




An integrated water quality assessment of Damietta and Rosetta branches (Nile River, Egypt) using chemical and biological indices

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Abstract Rosetta and Damietta are the main branches of the Nile River in Egypt. They provide the required freshwater for different usage for about 20 million people. In the present study, chemical and biological indices were used to assess the water quality and provide a full image of the environmental status in the investigated area. Generally, the chemical parameters, except the dissolved oxygen, were at higher levels in Rosetta Branch when compared to Damietta Branch. Also, Damietta Branch frequently showed the presence of the macroinvertebrate families that are bioindicators of moderate and good water quality. Contrarily, the most resistant species to pollution were frequently recorded in the Rosetta Branch. According to Canadian WQI, the water of Rosetta Branch is classified from “marginal” to “poor” for the drinking and aquatic life uses and “fair” to “good” for irrigation usage. On the other side, the water quality of Damietta Branch is classified as “fair” with respect to drinking water and “good” to aquatic life and irrigation. Based on using macroinvertebrate families as bioindicators, the Biological Monitoring Working Party (BMWP) index and the Nile Biotic Pollution Index

(NBPI) indicated that the water quality of the Damietta Branch was within “moderate” class, while Rosetta Branch is categorized from “very polluted” to “extremely polluted” classes. The results proved that both BMWP and NBPI have coincided with the CWQI for the drinking and aquatic life indices ($p < 0.0001$) indicating the validity of BMWP and NBPI to assess the water quality of the investigated area.

Keywords Chemical properties · Water quality index (WQI) · Macroinvertebrates · Biological Monitoring Working Party (BMWP) · Nile Biotic Pollution Index (NBPI) · Bioindicator

Introduction

Surface freshwater ecosystems, rivers, lakes, and swamps, make up approximately 0.01% of the total water volume in the earth planet (Pidwiny 2006); nevertheless, they support a large number of unique species. Freshwater ecosystems are subjected to great threats by climate change, industrial activities, pollution, and other anthropological impacts. The water of the rivers has considerable importance for drinking, irrigation, and other economic uses of water (Dunca 2018). The assessment of water quality is the first stage of any management, conservation, or restoration process of the freshwater ecosystems. A complete water quality assessment of any

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water body is based on the monitoring of its hydrological, physical, chemical, and biological parameters (Jiang 2006). Each freshwater body is characterized by an individual pattern of physical, chemical, and biological characteristics which are mainly determined by the environmental conditions and human activities (Meybeck and Helmer 1996). The physical, chemical, and biological indices are becoming the most recent tools to assess water quality (Poonam et al. 2013).

Water quality indices are techniques that simplify the results of many water quality parameters into a single value which express the status of water quality (Goher et al. 2015). They are useful tools that give efficiently the water quality status of a definite area in terms of a single value and classified rank. In general, the classes of the water quality indices are summarized into four main groups (Jena et al. 2013): first, the water quality index approach; second, trophic status index approach; third, statistical analysis approaches of water quality data such as correlation analysis; and fourth, biological analysis approaches such as genetic algorithms method and other biological indices.

Canadian water quality index (CWQI) is one of the famous widely used tools to assess the water quality of different water bodies regarding various usages. The indifference with many other quality indices, CWQI calculates values over an index period, typically a season or a year. Thus, it is designed to assess average water quality over a specified period rather than to be used as a tool for identifying immediate water quality problems (Davies 2006).

On the other hand, macroinvertebrates are good candidates as biological indicators of water quality because they have a relatively long life, fairly sessile, and whole communities can respond to the environmental changes, thus they can indicate to the overall water quality status for several months (Hellawell 1986). The development of biotic pollution indices to be applied in integration with chemical data is one of the water quality evaluation techniques (Zeybek et al. 2014). The biota reflects the impact of pollution on aquatic life because it reacts in different ways with the natural changes and anthropogenic disturbances (Roozbahani et al. 2010).

There are several biotic indices, especially, that depend on macroinvertebrates, which have been developed in both developed and developing countries. The Biological Monitoring Working Party (BMWP) is the most common biotic indices that utilized

macroinvertebrates to assess freshwater quality (Armitage et al. 1983). It was established initially in the UK (ISO 1979), and then several authors developed it to be applicable in other water bodies around the world (Barton and Metcalfe-Smith 1992; Zamora-Munoz and Alba-Tercedor 1996; Capítulo et al. 2001; Mustow 2002; Czerniawska-Kusza 2005). The application of biotic indices, specifically which depend on macroinvertebrates, is still scarce in Egypt. Nevertheless, Fishar and Williams (2008) 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). The main modification of the BMWP index to develop the NBPI was to increase the number of recorded taxa from 29 to 43.

The Nile is the main source of life in Egypt. On its banks, the oldest civilization in the world has been established. The ancient Egyptian knew that well and appraised the value of this river. Over the last decades, the Nile River and its branches have been subjected to the attack of industrial wastes as a direct result of several factories constructed along the river banks. Consequently, several ecological effects have been detected in the Nile River environment (Goher et al. 2019). The serious health consequences, environmental degradation, and global life quality issues are results of the water pollution that have a high cost to all humanity as well as increasing the severity of water scarcity problems (El-Amier et al. 2015). Hence, increasing water pollution not only causes the deterioration of water quality, biodiversity, and the balance of aquatic ecosystems but also threatens human health, economic development, and social prosperity (Hassan et al. 2017).

