshpande (2003). The calculation of OPI was performed using Equation (5).

$$\mathrm{OPI} = 1/\mathrm{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{Pi} \quad \text{..................................(5)}$$

where Pi = pollution index for a parameter and it was obtained using equation (6); n= number of parameters.

Pi= (Vn (observed value of parameters)) / (Vs (standard value of parameters)) …………….(6)

The values of Vs for each parameter are shown in Table 2. Then, the water quality for each site was estimated by calculating the average OPI and it was categorized as reported by Sargaonkar & Deshpande (2003).

Statistical analysis

All data are presented in means±standard deviation. Two-way analysis of variance (ANOVA; from Minitab version 18.1) was concisely used to determine the significant difference between pollution and seasonal variability in water quality. One-way ANOVA was used to state the significant effect of pollution types in each season. Turkey's pair wise comparisons were used to set the grouping of statistical differences.

Principal component analysis (PCA) was performed using Minitab (version 18.1) to achieve a multivariate analysis of the parameters of water quality analysis.

Results

General physico-chemical properties of water

The data of temperature, pH, flow rate, transparency, conductivity, TDS, DO, BOD, and COD of the water in the selected sites are provided in Table 3.

Water temperature varied seasonally and was significantly affected by different pollution types. The amplitude of the temperature range was significantly altered due to pollution type. Site 3 recorded the highest temperature range in summer (24.0±0.00ºC), followed by site 2, site 1, and site 4,respectively (Table 3).

Water pH was significantly affected by pollution type in most seasons. Values of pH were on the slightly alkaline side. The highest pH value (8.1±0.01) was recorded in the spring for site 3, which was subjected to industrial pollution, and the lowest value (7.36±0.05) was related to agricultural pollution (site 4).

TABLE 2. The standards of the parameters of the OPI and classification of water quality classes based on OPI score

Parameter	pH	Conductivity (µS/cm)	Turbidity (NTU)	TDS (mg/L)	DO (mg/L)	BOD (mg/L)	Total hardness (mg/L)	Ca (mg/L)	Mg (mg/L)
V_s	6.5	300	5	500	5	5	300	75	30
OPI score	**Water quality- class**								
OPI <1.9	Excellent- C1								
1.9 <OPI<3.9	Acceptable- C2								
3.9 <OPI <7.9	Slightly polluted- C3								
7.9 <OPI<15.9	Polluted- C4								
OPI>16	Heavily polluted- C5								

TABLE 3. Physico-chemical characteristics of the water from the selected sites. Values are shown in mean ± SD. (n=3)

