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Application of Chemical and Biological Indices to Water Quality Assessment of the Nile River at Assiut City, Egypt

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ABSTRACT

Chemical and biological indices provide a comprehensive picture of monitoring and evaluating water quality. There are few studies that use biological indices to assess the freshwater quality in Egypt. Therefore, the purpose of this study is to evaluate the water quality of the Nile River and the treated wastewater canal at Assiut City, Egypt, using the biotic indices that depend on macroinvertebrates (Nile Biotic Pollution Index: NBPI) or zooplankton (Wetland Zooplankton Index: WZI), and compare the results with the physicochemical index (Water Quality Index: WQI). During the summer of 2022 and winter of 2023, water and invertebrate samples were collected from four different sites. The collected data of physicochemical parameters, zooplankton, and macroinvertebrates were used for calculating the investigated water quality indices. The results revealed significant differences between the collected samples for all studied indices. The biological indices NBPI and WZI showed significant regression with the WQI. NBPI index was highly significant regression with WQI, which indicates that macroinvertebrates are more suitable than zooplankton for assessment of water quality.

INTRODUCTION

The freshwater of rivers is vital for drinking, irrigation, and other commercial uses of water [1]. The increasing number of people and their activities have led to the pollution of freshwater resources [2]. Water pollution upsets ecosystem balance, which has a major negative influence on human health and the economy. As a result, monitoring and evaluating the quality of the water is crucial to maintaining its ecological status [3]. Several methods have been developed for assessing the quality of water. These indices ranked and provided a single value summarising all the water quality parameters of a particular body of water [4]. These indices primarily rely on the collected chemical, physical, and biological data that provide a comprehensive picture of the ecological state of a particular body of water [5].

River water quality is largely determined by the configuration of physicochemical parameters [6, 7]. Tanjung *et al*. [8] mentioned that Water quality index (WQI) is an important tool that can provide information on pollutant source indicator parameters in various water bodies as well as summarise and simplify various values for an accurate and efficient determination of water quality [9, 10]. Using a lot of water quality data, WQI helps to summarise the general state of water quality [11]. The Canadian Council of Ministers of the Environment CCME-WQI method, created by the CCME [12], is one of the approaches that is highly sensitive and objective when responding to the local characteristics and water quality dynamics at each location [13].

A widely used method in the world of environmental assessment is the use of bioindicators to measure the impact of pollutants on freshwater habitats. Among all the freshwater aquatic invertebrates, communities of zooplankton and macrobenthos generally reflect environmental conditions and can be employed as bioindicators to gauge pollution levels and aquatic environment quality [14, 15, 16]. Based on the interaction between zooplankton species and environmental factors, the Wetland Zooplankton Index (WZI) is widely used to evaluate the quality of water [17]. This index, which describes the relationship between the zooplankton taxon and environmental factors, is dependent on three factors: relative abundance, species tolerance, and optimal environmental conditions for each zooplankton taxon. This index is frequently used in many types of water habitats [10, 17, 18, 19, 20, 21].

Macroinvertebrates are excellent choices for biological indicators of water quality since they can detect changes in the environment over the course of time [22]. Creating biotic pollution indices to be used in conjunction with chemical data is one method of evaluating the quality of water [23]. The most widely used biotic index that evaluates freshwater quality using macroinvertebrates is the Biological Monitoring Working Party (BMWP) [24]. In Egypt, there is still limited use of biotic indices, particularly those that rely on macroinvertebrates. However, Fishar and Williams [25] modified the BMWP index to be more suitable to evaluate the water quality of the Nile River, and they established the Nile Biotic Pollution Index (NBPI).

Few attempts have been made to evaluate Egypt's freshwater quality using biological indices [3, 21, 25, 26, 27]. Therefore, this study aims to use the biotic indices that depend on zooplankton (WZI) or on macroinvertebrates (NBPI) to assess the water quality of treated wastewater canal and the Nile River at Assiut City, Egypt, and compare them with the index that depends on physicochemical parameters (WQI).