At the north of Cairo at Delta Barrage, the Nile River bifurcates into two branches, namely, Damietta and Rosetta branches. These two branches offer the required freshwater for about 20 million people in addition to industrial, irrigation and municipal purposes. However, they, especially Rosetta Branch, receive a variety of wastewater from a different point and non-point sources of pollution including agriculture, domestic and industrial wastes.

Since that date, there have been no other attempts to use such indices to assess the quality of freshwater in Egypt. Therefore, this study aims to use the biotic indices that depend on macroinvertebrates (biological information) to assess the water quality of the two Nile

branches, Damietta and Rosetta, in integration with the indices that depend on chemical analysis to provide a full image of the pollution status in the investigated area.

Material and methods

Area of investigation

Before EL-Kanater El-Khayria city (20 km north of Cairo), the Nile River bifurcates to two main branches, Rosetta and Damietta branches. The former is about 225 km in length, 180 m in width, and its depth ranges from 2 to 4 m. It starts at EL-Kanater El-Khayria and ends at Rosetta Estuary in Rashid city, while the freshwater of Rosetta Branch ends at Edfina Barrage, 30 km upstream of the sea, which releases excess water to the Mediterranean Sea via the Rosetta Estuary. It receives a huge amount of different wastes along with its extension through several drains including El-Rahawy Drain, Sabal Drain, El-Tahreer Drain, Zaweit El-Bahr Drain, and Tala Drain in addition to the effluents of Kafr El-Zayat industrial area (Ezzet et al. 2012). El-Rahawy Drain, 20 km downstream EL-Kanater El-Khayria city, is considered the main source of pollution, where it discharges daily about 1.5 million cubic meters of sewage and agriculture wastes into the branch (APRP 2002).

On the other hand, Damietta Branch is about 242 km in length with an average width of 200 m and an average depth of 12 m. The branch is cut off by Farskour Dam to two different areas: freshwater southern the dam and saline water northern the dam. Damietta Branch receives an increasing amount of waste discharges from several sources of pollution, industry, domestic, and agriculture (APRP 2002). The effluents of Talkha fertilizer factory and the Talkha electric power station, in addition to the discharge of much minor agriculture and domestic drains and neighboring villages, are the main sources of pollution in the branch.

As mentioned above, Rosetta and Damietta branches are the main source of freshwater for all human activities in the Delta region covering about 12,357 km² and have approximately a population of 20 million, in addition to Alexandria and El Beheira Governorates that gets their freshwater via the sub-branches of the Nile (El Rayah El Behairy and El Rayah El Nassery) that originate from Rosetta Branch.

Water and macrobenthic samples were collected seasonally during 2017 from the selected locations (Fig. 1 and Table 1).

Sampling and methodology

Water sampling and analysis

Water samples were taken from the subsurface (about 30 cm) for each site. A Ruttner water sampler bottle with a capacity of 2 L was used to collect the samples and then kept in well-cleaned plastic bottles. Hydrographic parameters were measured in each station during the sample collection. Glass stoppered bottles for dissolved oxygen and biochemical oxygen demand analyses were filled carefully with water samples and fixed immediately on the spots.

The methods described in the American Public Health Association (APHA 2005) were used for the determination of the abiotic parameters including water temperature, conductivity, total dissolved solids (TDS), pH value, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), NO₂-N, NO₃-N, NH₄-N, total nitrogen (TN), PO₄-P, total phosphorus (TP), SiO₂, CO₃, HCO₃, chloride, sulfate, calcium, magnesium, sodium, and potassium. Water temperature (°C), pH, and conductivity (EC, mScm-1) were measured in situ using Hydrolab model (Multi Set 430i WTW) after applying the calibration procedure.