Season	Site	Temperature (ºC)	pH	Flow rate (m/min)	Transparency (m)	Turbidity (NTU)	Conductivity (µS/cm)	TDS (mg/L)	DO (mg/L)	BOD (mg/L)	COD (mg/L)
Spring	1	22.3±0.10^{a*}	7.9±0.05^{a}	6.7±0.60^{a}	1.7±0.00^{a}	19.1±0.00^{a}	251±12.30^{a}	150±7.40^{a}	8.4±0.60^{a}	1.5±0.01^{a}	0.6±0.00^{a}
	2	22.8±0.05^{b}	7.5±0.03^{b}	11.7±0.30^{b}	1.1±0.07^{b}	37.7±2.39^{b}	257±11.20^{a}	154±6.70^{a}	4.2±0.30^{b}	1.2±0.10^{b}	0.6±0.00^{a}
	3	23.2±0.15^{c}	8.1±0.01^{c}	22.3±0.60^{c}	0.1±0.05^{c}	163.0±0.81^{c}	430±21.90^{b}	258±13.2^{b}	4.2±0.30^{b}	3.7±0.10^{c}	1.0±0.00^{b}
	4	18.0±0.05^{d}	7.5±0.03^{b}	14.3±0.60^{d}	0.9±0.06^{d}	51.7±2.79^{d}	264±12.90^{a}	158±7.70^{a}	4.4±0.40^{b}	1.5±0.10^{a}	0.5±0.00^{c}
Summer	1	23.5±0.05^{a}	7.6±0.28^{a}	5.5±0.50^{a}	1.7±0.20^{a}	19.08±2.33^{a}	253±8.10^{a}	152±4.80^{a}	2.4±0.40^{bc}	1.9±0.10^{a}	1.3±0.00^{a}
	2	23.9±0.05^{b}	7.5±0.03^{a}	5.8±0.30^{a}	1.1±0.00^{b}	37.7±0.00^{b}	275±11.00^{ad}	165±6.50^{ad}	2.5±0.20^{bc}	4.0±0.1^{b}	1.4±0.00^{b}
	3	24.0±0.00^{c}	7.8±0.28^{a}	15.3±0.30^{b}	0.6±0.05^{c}	97.5±1.17^{c}	457±25.30^{b}	274±15.^{b}	1.8±0.30^{a}	8.7±0.60^{c}	1.8±0.00^{c}
	4	21.0±0.05^{d}	7.8±0.20^{a}	13.2±0.30^{c}	1.0±0.03^{b}	43.9±1.64^{b}	299±14.50^{cd}	180±0.60^{cd}	2.6±0.20^{b}	2.6±0.5^{d}	1.0±0.00^{d}
Autumn	1	15.0±0.05^{a}	7.8±0.10^{a}	0.7±0.30^{a}	1.5±0.00^{as}	23.2±0.00^{ac}	146±4.60^{a}	88±2.70^{a}	7.8±0.30^{a}	1.2±0.10^{a}	1.0±0.00^{ab}
	2	16.0±0.05^{b}	7.5±0.05^{b}	0.8±0.30^{a}	1.3±0.00^{b}	29.1±0.00^{b}	153±8.60^{a}	92±5.10^{a}	3.6±0.00^{b}	1.6±0.00^{b}	1.1±0.00^{b}
	3	15.9±0.05^{b}	7.7±0.05^{a}	0.7±0.30^{a}	0.1±0.01^{c}	163.0±0.16^{c}	347±15.20^{b}	208±9.10^{b}	4.2±0.30^{c}	7.0±0.0^{c}	2.0±0.00^{c}
	4	16.0±0.1^{b}	7.5±0.00^{b}	0.7±0.30^{a}	0.5±0.02^{d}	130.3±1.30^{d}	110±10.00^{c}	66±6.00^{c}	2.1±0.20^{d}	3.3±0.10^{d}	1.0±0.00^{a}
Winter	1	15.0±0.05^{a}	7.5±0.00^{a}	2.0±0.00^{a}	3.7±0.00^{a}	5.6±0.00^{a}	130±7.90^{ab}	78±4.70^{ab}	3.9±0.02^{a}	1.1±0.10^{a}	0.8±0.00^{a}
	2	16.0±0.05^{b}	7.5±0.00^{a}	1.5±0.00^{b}	3.4±0.00^{b}	6.42±0.00^{b}	140±6.20^{b}	84±3.70^{b}	1.7±0.30^{b}	2.0±0.00^{b}	0.8±0.00^{a}
	3	17.0±0.05^{c}	8.0±0.00^{b}	1.7±0.30^{bc}	0.4±0.00^{c}	184.0±0.00^{c}	214±9.60^{c}	128±5.70^{c}	1.6±0.00^{b}	4.9±0.10^{c}	2.0±0.10^{b}
	4	16.0±0.05^{b}	7.3±0.05^{c}	2.7±0.30^{c}	1.4±0.00^{d}	25.88±0.00^{d}	199±3.80^{d}	60±2.20^{d}	1.2±0.30^{c}	3.1±0.10^{d}	0.9±0.00^{c}

[1] Different letters indicate significant difference at $P \leq 0.05$ (obtained by one-way ANOVA of data in each site.

The flow rate was significantly different in response to both seasonal variation and pollution. The flow rate varied significantly, with the maximum figure (22.3±0.6m/min) being recorded at site 3 in the spring. Autumn saw a lagging flow rate that was unaffected by the type of pollutants (Table 3).

Water transparency was significantly influenced by both seasonal variation and pollution. It was evidently reduced due to industrial pollution (site 3), recording the lowest values in all seasons, where as the highest transparency was measured for site 1. In winter, the transparency was highly significantly different in response to pollution type with high amplitude. Transparency and turbidity both responded similarly to seasonal changes and different kinds of pollution. However, they are significantly inversely correlated. Turbidity was enhanced in response to industrial pollution (site 3), recording the highest values in all seasons.

Water conductivity and TDS exhibited similar responses and significantly varied due to both seasonal variation and pollution type. The highest values of water conductivity and TDS were recorded in summer and were significantly enhanced due to pollution. The values of DO were significantly different in response to seasonal variation and pollution types. It was markedly reduced at site 3, recording the lowest values during all seasons. The highest values were measured in the spring (Table 3).