MATERIALS AND METHODS

Sampling area and study sites

The sampling was carried out at Assiut city, Egypt (27º 14′ N, 31º 11′ E). Water and invertebrates samples were collected from four sites during two seasons (summer 2022 and winter 2023). Site1 is the canal where the water from the Arab El-Madabegh wastewater treatment plant effluent is released. Site2 is located at the meeting of treated wastewater with the Nile River. Site3 is located upstream of the Nile River before the treated wastewater discharge. Site4 is located downstream of the Nile River after the meeting point of the treated wastewater. Details of sampling sites are presented in Tawfik *et al.* [28]. Three duplicate samples of water and invertebrates (zooplankton and macrobenthos) samples were collected from four sampling sites during the study. Water samples were sorted and packed with ice in an icebox prior to reaching the laboratory for analysis.

Measurement of physicochemical variables

Some physicochemical variables were measured in situ, including temperature of the air and water, electrical conductivity, pH of the water (using EcoScan pH 6), total dissolved solids (using a digital TDS handheld meter), transparency (using a Secchi-disk with a diameter of 20 cm), and dissolved oxygen (using portable water quality instruments). In the laboratory, according to APHA-AWWA-WPCF (1989) [29], water nitrate (NO_3), ammonia (NH_4) and phosphate (PO_4) were measured. Zn concentrations in water samples were estimated according to Jackson [30] (1974) by using iCAP 6200 Emission Spectrometer.

Sampling and analysis of invertebrates

For zooplankton collction, the standard plankton net of 55 µm was used to filter 30 liters of water. The filtrate samples were fixed with 5% formalin and preserved in labeled vials. Three replicates (one ml) for each collected samples were investigated under a binocular Microscope. Identification of the colllectd zooplankton was made referring to [31, 32, 33].

Benthos samples were collected by a van Veen grab (sampling area of 225 cm2). All samples were fixed in 5% formaldehyde solution in labeled plastic containers. In the laboratory, samples were washed with tap water and sieved through a 0.5 mm mesh size sieve. The sorted macrobenthic invertebrates were counted, identified, and classified using stereomicroscope and guides by [34- 40].

Calculation of Water Quality Index (WQI)

The term "WQI" refers to the CCMEWQI method CCME [12], which was chosen to assess the general state of the samples under investigation in terms of water quality. The recognized physicochemical parameters were used for WQI estmation. Remarkably, Baughman et al. [41] converted the Secchi disc transparency measurements for turbidity into standard NTU (Nephelometric Turbidity Units). WQI was conducted using the minimum Egyptian standards set forth in Law 48/1982 (EEAA, 1999)[42] for the Nile River's water quality.

WQI was calculated according to the following equation.

$$\mathbf{WQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$$

Where F1 (Scope) is the proportion of parameters, out of all the parameters measured, that fail to meet their guidelines at least once during the period under consideration (referred to as "failed parameters"). F2 (frequency) variable is the percentage of individual tests that do not meet guidelines "failed tests". F3 (Amplitude) is the amount by which failed test values deviate from their specifications is indicated. F3 is a calculated value involvesd by three steps. The resulting values are normalised by divisor

1.732 to a range of 0 to 100, where 0 is the "worst" water quality and 100 is the "best" water quality.

Calculation Wetland Zooplankton Index (WZI)

According to Lougheed and Chow-Fraser [17] WZI was calculated using weighted means in the following equation:

$$\mathbf{WZI} = \frac{\sum_{i=1}^{n} YiTiUi}{\sum_{i=1}^{n} YiTi}$$

Where Ui is the ideal (1–5), Ti is the tolerance (1–3), and Yi is the quantity or presence of species I. As a result, the index can be anywhere from one, which denotes a low-quality wetland, to five, which indicates a high-quality wetland.