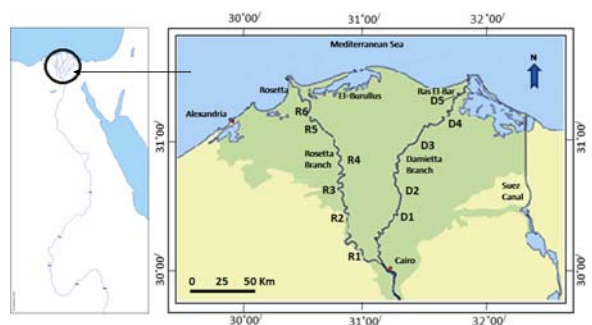


Fig. 1 Map showing the Nile branches and the selected sampling sites

Table 1 Short description and locations of the selected study sites

Rosetta branch			Damietta branch		
Code	Features of station	Coordinates	Code	Features of station	Coordinates
R1	At El Qata city, about 6.8 and 14 km downstream of El-Rahawy Drain and Nile bifurcate, respectively	30° 13' 12.93" N 30° 58' 33.77" E	D1	At Benha city, characterized by the large number of cruise ships, 50 km downstream from Nile bifurcate	30° 27' 28.07" N 31° 10' 34.61" E
R2	At Tamalay city and Tamalay bridge; about 50 km downstream of R1	30° 30' 32.32" N 30° 49' 57.29" E	D2	At Zefta city, characterized by the presence of a river ferry, 35 km downstream of D1	30° 42' 53.07" N 31° 15' 04.58" E
R3	At Kom Hamada city, downstream of an agriculture drain, 30 km downstream of R2	30° 42' 52.91" N 30° 45' 44.28" E	D3	At Talkh city, 1 and 60 km downstream of electric power station discharge and D2, respectively	31° 03' 45.91" N 31° 24' 05.49" E
R4	At Kafr El-Zayat city, 1 and 21 km downstream of an industrial zone and R3, respectively	30° 49' 22.64" N 30° 48' 38.93" E	D4	At El Serw city, 42 km downstream of D3	31° 14' 30.31" N 31° 38' 50.41" E
R5	At Desok city, characterized by the large number of fishing boats; 50 km downstream of R4	31° 08' 05.09" N 30° 38' 01.26" E	D5	At Farskure city, 35 km downstream of D4 and 0.5 km upstream of Farskure Dam	31° 24' 22.52" N 31° 46' 57.97" E
R6	At Fewa city, 13 km downstream of R5 and 0.5 km upstream of Idfina Dam	31° 12' 00.67" N 30° 33' 11.18" E			

Sampling and analysis of macrobenthic invertebrate

Macrobenthic samples were collected by dragging the Ekman dredge (10 cm height and 80 cm length) from the middle stream towards the Nile bank. The samples were washed by small hand sieve (0.5-mm mesh size) and then kept by adding adequate drops of formaldehyde (5%) in plastic jars. In the laboratory, macrobenthic invertebrates were identified, counted, and classified using stereomicroscope according to Edmondson (1966), Bishai et al. (2000), and Thorp and Covich (2009).

Water quality indices

Canadian water quality index (CWQI)

Canadian Council of Ministers of the Environment (CCME 2001) developed the CWQI to simplify the water quality data; CWQI is calculated as follows:

$$CWQI = 100 \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad (1)$$

where 1.732 is a correction factor.

$$F1 \text{ (Scope)} = \left[\frac{\text{Failed of number variables}}{\text{Total of number variables}} \right] \times 100$$

$$F2 \text{ (Frequency)} = \left[\frac{\text{Number of failed tests}}{\text{Total of number tests}} \right] \times 100$$

$$F3 \text{ (Amplitude)} = \left[\frac{\text{nse}}{0.01 \text{ nse} + 0.01} \right]$$

Table 2 CCME-WQI categories*

Rating	CCME-WQI Value	Remarks
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
Good	80–94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0.0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

*CCME 2001, 2017

nse (normalized sum of excursions)

$$= \left[\frac{\sum_{i=1}^n \text{excursion}_i}{\text{Number of tests}} \right]$$

where excursion i is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective and is calculated as follows:

excursion $i = \left[\frac{\text{failed test value}_i}{\text{Objective}_i} \right] - 1$, when the test value must not exceed the objective.

excursion $i = \left[\frac{\text{Objective}_i}{\text{failed test value}_i} \right] - 1$, when the test value must not fall below the objective.

According to CWQI, the water quality is classified as one of five categorizes that are shown in Table 2.

Biotic indices

The Biological Monitoring Working Party (BMWP) index and the Nile Pollution Index (NBPI) were applied to assess the water quality of the study area. Both indices evaluate water quality using macroinvertebrate families as bioindicators. The BMWP and NBPI score equal the sum of the sensitive scores of all macroinvertebrate

families in the sampling sites. The list scores of each indicator macroinvertebrate family of the BMWP and NBPI indices are calculated according to ISO (1979) & (1980) and Fishar and Williams (2008), respectively. Water quality classes of the BMWP and NBPI index were identified according to Maue and Springer (2008) in Table 3.

Statistical analysis

One-way ANOVA analysis, followed by a post hoc comparison using Tukey’s test, was applied to identify significant differences in all chemical parameters among sites and sampling time for water samples. Significance levels of tests were taken as $p < 0.05$ and highly significant as $p < 0.01$. Pearson’s correlation analysis was performed to evaluate potential relationships between the different variables. The biotic indices were statistically tested against the chemical indices using regression analysis to find out how far these indices coincide with the chemical indices. All statistical analyses were preformed using XLSTAT software (version 2016.02.28451).

Results and discussion

Water chemical properties

In Rosetta and Damietta branches, the temperature was in the ideal range for most of the aquatic organisms except in summer seasons. The water temperature was varied in the range 17–31.2 and 18.3–31.4 °C in Rosetta and Damietta branches, respectively (Table 4), with highly seasonal significant difference ($p < 0.01$). Temperature is negatively correlated with HCO_3^- ($r = -0.42$) and Ca ($r = -0.44$), which confirms that the de-

Table 3 BMWP and NBPI scores and corresponding water quality classes according to Maue and Springer (2008)

Score	Level of water quality
> 120	Excellent quality
101–120	Good quality
61–100	Moderate quality
36–60	Polluted
16–35	Very polluted
< 15	Extremely polluted

Table 4 Ranges and mean ± standard deviation of the water parameters of the investigation area in 2017 compared to water standard guidelines