BOD and COD values varied significantly in response to seasonal variation and pollution. They were significantly enhanced at site 3 in all seasons, peaking in summer. BOD declined in winter. The highest values of COD were detected in the summer.

Measurements of nutrient minerals

The content of mineral nutrients in the water of the different sites is described in Table 4. The pollution type significantly influenced the concentration of Ca^{+2}. In all seasons, the highest values were recorded at site 3, whereas the lowest values were detected at site 1.

Both seasonal variation and pollution type significantly affected Mg^{+2} concentration. Mg^{+2} exhibited lower values (of about half-folds) in comparison with Ca^{+2}. However, the two elements had a similar pattern in their occurrence in the different sites. The highest value for Mg^{+2} (16.8±0.1mg/L) was measured in summer at site 3. The total hardness was calculated from the data of Ca^{+2} and Mg^{+2} concentrations as described in section (2.3). The results were used to calculate OPI as described in section (3.4).

The mean content of (SO_4^{-2}) was significantly affected in response to seasonal variation and pollution type. It had a similar pattern as divalent cations (Ca^{+2} and Mg^{+2}), showing the highest values at site 3. In winter, SO_4^{-2} exhibited maximum concentrations at sites 2 and 3 (36.23±1.12 and 39.25±1.09mg/L, respectively) compared with other sites.

Chlorides were significantly affected by variations in seasons and pollution type. However, the highest and lowest value ratios were moderately the same during all seasons. The highest value (8.2±0.3mg/L) was recorded at site 3 in autumn.

Seasonal variation had a significant effect on the mean concentration of PO_4^{-3}. However, there was no significant influence due to the pollution type. Site 3 had the highest values in all seasons except in winter. Conversely, the lowest value was recorded at site 1 in the spring.

Both Br^- and F^- exhibited similarly ranged values and were affected in response to the seasonal variation and the pollution type. In winter, these two anions recorded low values at all sites. Seasonal variation and pollution type significantly influenced the concentration of NO_3^-. In spring, site 3 exhibited the highest concentration (1.89±0.02mg/L), nearly 6-folds of its concentration in site 4 or site 1 in the same season (Table 4).

Multivariate statistical characterization of the general physico-chemical properties and nutrient minerals of water

Quantitative data of the different measured parameters of the physico-chemical properties and nutrient minerals of water in the different sampling sites during the four seasons were subjected to PCA (Fig. 2).

TABLE 4. Mineral nutrients of the water from the selected sites. Values are shown in mean ± SD. (n=3). (from Mohamed et al, 2021)