Calculation Nile Biotic Pollution Index (NBPI)

The Nile Biotic Pollution Index (NBPI) and the Nile Average Score Per Taxon Index (NBPI-ASPT) at investigated sites during the two different seasons was calculated according to Fishar and Williams [25]. For each sample, the number of families having Nile Pollution Tolerance Scores (NPTS) were used for NBPI-ASPT estimation according to the following equation;

$$\mathbf{NBPI - ASPT} = \frac{A}{B}$$

Where; A= Summation of NBPI family score, B= No. of NBPI scoring family. Here in and over all the paper NBPI refer to NBPI-ASPT

Data analysis

All data analyses were preformed using IBM SPSS Statistics (Version 20), Excel Office (2013), and PAST4 programs. One-way Analysis of variance (ANOVA) was applied to investigate significant differences of investgated water quality indices between the studied samples followed by the Duncan test to determine pairwise differences between means. Pearson correlation was used to consider the association between the studied water quality indices and physicochemical variables. Following data standardisation, a hierarchical cluster and principal component analysis (PCA) of the mean values of the variables under study were applied.

RESULTS

The studied physicochemical variables fluctuate among the investigated sites. Table (1) illustrates the minimum and maximum values of each parameter at the investigated sites compared with Egyptian water standard guidelines. In general, water temperature and electrical conductivity meet the standard guidelines while ammonia and Zn concentration exceed the permissible limits in some samples from all study sites. Other samples especially from contaminated sites (site1 and site2) show values does not meet the Egyptian standards for water pH, Turbidity, TDS, Dissolved oxygen, Phosphate, Nitrate, and Ammonia.

Table 1. Ranges (Minimum-Maximum) of the physicochemical variables of the investigated sites and water standard guidelines (Stand_G).

Physicochemical variables	Site1	Site2	Site3	Site4	Stand_G
Water temperature (°C)	19.4-31.3	19.7-30.3	19.4-28.9	19.7-29	20-30
pH	6.26-7	6.29-7.4	7.3-8.3	7.1-8.1	6.5
Conductivity (uS/cm)	41-47	40-45	39-46	40-45	1000
TDS (ppm)	403-563	319-584	122-174	154-210	500
Turbidity (cm)	23-26	10-50	120-160	140-180	10 NTU
Dissolved oxygen (mg/L)	1.2-1.5	0.95-1.5	6.2-7.1	5.4-6.5	5
Phosphate (mg/L)	5.04-7.92	5.8-7.61	0.02-0.53	0.36-0.82	1
Nitrate (mg/L)	34.02-59.38	34.02-83.16	11.34-37.8	14.34-34.02	45
Ammonia (mg/L)	27.7-65.03	27.7-72.91	6.83-31.18	9.59-27.7	0.5
Water Zinc (mg/L)	0.06-0.21	0.05-0.18	0.09-0.29	0.11-0.26	0.5

Table (2) represente the mean values of the investgated chemical water quality index (WQI) and biological indices (NBPI and WZI) at study sites during summer and seasons. Statistical analysis revealed a significan differencs between studied sample for WQI ($F= 206.022$, $p< 0.001$). The WQI ranged from 46.3 in Site2-Win and 84.7 in Site3-Sum. The samples collected from contaminated sites (Site1 and Site2) had a relativly low values of WQI than samples from the main Nile River (Site3 and Site4). ANOVA for WZI shown significant difference ($F= 3.976$, $p= 0.011$) between different samples collected from the study sites during the two different seasons. Generally, the average value of WZI was higher in summer than that in winter at the investigated sites. The highest WZI value (3.46) was recorded at Site4-Sum while the lowest value (2.05) was recorded at Site1-Win (Table 2). On the other hand, the results of NBPI indicate significant differences among the samples in the NBPI ($F= 3.832$, $p= 0.014$). The NBPI value was significantly lower at site2-Sum and site1-Win (1 and 1.22, respectavily) in comparison to higher value at site3-Win (2.56) (Table 2).

Table 2. Water Quality indices (WQI, NBPI, and WZI) at investigated sites during summer (Sum) and winter (Win) seasons with statistical results (similar characters for each index show no significant difference).