Parameter	Rosetta	Mean	Damietta	Mean	Drinking E W Q S 2007	Drinking W H O 2017	Irrigation FAO ^{**}	Aquatic live C C M E 2017
Temperature (°C) ^c	17–31.2	23.5 ± 4.55	18.3–31.4	24.21 ± 4.61			< 35	8–28
Transparency(cm)	17–80	46.75 ± 18.06	65–200	124.75 ± 38.71				
EC (µScm-1) ^{a,b}	538–1176	699.25 ± 131.28	371–516	442.15 ± 39.31	2000		3000	
TDS (mg/L) ^{a,b,c}	344.32–752.64	433.57 ± 84.82	237.44–330.24	274.09 ± 26.24	1000	500	2000	500
pH ^{a,b,c}	7.2–8.57	7.83 ± 0.36	7.92–8.54	8.22 ± 0.15	6.5–8.5	6.5–8.5	8.5	6.5–9
DO (mg/L) ^{a,b,c}	0.75–6.33	3.5 ± 1.68	4.8–9.8	7.08 ± 1.28	6	6		5.5
COD (mg/L) ^{a,b}	7.43–54.65	12.98 ± 11.27	1.9–5.58	3.68 ± 1.15	10	11		
BOD (mg/L) ^a	5.34–35	19.19 ± 7.1	3.16–7.84	5.56 ± 1.07	3			
NO ₂ -N (mg/L) ^{a,b,c}	0.007–0.408	0.054 ± 0.08	0.005–0.037	0.016 ± 0.006	0.06	0.9		0.06
NO ₃ -N (mg/L) ^{a,b,c}	0.042–0.792	0.159 ± 0.17	0.042–0.390	0.136 ± 0.11	10	11	10	2.93
NH ₄ -N (mg/L) ^{a,b,c}	2.7–13.9	6.39 ± 2.57	0.177–0.55	0.31 ± 0.1	0.41	0.2	5	1.27–0.077*
TN (mg/L)	3.76–18.52	8.71±	0.319–1.095	0.61±				
PO ₄ -P (mg/L) ^b	0.163–0.770	0.344 ± 0.14	0.01–0.075	0.026 ± 0.02			2	
TP (mg/L) ^a	0.305–1.483	0.612 ± 0.28	0.03–0.168	0.062 ± 0.04	1	1		
SiO ₂ (mg/L)	1.72–9.79	4.46 ± 2.01	1.18–6.42	2.95 ± 1.37				
CO ₃ (mg/L) ^b	0–0	0 ± 0	0–14	3.02 ± 3.17			30	
HCO ₃ (mg/L) ^b	176.9–289.14	216.87 ± 31.16	120.78–198.25	161.57 ± 20.07			610	
Cl (mg/L) ^{a,b,c}	47.94–198.55	69.49 ± 30.13	21.43–37.72	28.33 ± 4.98	250	200	1036	120
SO ₄ (mg/L) ^{a,b}	28.14–74.65	36.87 ± 9.06	14.46–23.39	18.1 ± 2.81	250	250	960	
Mg (mg/L) ^{a,b}	14.7–43.19	20.69 ± 5.77	11–77–17.69	14.47 ± 1.57	50	50	60	
Ca (mg/L) ^{a,b}	30.41–65.87	38.41 ± 7.6	21.65–33.93	26.8 ± 4.04	75	75	400	
Na (mg/L) ^{a,b}	43.17–110.83	57.73 ± 14.13	22.53–35.88	28.32 ± 4.06	200	200	919	
K (mg/L) ^b	9.36–13.55	11.53 ± 1.35	7.69–9.93	9.07 ± 0.62			2	

*Ammonia permissible level dependent on temperature (20–30 °C) and pH value (7.5–8.5), **FAO according to Ayers, & Westcot (1994),
^{abc} The parameter used to calculate the CWQI for (a) drinking, (b) irrigation, and (c) aquatic life purposes

crease of water temperature increases the solubility of CO₂ and later increases bicarbonate ions and Ca₂⁺ which exist in water as hydrogen carbonate; this result agrees with that obtained Abdel-Satar et al. (2017). In general, the elevation of temperature increases the chemical reactions rate, exerts a chief effect on the growth and biological activity of the aquatic organism, and controls the organism’s kinds that habitat in lakes and rivers (Kale 2016).

Transparency showed a highly spatial significant difference ($p < 0.01$) in the Rosetta Branch and ranged between 17 and 80 cm (Table 4). The low value of transparency in the Rosetta Branch may be attributed to the receiving of the effluent discharge from many sources of pollution heavily loaded with agriculture,

industrial, and domestic wastes. This is approved by the high negative correlated with EC, TDS, BOD, COD, and NH + 4 ($r = -0.58, -0.6, -0.74, -0.74,$ and $-0.62; n = 24; p < 0.01$), and this results coincide with the results of many authors (Goher et al. 2014; Abdel-Satar et al. 2017). Matta (2014) cited that the water transparency is affected by particulate content of river water from suspended matter and floating substances. Regarding the Damietta Branch, water transparency fluctuated between 65 and 200 cm (Table 4) which reflects the clarity of its water in comparison with that of Rosetta Branch.