Season	Sites	Ca^{+2}(mg/L)	Mg^{+2} (mg/L)	SO$_4^{-2}$(mg/L)	Cl^{-1}(mg/L)	PO$_4^{-3}$(mg/L)	Br^{-1} (mg/L)	F^{-1} (mg/L)	NO$_3^{-1}$(mg/L)
Spring	1	11.25±0.1^{a1}	5.2±0.0^{a}	12.00±1.5^{ac}	5.7±0.2^{a}	0.05±0.00^{a}	0.4±0.0^{a}	0.4±0.0^{a}	0.35±0.01^{ac}
	2	18.26±0.0^{b}	7.2±0.0^{bc}	10.22±0.94^{bc}	6.5±0.1^{b}	0.06±0.00^{ab}	0.3±0.0^{ac}	0.6±0.0^{bc}	0.43±0.02^{a}
	3	39.22±0.0^{c}	15.2±0.1^{c}	25.37±1.23^{b}	5.2±0.3^{c}	0.74±0.03^{b}	0.4±0.0^{b}	0.7±0.0^{c}	1.89±0.02^{b}
	4	18.51±0.0^{d}	8.5±0.0^{d}	9.23±0.25^{c}	5.8±0.3^{a}	0.13±0.03^{c}	0.3±0.0^{c}	0.4±0.0^{d}	0.32±0.02^{c}
Summer	1	10.02±0.0^{a}	6.9±0.0^{a}	1.86±0.71^{a}	5.0±0.1^{a}	0.63±0.02^{a}	0.2±0.0^{a}	0.3±0.0^{a}	0.01±0.00^{a}
	2	24.09±0.0^{b}	7.7±0.0^{b}	18.98±1.47^{b}	5.9±0.3^{b}	6.49±0.05^{b}	0.3±0.1^{ab}	0.5±0.0^{b}	0.06±0.00^{b}
	3	35.93±0.0^{c}	16.8±0.1^{c}	20.63±1.15^{b}	6.1±0.3^{b}	7.08±0.03^{c}	0.4±0.2^{b}	0.6±0.0^{c}	0.14±0.00^{c}
	4	19.62±0.1^{c}	8.5±0.1^{d}	8.25±0.81^{c}	5.1±0.1^{ad}	1.37±0.02^{d}	0.3±0.0^{ab}	0.3±0.0^{a}	0.15±0.00^{c}
Autumn	1	13.61±0.1^{a}	6.4±0.0^{a}	4.92±0.14^{a}	6.1±0.1^{a}	2.13±0.32^{a}	0.1±0.1^{a}	0.1±0.0^{a}	0.003±0.0^{a}
	2	18.44±0.0^{b}	6.9±0.1^{a}	4.17±0.06^{b}	5.3±0.3^{b}	4.10±0.0^{b}	0.2±0.1^{b}	0.1±0.0^{a}	0.082±0.0^{b}
	3	29.51±0.1^{c}	11.5±0.0^{b}	18.91±0.38^{c}	8.2±0.3^{c}	4.53±0.06^{b}	0.4±0.0^{c}	0.5±0.0^{b}	0.094±0.0^{c}
	4	19.72±0.0^{d}	7.5±0.0^{c}	10.27±0.31^{d}	3.9±0.1^{d}	1.36±0.15^{c}	0.1±0.0^{d}	0.1±0.0^{a}	0.095±0.0^{c}
Winter	1	14.08±0.0^{a}	5.6±0.0^{a}	0.83±0.02^{a}	4.3±0.3^{a}	2.71±0.08^{a}	0.1±0.0^{a}	0.1±0.0^{a}	0.001±0.0^{a}
	2	18.25±0.0^{b}	6.7±0.1^{ab}	36.23±1.12^{b}	5.3±0.3^{b}	2.03±0.05^{b}	0.2±0.1^{b}	0.1±0.0^{a}	0.005±0.0^{b}
	3	32.95±0.3^{c}	12.2±0.1^{c}	39.25±1.09^{c}	4.9±0.1^{bc}	1.63±0.32^{c}	0.3±0.1^{b}	0.3±0.1^{a}	0.02±0.00^{c}
	4	18.27±0.0^{b}	7.6±0.0^{d}	9.10±0.10^{d}	3.4±0.5^{d}	3.76±0.25^{d}	0.1±0.0^{a}	0.1±0.0^{a}	0.01±0.00^{cd}

[1] Different letters indicate significant difference at P≤ 0.05 (obtained by one-way ANOVA of data in each site.