	WQI	NBPI	WZI
Site1-Sum	55.39**b**	1.57**bcd**	2.92**ab**
Site1-Win	47.47**c**	1.22**d**	2.05**c**
Site2-Sum	56.11**b**	1.00**d**	3.08**ab**
Site2-Win	46.30**c**	1.33**cd**	2.08**c**
Site3-Sum	84.70**a**	2.25**abc**	2.88**abc**
Site3-Win	76.32**a**	2.56**a**	2.33**bc**
Site4-Sum	83.94**a**	2.33**ab**	3.46**a**
Site4-Win	76.90**a**	1.67**abcd**	2.45**bc**

The similarity between the collected samples based on water quality indcies and the studied physicochemical variables, a dendrogram of hierarchical cluster analysis divided them into four groups (Figure 1); Group 1 including winter samples from contaminated sites (Site1-Win and Site2-Win); Group 2 including summer samples from contaminated sites (Site1-Sum and Site2-Sum); Group 3 including Site3-Win and Site4-Win; and Group 4 including Site3-Sum and Site4-Sum.

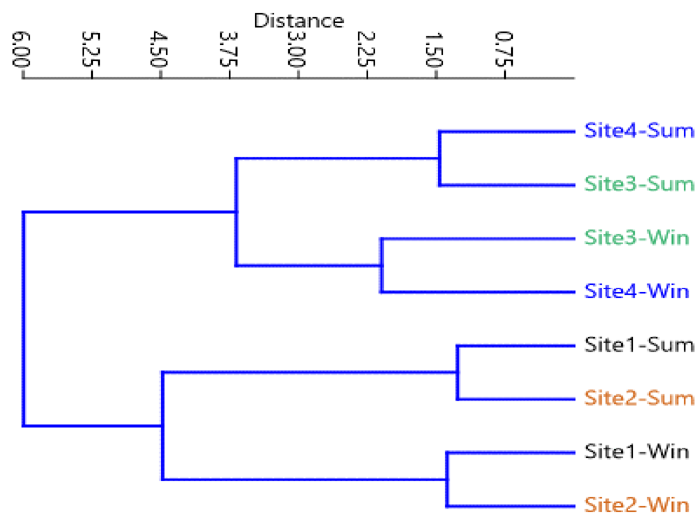

Figure 1. Cluster dendrogram showing the similarity between the studied samples based on quality indcies and the studed physicochemical variables.

Table (3) shows the correlations between the investigated physicochemical variables and the water quality indcies. WQI and NBPI exhibited a negative correlation with TDS, phosphate, nitrate, and ammonia and a positive correlation with pH, turbidity, and dissolved oxygen. WQI additionally showed a positive correlation with the concentration of Zn. WZI exhibited a positive correlation with conductivity and water temperature and a negative correlation with nitrate and ammonia. Principal component analysis (PCA) was used to confirm the relationships between the studied water quality indcies and the investigated physicochemical variables (Figure 2).

The regression results of the chemical index (WQI) score versus the biological index (NBPI, WZI) scores of the samples that were collected is shown in Figure (3). The NBPI scores have been plotted against the chemical index WQI (Figure 3A). The significance value of the regressions was $R^2 = 0.706$ ($p = 0.009$). This shows a highly significant regression between NBPI with the chemical index WQI. While the regression between WZI index and the chemical index WQI for the collected samples was not significant ($p = 0.208$; $R2 = 0.249$) (Figure 3B).

Table 3. Pearson correlation coefficients (r) between the water quality indcies with the studed physicochemical variables (*. The correlation is significant at the 0.05 level and **. The correlation is significant at the 0.01 level).

Physicochemical variables	WQI	NBPI	WZI
Water temperature (°C)	0.093	0.042	**0.665****
pH	**0.695****	**0.502***	-0.276
Conductivity (uS/cm)	0.073	0.061	**0.688****
TDS (ppm)	**-0.947****	**-0.675****	-0.308
Turbidity (cm)	**0.958****	**0.630****	0.232
Dissolved oxygen (mg/L)	**0.955****	**0.684****	0.154
Phosphate (mg/L)	**-0.926****	**-0.673****	-0.094
Nitrate (mg/L)	**-0.844****	**-0.512***	**-0.489***
Ammonia (mg/L)	**-0.848****	**-0.520***	**-0.488***
Water Zinc (mg/L)	**0.408***	0.048	0.351