The high increase of EC may be an indicator of pollution due to the liquid effluents discharged into the water bodies. Electrical conductivity showed an obvious

increase along the Rosetta Branch in comparison with Damietta Branch. The water electrical conductivity varied in the ranges of 538–1176 and 371–516 $\mu\text{S}/\text{cm}$ in Rosetta and Damietta branches, respectively, with spatial and seasonal significant difference ($p < 0.01$).

Total dissolved solids (TDS) is the mineral content and dissolved organic material in the water that reduces the suitability of water for different usages when available at high levels. Regarding the current study, TDS varied in the ranges of 344.32–752.64 and 237.44–330.24 mg/L in Rosetta and Damietta branches, respectively, with spatial and seasonal significant difference ($p < 0.01$). TDS showed a wide range with a noticeable increase along the Rosetta Branch especially at the low water level during the drought period (winter and autumn). TDS is highly positive correlated with major cations and anions ($r = 0.90$; $n = 44$; $p < 0.01$).

pH is the key parameter for the water properties and organisms in the aquatic environment (Goher et al. 2014). It controls metal solubility and affects natural aquatic life. Most aquatic organisms can tolerate to pH range (6.0–9.0), but they are more active when the pH value is around (7) (Chin 2000). The pH of the two branches lies on the alkaline side. pH varied in the ranges of 7.2–8.57 and 7.92–8.54 in Rosetta and Damietta branches, respectively, with high spatial significant difference ($p < 0.01$) in Rosetta Branch and among seasons in Damietta Branch. This observation may indicate the high anthropogenic effect on Rosetta Branch water more than the Damietta Branch. The lowest pH value 7.2 was recorded at site R1 due to the greater input of sewage and wastes into Rosetta Branch via El Rahway Drain and to bacterial and fungal action in the sediment; these activities liberated methane and hydrogen sulfide and the formation of organic acids and other breakdown products (El-Sayed 2011). pH is positively correlated with DO ($r = 0.55$; $n = 44$; $p < 0.01$), which confirmed the effect of photosynthetic activity on the elevation of pH value (Moustafa et al. 2010). On the other hand, pH is negatively correlated with BOD ($r = -0.63$; $n = 40$; $p < 0.01$) and COD ($r = -0.62$; $n = 44$; $p < 0.01$).

The DO varied in the range of 0.75–6.33 mg/L with the highly significant difference among sites ($p < 0.01$) in the Rosetta Branch. While in Damietta Branch, DO showed a highly seasonally significant variation and changed between 4.8 and 9.8 mg/L. The lowest concentrations in Rosetta Branch were observed in drought period (low flow conditions) that can be related to the high transport of organic pollution and nutrients

combined with the low effluent rate of river and the microbial decomposition of the organic matter (El Bouraie et al. 2011). This result agrees with that obtained by El-Sayed (2011), who reported that the dissolved oxygen was consumed by the oxidation of nitrogenous compounds and organic matter. This result is confirmed by the high negative correlation with COD ($r = -0.74$), BOD ($r = -0.74$), NH_4 ($r = -0.66$), PO_4 ($r = -0.69$), and TP ($r = -0.7$), with major cations and anions especially in Rosetta Branch.

Biological oxygen demand (BOD) and chemical oxygen demand (COD) are two of the most important parameters to indicate the organic pollution of water. The obtained values of BOD and COD were varied in ranges of 1.9–5.58 and 3.16–7.84 mg/L, respectively, in the Damietta Branch with high spatial and seasonal significant differences. The corresponding values of BOD and COD in Rosetta Branch fluctuate in the ranges of 5.34–35 and 7.43–54.64 mg/L, respectively, with the highly significant difference among sites ($p < 0.01$). BOD and COD values were higher in the Rosetta Branch than that of Damietta Branch. These results indicate clearly the increase of pollution in Rosetta Branch in comparison with Damietta Branch, which may be attributed to the huge amounts of agricultural, industrial, and domestic effluents that are discharged along Rosetta Branch, especially from EL-Rahawy Drain, which is in consistency with the results obtained by Mostafa and Peters (2016). It is worth mentioning that site R1 recorded the highest BOD and COD values, On the contrary, site D1 recorded the lowest values.

The nutrient salts include compounds that contain nitrogen, phosphorus, or silicate in different forms either in available or nonavailable forms. Nutrient salts (NO_2^- , NO_3^- , NH_4^+ , PO_4^{3-} , TP, and SiO_2^{2-}) showed wide fluctuations with an obvious increase in Rosetta Branch in all seasons. Nitrite levels usually are very low in natural water, and even in wastewater treatment plant, effluents are relatively low, mainly as a result of the nitrogen will tend to exist in the more oxidized (nitrate, NO_3) or more reduced (ammonia, NH_3) forms. Nitrite fluctuated between 0.007–0.408 and 0.005–0.037 mg/L, in Rosetta Branch and Damietta Branch, respectively, with no spatial and seasonal significant difference between. Nitrite is highly positive correlated with NO_3 ($r = 0.87$) in the Rosetta Branch, and this indicates that the studied area was heavily loaded by domestic diffuse sources. EWQS (2007) has set 60 $\mu\text{g}/\text{L}$ as a maximum admissible limit for nitrite nitrogen in drinking water.