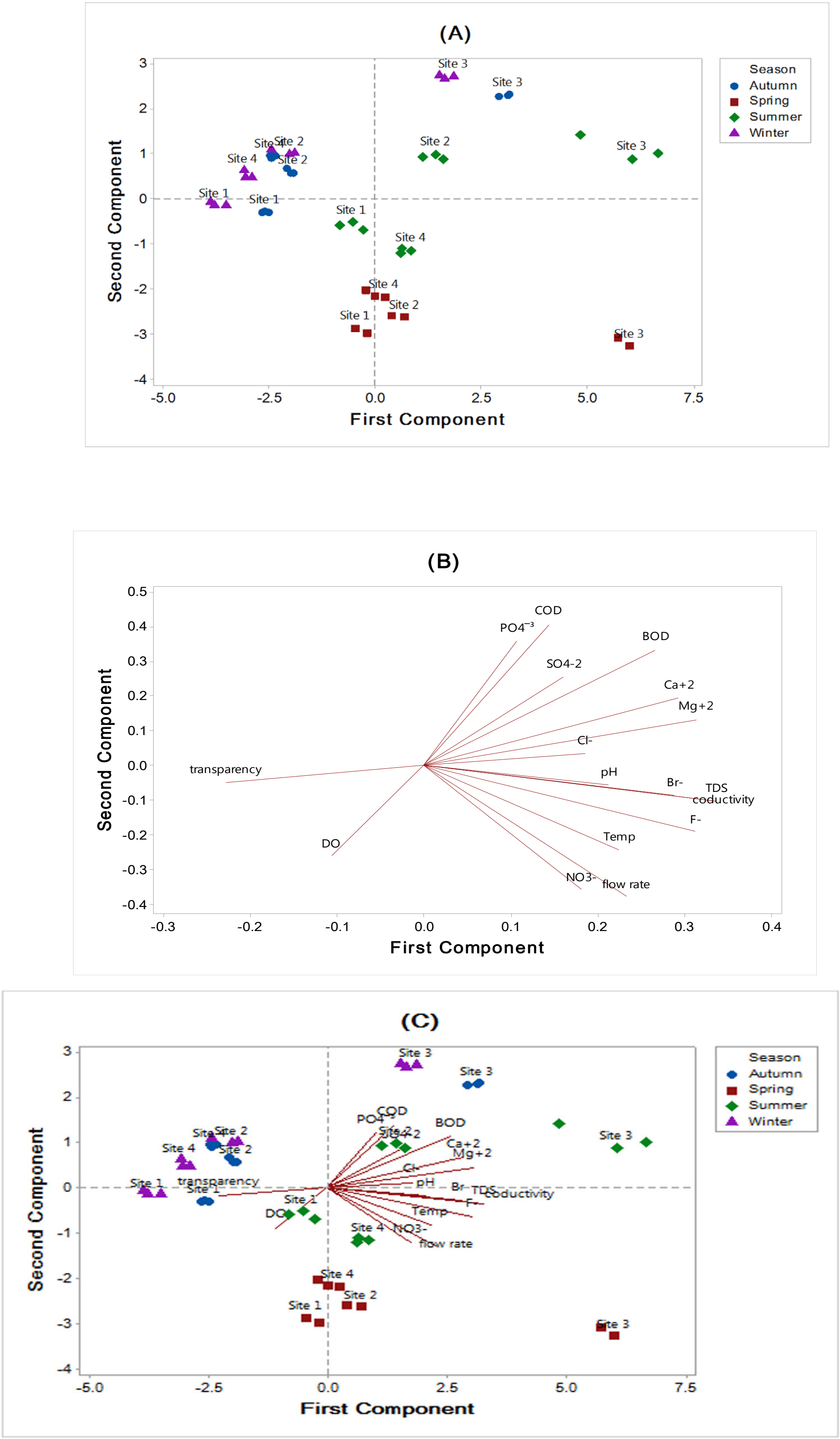

Fig. 2 . Multivariate data analysis showing PCA plots [Score plot (A), Loading plot (B) and Biplot (C)] of the Physico-chemical parameters and nutrient minerals in the different sites

The score plot shows a clear discrimination of different sites. For example, the site subjected to industrial pollution (site 3) in summer, autumn, and winter was aligned on the uppermost right-hand side, whereas other sites were aligned on the other sides of the plot. In contrast, site 1 was not subjected to any pollution type and was aligned on the bottom left-hand side of the plot (Fig. 2 A).

The loading plot of PCA shows the measured parameters responsible for the discrimination obtained from the score plot. It was clearly recognized that the high values of COD, BOD, PO$_4^{-3}$ Ca^{+2}, Mg$^{+2,}$ and SO$_4^{-2}$ were responsible for the characterization of site 3 in summer, fall, and winter. High transparency and DO were responsible for the characterization of site 1 (Fig. 2 B). The results of the biplot of PCA confirmed the results of score and loading plots showing the grouping and parameters responsible for the discrimination in the same plot (Fig. 2 C).

Pearson's correlation was performed to test the relation between the different measured parameters to understand their cumulative effect on the water quality of the different sites in different seasons. There is a highly significant correlation between temperature and flow rate. Additionally, temperature, pH, and flow rate are significantly correlated with conductivity and TDS, whereas transparency is negatively correlated with both variables. While transparency and BOD showed a significant negative correlation, COD and transparency showed a significant positive correlation. There is also a significant positive correlation between Br^{-}, F^{-} and Ca^{+2}, Mg^{+2}, and Cl^{-}. Nitrate correlates with Ca^{+2} and F^{-} (Table 5).

Estimation of the overall pollution indexand water quality status

The values of OPI for each site during different seasons are described in section (2.4)*. The results of OPI calculations are summarized in Table 6. The lowest values of OPI were calculated at site 1 compared with other sites; they ranged between (2.15) in autumn and (0.77) in winter. At site 2, OPI values were so close in spring and summer (3.20 and 3.25, respectively) and were the highest compared with the other seasons. The OPI values at site 3 were the highest among the different sites. In winter, the highest value of OPI was recorded (14.01), and the values in spring and autumn were approximately the same (12.58 and 12.56, respectively). The highest value at site 4 (10.00) was registered in autumn, and the lowest value (2.27) was in winter.