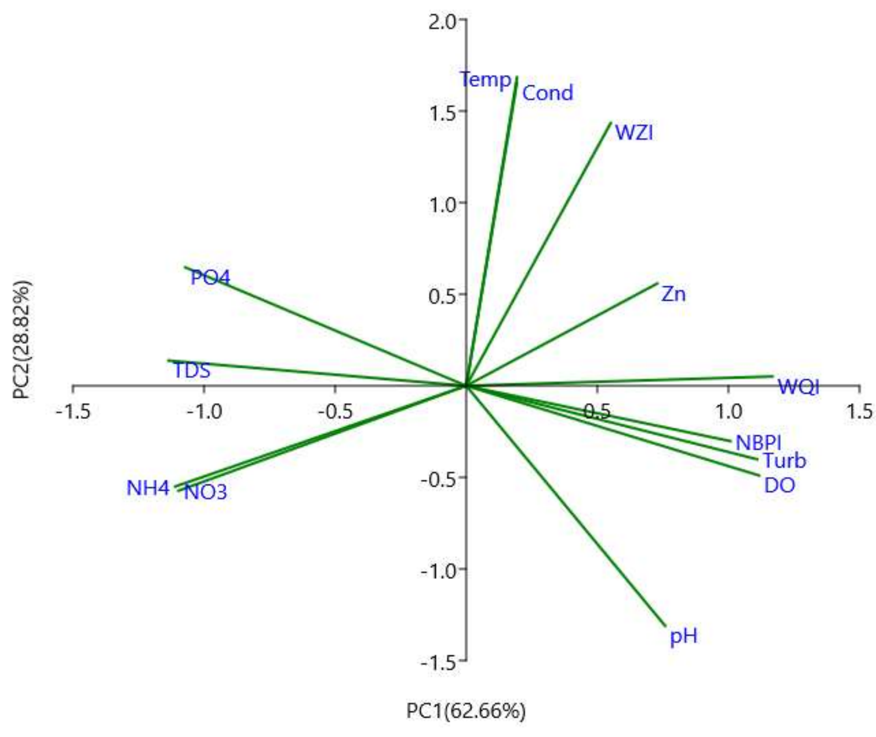

Figure 2. Principal component analysis (PCA) results of water quality indcies and physicochemical variables at study sites. Variables notation: Water Quality Index (WQI) , Wetland Zooplankton Index (WZI), Nile Biotic Pollution Index (NBPI), Water temperature (Temp), Water pH (pH), Conductivity (Cond), Total dissolved solids (TDS), Turbidity (Turb), Dissolved oxygen (DO), Phosphate (PO4), Nitrate (NO3), Ammonia (NH4), and Water Zinc concentration (Zn).