Nitrate is the prime plant nutrient, and raising its content might be expected to increase eutrophication of waters. The high nitrate content may be accompanied by high chloride concentration in areas of organic pollution (Flemer et al. 1998). Nitrate varied between 0.04–0.791 mg/L in Rosetta Branch and 0.042–0.390 mg/L in Damietta Branch with a seasonal significant difference. WHO (2017) and EWQS (2007) have set a limit of 11 and 10 mg/L nitrate nitrogen as a maximum admissible limit in drinking water.

Total ammonia includes the toxic NH_3 , the non-ionized form, and the ionized nontoxic form (NH_4^+) (Bhatnagar and Devi 2013). Ammonia ranged between 2.7 and 13.909 mg/L in Rosetta Branch with a highly significant difference between seasons and highly positive correlation with $\text{PO}_4\text{-3}$ and TP ($r = 0.59$ and 0.56 , respectively). NH_4^+ fluctuated between 0.177 and 0.550 mg/L in the Damietta Branch with no spatial and seasonal significant difference. EWQS (2007) has set a limit of 0.41 mg/L of nitrogen as a maximum admissible limit for ammonia. The levels of ammonia exceed this value in all stations in Rosetta Branch that attributed to the enormous amount of different wastes along the branch, in particular, the domestic wastes from El-Rahawy Drain and the effluents of Kafr El-Zayat industrial area. Orthophosphate and TP ranged between 0.163–0.770 and 0.305–1.482 mg/L in Rosetta Branch, respectively, with a highly spatially and seasonally significant difference. The corresponding values in the Damietta Branch were in the ranges of 0.01–0.075 and 0.03–0.168 mg/L for PO_4 and TP, respectively.

Silica is widespread and always present in surface waters, and it exists in water in dissolved, suspended, and colloidal states. Dissolved forms are represented mostly by silica acid, products of its dissociation and association, and organosilicon compounds (Chapman and Kimstach 1996). Silicate concentration ranged between 1.72–9.79 and 1.18–6.42 mg/L for Rosetta and Damietta branches, respectively, with a highly spatially significant difference in the Rosetta Branch. It is noteworthy that Rosetta Branch has seemed as a drain or reservoir of wastes, during the study period, especially in the drought period, and recorded the maximum values of N-NH_4 (13.91 mg/L), N-NO_3 (0.791 mg/L), P-PO_4 (0.77 mg/L), and TP (1.48 mg/L). This may be attributed to the deteriorating effect of the great amounts of wastes that are introduced into the branch accompanied by the low water level.

Carbonate, bicarbonate, chloride, and sulfate are the major anions in water bodies. In the present study, the bicarbonate level was much more than the carbonate content. Where $\text{CO}_3\text{-2}$ depleted completely in the Rosetta Branch, while it varied between 0.0 and 14 mg/L in Damietta Branch. On the other hand, HCO_3^- concentrations were in the ranges of 176.9–289.14 and 120.78–198.25 mg/L in Rosetta and Damietta branches, respectively, with a highly spatially significant difference ($p < 0.01$). Bicarbonate concentrations are highly positive correlated with major cations and anions ($r = 0.6\text{--}0.89$; $n = 44$; $p < 0.01$). Site R1 (6.8 km downstream of El-Rahawy Drain) recorded the highest values of bicarbonate due to the effect of domestic sewage and other pollutants discharged at this area. In the same context, sulfate and chloride ranged between 28.14–74.65 and 14.46–23.39 and 47.94–198.54 and 21.43–37.72 mg/L in Rosetta and Damietta branches, respectively, with a highly spatially and seasonally significant difference ($p < 0.01$).

Egyptian Water Quality Standard (EWQS 2007) has set 250 mg/L of sulfate and chloride ion as the permissible limits for drinking water, while WHO (2017) stated 250 and 200 mg/L a standard water guidelines lines for SO_4 and Cl, respectively. The obtained results showed that the highest chloride concentration in Rosetta Branch is close to the permissible limit stated by WHO (2017). WHO (2003) reported that 250 mg/L of chloride is sufficient to cause detectable taste in water, while the associated cations designate the threshold levels.

Ca and Mg have shown a homogenous distribution in the two branches, and they were in the ranges of 30.41–65.87 and 14.7–43.19 mg/L in Rosetta Branch with marked increase in Ca during the drought period, which attributed to the increase of their solubility and re-dissolution of CaCO_3 by effect of CO_2 derived from the decay of organic matter, and this was confirmed by the positive correlation of $\text{Ca} + 2/\text{HCO}_3$ ($r = 0.85$, $r = 24$, $p < 0.01$). On the other hand, in the Damietta Branch, they fluctuated in the ranges of 14.7–43.19 and 11.7–16.69 mg/L with a highly spatially and seasonally significant difference ($p < 0.01$). The decrease of Mg during the hot seasons in the studied area may due to the adsorption of MgCO_3 onto clay minerals and deposition to the bottom by the rise in water temperature as reported by Chiu et al. (2010). This was confirmed by the negative correlation of Mg with