The water quality status based on OPI calculations of the selected sites can be classified and judged into different types as follows: site 1 (class1; excellent water)–site 2 (class 2; accepted water)–site 3 (class 4; polluted water)–site 4 (class 3; slightly polluted) and in autumn it was changed to polluted status.

Discussion

The maintenance and survival of aquatic life depend on information regarding the surface water quality of the river (Kamboj & Kamboj, 2019). Therefore, the present study assessed the surface water quality of the selected sites along the Nile River.

Water temperature greatly impacts the water system's physical, chemical, and biological components. So, it is an important parameter in the water ecosystem due to its effects on the organism's existence, evolution, distribution, and reproductive performance (Tayel et al., 2008; Abdo, 2010). Additionally, it has economic and ecological significance when considering issues such as water quality and biotic conditions in rivers, and it influences the growth rate and distribution of aquatic organisms (Ebersole et al., 2001) (The results are depicted in Supplements Tables S1, S2, S3, and S3 for sites 1, 2, 3, and 4, respectively).

It was investigated in this study that the Nile water temperatures varied seasonally as reported by Abdel-Satar et al. (2017). However, its amplitude was affected by pollution (Taylor & Stefan, 2009). Also, it was evident that there is a relationship between several factors, such as flux, which might cause fluctuations in river water temperature.(Sinokrot & Gulliver, 2000). Additionally, an increase in water temperature might be due to the microbial activity accompanied by pollution (Ferreira & Chauvet, 2011).

Water pH affects both biological and chemical processes in water as the biological processes can be affected at less extreme pH values (Said, 2013). In this study, pH values were generally neutral and slightly alkaline. Variations in pH levels could occur when organic acid-loaded effluents are discharged. The decrease in pH may be attributed to the decomposition of plankton and organic matter, releasing H$_2$S and the formation of organic acids (Elewa & Ghallab, 2000).

TABLE 5. Pearson's correlation analysis for the physico-chemical characteristics and different nutrient minerals in water

	Temp	pH	Flow rate	Transpar	Cond	TDS	DO	BOD	COD	Ca^{+2}	Mg^{+2}	Cl^-	Br^-	F^-	SO_4^{-2}	NO_3^-
pH	0.297															
Flow rate	0.705	0.371														
Transparency	-0.295	-0.39	-0.366													
Conductivity	0.711	0.557	0.761	-0.548												
TDS	0.711	0.557	0.761	-0.548	1											
DO	-0.216	0.022	-0.097	0.057	-0.219	-0.219										
BOD	0.208	0.289	0.154	-0.551	0.612	0.612	-0.373									
COD	0.025	0.288	-0.29	-0.388	0.247	0.247	-0.403	0.608								
Ca^{+2}	0.231	0.468	0.452	-0.623	0.667	0.667	-0.39	0.781	0.413							
Mg^{+2}	0.336	0.528	0.559	-0.63	0.777	0.777	-0.353	0.819	0.407	0.937						
Cl^-	0.208	0.262	0.127	-0.312	0.551	0.551	0.077	0.343	0.264	0.245	0.256					
Br^-	0.588	0.583	0.579	-0.379	0.822	0.822	-0.16	0.45	0.183	0.544	0.59	0.559				
F^-	0.811	0.449	0.764	-0.517	0.905	0.905	-0.115	0.426	0.086	0.552	0.605	0.566	0.794			
SO_4^{-2}	0.057	0.357	0.084	-0.19	0.271	0.271	-0.423	0.476	0.353	0.659	0.526	0.155	0.411	0.258		
NO_3^-	0.419	0.485	0.746	-0.363	0.544	0.544	0.11	0.019	-0.21	0.503	0.475	0.063	0.436	0.624	0.204	
PO_4^{-3}	0.013	-0.18	-0.174	-0.09	0.198	0.198	-0.199	0.66	0.386	0.383	0.347	0.194	0.105	0.049	0.12	-0.316

TABLE 6. The water quality classes for the selected sites during different seasons

Sites	Site 1			Site 2			Site 3			Site 4		
Seasons	**OPI**	**Class**	**Water quality status**	**OPI**	**Class**	**Water quality status**	**OPI**	**Class**	**Water quality status**	**OPI**	**Class**	**Water quality status**
Spring	1.91	C-1	Excellent	3.20	C-2	Acceptable	12.58	C-4	Polluted	4.25	C-3	Slightly polluted
Summer	1.79	C-1	Excellent	3.25	C-2	Acceptable	7.88	C-4	Polluted	3.80	C-3	Slightly polluted
Autumn	2.15	C-1	Excellent	2.52	C-2	Acceptable	12.56	C-4	Polluted	10.00	C-4	polluted
Winter	0.77	C-1	Excellent	1.85	C-2	Acceptable	14.01	C-4	Polluted	2.27	C-3	Slightly polluted
Average	**1.655**	**Class (1) 1.9>OPI**		**2.705**	**Class (2) 2<OPI<3.9**		**11.757**	**Class (4) 7.9<OPI<15.9**		**5.08**	**Class (3) 4<OPI<7.9**	