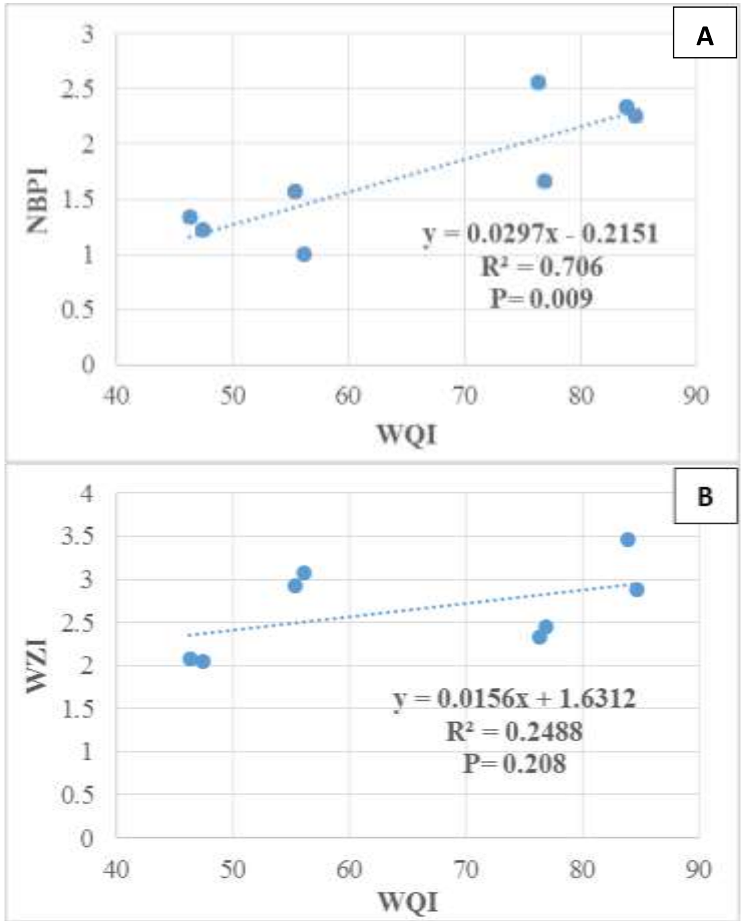

Figure 3. Regression plot of the chemical index (WQI) score against the biological index (A: NBPI, B: WZI) scores of the collected samples.

DISCUSSION

Due to the changes in physicochemical varabiles, the water quality index (WQI) was varied between the collected samples. The sample's comparatively low WQI value could be attributed to the wastewaters high Zn and ammonia concentrations. According to Abdel-Satar et al. [43], continuous pollution discharge, mostly of heavy metals and nutrients, negatively affected the health of the rivers and decreased their capacity to purify themselves, which in turn affected the use of Nile water for a range of purposes.

During the winter, the sites showed the lowest WQI values especially at contaminated sites (site1 and site2). Tawfik et al., [28] illustrated that a decrease in the Nile flow level during the winter led to concentrating the ions in the water. The water level of the Nile dropped by roughly 2.5 meters during the winter, according to Abdelmageed et al. [44]. There has been documented seasonal variation in the environmental pollutants' concentrations [45, 46, 47]. Additionally, Vega et al. [48] stated that seasonal variations in natural processes, such as temperature, have an impact on the quality of water in rivers and result in distinct features for different seasons. Similarly to

WQI, the biologicl index WZI recorded the lowest during winter season at all studied sites. Previous research demonstrated that zooplankton produced a seasonal shift in the zooplankton community structure [28,49,50]. In general, zooplankton communities adapt to the water quality [28, 51].

In the present study, Nile Biotic Pollution Index (NBPI-ASPT) was significantly lower at samples collected from contaminate sites in comparison with the samples collected from the main Nile River. Generally, ANOVA results of NBPI-ASPT showed significant differences between the collected samples. The NBPI-ASPT has been shown to provide an excellent biological assessment of organic pollution in the Nile and would provide a very useful adjunct to chemical monitoring of water quality [25]. In the present study, NBPI-ASPT values were lower than those of Fishar and Williams [25]; this may be due to intermittent chemical pollution which affects the fauna but was not recorded in the chemical sampling programme.

The present results of WQI matched with that obtained in the biotic indices of the NBPI and WZI. These results confirmed that NBPI index was highly significant regression with WQI, while the regression between WZI index and WQI was not significant. NBPI index was modified from BMWP index (Biological Monitoring Working), and it was tested for evaluating the water quality of the Nile River [25]. BMWP index is extensively applied and valid to assess water quality in several countries [52]. Similar to the present results, Fishar and Williams [25] recorded a highly significant regression between the biotic indices (BMWP and NBPI) and Nile Chemical Pollution Index. Additionally, they stated that the Nile River's actual water quality is provided to both BMWP and NBPI. In agree with these results, El Sayed et al. [3] showed that BMWP and NBPI indices are effective to assess the water quality of the Rosetta Branch and Damietta Branch and coincided with the chemical index WQI for drinking and aquatic life uses.

CONCLUSION

Overall, the study demonstrated that the biological indices, specially, NBPI index are reliable for assessing the water quality in the investigated area and that they agree with the WQI. In the future, a measure of taxon diversity included in the NBPI may be helpful in evaluating water quality and habitat improvement..

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