temperature ($r = -0.42$, $r = 44$, $p < 0.01$), as well as the dilution effect of the raising of water level and its uptake by phytoplankton and plankton assimilation (El Bourie 2008). As expected, there is an obvious increase in Na concentration in the Rosetta Branch, which varied from 43.17 to 110.8 mg/L with a highly spatially and seasonally significant variation ($p < 0.01$). Na showed a narrow range in the Damietta Branch with 22.53 to 35.88 mg/L. Similarly, potassium varied between 9.36 and 13.55 and 7.69 and 9.43 mg/L in Rosetta and Damietta branches, respectively, with a high spatial and temporal significant difference ($p < 0.01$). In general, all cations and anions recorded high concentrations in the Rosetta Branch compared to Damietta Branch reflective of the continuous contamination status of Rosetta Branch; this finding agrees with those obtained by El-Sayed (2011).

Water quality indices

WQI is defined as a technique of rating that provides the composite influence of individual water quality

parameter on the overall quality of water (Al-Mohammed and Mutasher 2013; Goher et al. 2015). Canadian WQI was used to assess the water quality of Rosetta and Damietta branches for different uses such as drinking, irrigation, and aquatic life. Fifteen, seventeen, and eight water quality parameters were selected in the CWQI calculations for drinking, irrigation, and aquatic life utilization, respectively (Fig. 2). The scores of CWQI in Rosetta Branch were in the ranges of 44–51, 42–49, and 77–83, for drinking, irrigation, and aquatic life purposes. The scores were 75–78, 82–91, and 80–85 in Damietta Branch. CWQI scores indicate Rosetta Branch as a marginal for drinking and aquatic life uses, except R1 and R3 which are classified as poor, and it is classified from good to fair for irrigation water. On the other hand, the water of Damietta Branch is categorized as fair for drinking use and good for aquatic life and irrigation water. The CWQI scores confirmed the notable increase of the most parameters (except DO) in Rosetta Branch than Damietta, indicating the high pollution level in the Rosetta Branch due to the huge amount of different wastes that discharged into the branch from several pollution sources.

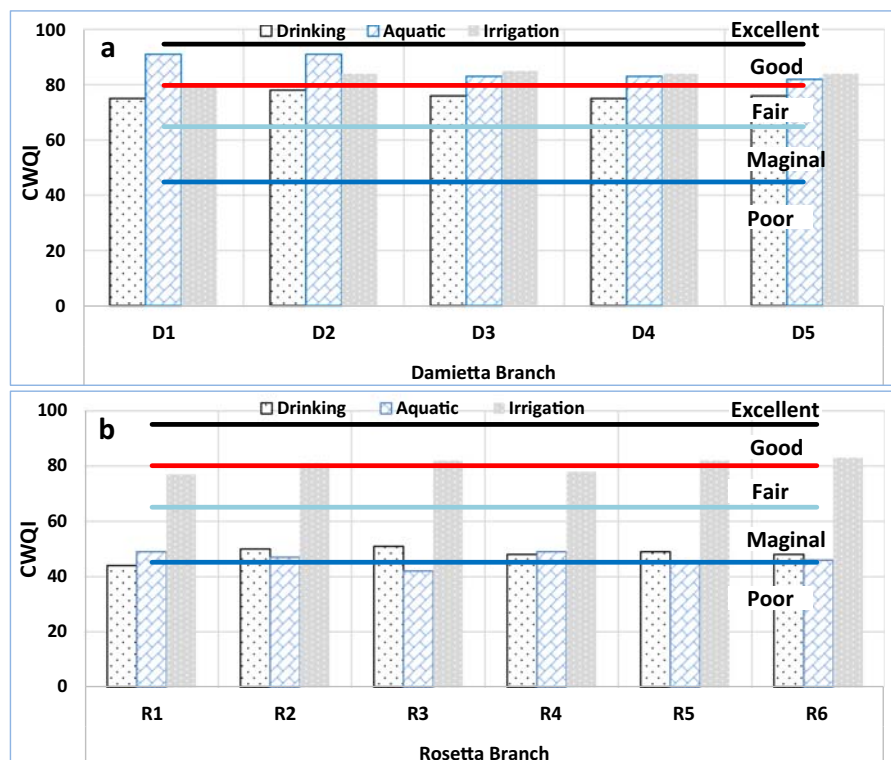


Fig. 2 Water quality index of a Damietta Branch and b Rosetta Branch for the different purposes according to the CWQI categorizes

Biological investigation

Community composition of macrobenthic invertebrates

Macrobenthic invertebrates are good indicators of environmental health because their distribution varies with space, time, and available habitats (Kumar et al. 2013). In the present study, macrobenthic invertebrates were composed of Annelida, Mollusca, and Arthropoda, being 51%, 25%, and 24% in Damietta Branch and 76%, 2%, and 22% in Rosetta Branch, respectively, according to the total density of macroinvertebrates. Twenty-three species were recorded in Damietta Branch (12

molluscan species, 5 annelids, and 6 arthropods), while nineteen species (8 Mollusca, 6 Annelida, and 5 Arthropoda) were recorded in Rosetta Branch (Table 5). A comparison with the previous studies in the Nile course in Egypt (Fishar et al. 2006; Sleem and Hassan 2010; Iskaros and El Dardir 2010; Mola and Gawad 2014; Khalifa and Bendary 2016) showed a similar macrobenthic invertebrate's composition but with different relative abundances and species numbers.