The river flow is highly variable in time, depending on the climatic situation and the drainage pattern. River flow is unidirectional and frequently has strong lateral and vertical mixing, but it can vary greatly depending on the meteorological, climatic conditions, and drainage patterns. Additionally, a clear relationship exists between river water temperature, river flow rate, and the density of the hydrophytes, which may decrease the water flow (Sinokrot & Gulliver, 2000).

This study shows that the decrease in transparency, which means an increase in turbidity, is related to anthropogenic activities (industrial, agriculture, and domestic wastes). Turbidity is an important parameter in monitoring water quality. High turbidity decreases light penetration in the water bodies (Verma & Saksena, 2010). In this study, turbidity at most sites decreased in winter. This might result from a decrease in blooming in winter (Abdel-Satar, 2005a).

The electrical conductivity of surface water is the aqueous solution's ability to transfer the current of electricity that is influenced by the total concentrations of ions and proportional to the availability of ions (Gaber et al., 2013). The conductivity of most freshwater ecosystems ranges from 10 to 1000µS/cm but may exceed 1000µS/cm in polluted waters (Kabir et al., 2002). The elevation of the electrical conductivity of water reflected the high levels of anion and cation concentrations due to the waste and discharge into the water (Gaafer et al., 2009). In this study, the electrical conductivity is directly proportional to temperature decrease in winter with the decreasing of ions with low water discharges, which agrees with the study of Abdel-Satar (2005b) and increases in summer (Hayashi, 2004).

TDS primarily comprise chlorides, bicarbonates, phosphates, sulfates, and conceivably nitrates of magnesium, potassium, sodium, and calcium, in addition to traces of manganese, iron, and other ingredients (Akan et al., 2012). This study confirmed the positive correlation between TDS and electrical conductivity (Toufeek & Korium, 2009). The high values of TDS recorded in spring and summer in this study are probably due to the phytoplankton blooming (Williams & Sherwood, 1994). Additionally, the industrial effluents and the agricultural drainage elevated TDS values, which agreed with the findings of Soltan (2006).

High levels of DO are vital for aquatic organisms as it is required for aerobic organisms' metabolism and decomposition of organic matter (El Shakour & Mostafa, 2012). According to Das & Acharya (2003), DO depends on several factors, such as the degree of saltiness, phytoplankton photosynthesis, organic matter decomposition, and the consumed oxygen by organisms submerged at the bottom and the exchanged gas between water and the atmosphere. Therefore, it is important to assess the water's suitability for aquatic life and drinking (Abdel-Satar et al., 2017). It was highly dependent on temperature during the sampling year, with minimum levels during warm months and gradually increasing with decreasing temperature (Veado et al., 2000); decreasing water temperature makes water molecules hold DO (Radwan et al., 2003). In this study, DO registered its maxima in spring and autumn. This might be attributed to the activities of air movement, which allow more oxygen transfer across the air-water interface and due to water turbulence due to wind activity. The low DO values in polluted sites may be due to the organic compounds' bacterial decomposition, which consumes more oxygen (Tayel et al., 2007). The concentrations in non-polluted waters are usually less than 10mg/L (Gray, 1994). The values of DO are within Egyptian law (Abdel-Hamid et al., 2017).

The biodegradation of the organic compounds in the water systems can be determined by measuring BOD. Very polluted water is characterized by having an average BOD of 12mg/L or more. This study showed that the highest BOD value was equal to 8.7mg/L in the polluted site, reflecting the large aggregates of discharged pollutants (Hagras et al., 2018).

COD is defined as a measure of the capacity of water to consume oxygen in the decomposition of organic and inorganic matter. The discharged effluents of water increase the COD value (El-Gohary et al., 2011). Previous studies have claimed that COD is affected by solar radiation as the photosynthesis of phytoplankton is mainly controlled by solar radiation (Kawabe & Kawabe, 1997). In the same context, COD in this study increased in the summer.

High-nutrient concentrations can cause many problems, such as eutrophication, and acidification, ultimately damaging aquatic organisms (Camargo & Alonso, 2006). The elevated values of the cations (Ca^{+2} and Mg^{+2}) in the water sample wastes were introduced from industrial activities, domestic wastes, and agricultural drainages. The concentrations of Ca^{+2} and Mg^{+2} were less than the permissible limits (75mg/L) and (250mg/L), respectively, in this study, according to WHO (2006). It was observed that Mg^{+2} concentrations approximately halve those of Ca^{+2} because there is a superiority of Ca^{+2} over Mg^{+2} in sedimentary rocks (Hagras et al., 2017).

SO_4^{-2} can be found in almost all-natural water. The origin of most SO_4^{-2} compounds is the oxidation of sulfite ores, the presence of shales, or industrial wastes (Shin et al., 1995). High levels of SO_4^{-2} cause water hardening (El-Amier et al., 2015). The values in this study did not exceed the WHO permissible limit of 200mg/L.

Concentrations of Cl^- higher than 200mg/L are considered a risk of human health and may cause an unpleasant taste in water. Most rivers and lakes have Cl^- concentrations of less than 50mg/L. However, the Cl^- content of sewage effluent under dry weather flow could increase the Cl^- content of the receiving water by as much as 70mg/L. This is because it comes from activities carried out in agricultural areas and industrial activities.Rivers and lakes generally contain F^- and Br^- levels of less than 0.5mg/L and were found together in water bodies (Fakayode, 2005).

The use of phosphate fertilizers tended to increase the PO_4^{-3} content in the water. In most natural surface waters, phosphorous ranges from 0.005 to 0.020mg/L PO_4^{-3} (WHO, 2011). According to the European Union, the maximum allowable concentration of phosphorus is 5mg/mL. Therefore, the highest concentration of PO_4^{-3} in this study might be due to the excess of industrial effluents, which agreed with the studies of Dougherty et al. (2004) and Abdo (2013).

Nitrate is are gulating element limiting the biological productivity of the Nile water (Sharpley et al., 1987). WHO (2006) recommended a maximum limit for NO_3^-as 11.3mg/L representing a significant health risk. An increasing NO_3^- concentration was detected in the water bodies with increasing effluents and other remnants. The low values of NO_3^- in spring might be attributed to nitrate uptake by natural phytoplankton and its reduction by denitrifying bacteria (Sabae, 2004).

Conclusion

The present study investigates the surface water quality of the Nile River during four sites. The values of OIP scores indicated the polluted class of water quality in site 3receiving the industrial effluents. The water quality class was designated as acceptable and slightly polluted in site 2 and site 4, respectively. The excellent water quality status of Nile River in site 1 was calculated during all seasons. In autumn season, water quality of site 4 was changed to be polluted.

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تأثير التلوث والتنوع الموسمي على جودة المياه في مواقع مختلفة من نهر النيل، أسوان، مصر

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تم تحليل جودة المياه السطحية والديناميات الموسمية لنهر النيل في منطقة أسوان باستخدام تحليل البيانات متعدد المتغيرات وتحليل مؤشر التلوث العام (OPI). تم جمع عينات المياه من أربعة مواقع، تشمل موقع مرجعي (الموقع 1) وثلاثة مواقع تتلقى نفايات سائلة من مصادر تلوث مختلفة، على سبيل المثال، الملوثات المنزلية (الموقع 2)، والصناعية (الموقع 3)، والنفايات السائلة الزراعية (الموقع 4). تم تحليل معايير جودة المياه المختلفة، مثل الخصائص الفيزيائية والكيميائية والمعادن المغذية، في المواقع المختارة.

تم حساب متوسط قيم OPI عن طريق تصنيف جودة المياه السطحية لكل موقع على النحو التالي: في الموقع 1 (1.65: ممتاز)، الموقع 2 (2.70: مقبول)، الموقع 3 (11.75: ملوث)، الموقع 4 (5.08: ملوث قليلًا). في كل موقع، تباينت قيم OPI بشكل موسمي ضمن نطاق فئة جودة المياه ، باستثناء الخريف في الموقع 4، كانت قيمة OPI 10.00، وبالتالي تم تغيير فئة جودة المياه إلى (ملوثة).

بشكل عام، نستنتج أن المخلفات الصناعية السائلة لها تأثير سلبي على جودة المياه السطحية لنهر النيل بأسوان. وبالتالي، ينبغي ان نولي اهتمامات خاصة للحفاظ على الاستدامة البيئية.