Limnodrilus sp. was the most dominant species of phylum Annelida, where it was recorded at all studied sites except D2. Its highest average density (430 Org./m²) was observed at R4 of Rosetta Branch, while the

Table 5 The annual mean species (Org./m²) composition of macrobenthos in Damietta and Rosetta branches

Group/species	Families	R1	R2	R3	R4	R5	R6	Ave	%	D1	D2	D3	D4	D5	Ave	%
Total Annelida		60	429	133	567	84	218	249	75.8	127	5	136	34	36	68	8.24
<i>Limnodrilus udekemianus</i>	Tubificidae	1	8	17	93	3	2	21	6.3	0	0	1	5	4	2	0.24
<i>Limnodrilus hoffmeisteri</i>	Tubificidae	2	89	72	42	26	27	43	13.1	123	5	8	22	4	32	3.95
<i>Limnodrilus</i> sp.	Tubificidae	56	328	44	430	55	166	180	54.8	3	0	125	6	24	32	3.85
<i>Branchiura sowerbyi</i>	Naididae	0	1	0	0	0	12	2	0.7	1	0	0	1	1	1	0.07
<i>Chaetogaster laminae</i>	Naididae	1	1	0	2	0	3	1	0.4	0	0	0	0	0	0	0.00
<i>Pristina</i> sp.	Naididae	0	2	0	0	0	8	2	0.5	0	0	2	0	3	1	0.12
Total Mollusca		1	16	0	23	3	11	9	2.7	1593	77	136	179	256	448	54.66
<i>Melanoides tuberculata</i>	Thiaridae	0	15	0	2	0	3	3	1.0	1288	69	45	59	83	309	37.66
<i>Melanoides granivira</i>	Thiaridae	0	0	0	0	0	0	0	0.0	10	0	0	6	17	7	0.80
<i>Cleopatra bulimoides</i>	Paludomidae	0	1	0	0	0	0	0	0.1	9	0	0	1	0	2	0.24
<i>Bellamya unicolor</i>	Viviparidae	0	0	0	0	0	0	0	0.0	10	0	0	7	1	4	0.44
<i>Bulinus truncatus</i>	Planorbidae	1	0	0	0	0	0	0	0.1	1	0	0	22	4	5	0.66
<i>Physa acuta</i>	Physidae	0	0	0	0	1	0	0	0.1	0	0	0	3	0	1	0.07
<i>Corbicula consobrina</i>	Corbiculidae	0	0	0	2	0	3	1	0.3	0	1	0	5	0	1	0.15
<i>Lanistes carinatus</i>	Viviparidae.	0	0	0	1	0	1	0	0.1	131	3	20	40	83	55	6.76
<i>Lymnaea</i> sp.	Lymnaeidae	0	0	0	17	2	3	4	1.1	1	1	0	5	1	2	0.20
<i>Theodocus niloticus</i>	Neritidae	0	0	0	0	0	0	0	0.0	2	1	35	9	1	10	1.17
<i>Mytella</i> sp.	Iridinidae	0	0	0	0	0	0	0	0.0	9	2	36	22	11	16	1.95
<i>Caelatura</i> sp.	Unionidae	0	0	0	1	0	1	0	0.1	132	0	0	0	55	37	4.56
Total Arthropoda		23	60	84	129	16	112	71	21.5	957	33	138	175	217	304	37.07
<i>Chironomus</i> spp.	Chironomidae	23	60	81	126	12	111	69	21.0	366	2	96	125	166	151	18.41
<i>Ischnura</i> sp.		0	0	3	0	3	1	1	0.4	539	27	36	46	47	139	16.95
<i>Trichoptera</i> spp.		0	0	0	0	1	0	0	0.1	49	3	6	3	3	13	1.56
<i>Neph of Enallagma</i>		0	0	0	0	0	0	0	0.0	1	1	0	1	1	1	0.10
<i>Neph of Neurocordulina</i>		0	0	0	0	0	0	0	0.0	1	0	0	0	0	0	0.02
<i>Micronecta</i> sp.		0	0	0	2	0	0	0	0.1	1	0	0	0	0	0	0.02
<i>Crustacean larvae</i>	Potamonautidae	0	0	0	1	0	0	0	0.1	0	0	0	0	0	0	0.00
Total macroinvertebrates		84	505	217	719	103	341	328	—	2677	115	410	388	509	820	—

Ave average density; % the percentage to the total count

lowest average being 3 Org./m² was observed at D1 of Damietta Branch. Also, *Branchiura sowerbyi*, *Limnodrilus hoffmeisteri*, and *L. undekemianus* were frequently recorded at Damietta and Rosetta sites. *Pristina* sp. was rarely recorded at Damietta and Rosetta sites. *Chaetogaster laminae* was rarely recorded in Rosetta sites, while it completely disappeared in Damietta sites. Phylum Mollusca was represented by the highest number of species in the study area. *Melanoides tuberculata*, *Lanistes carinatus*, *Melanoides granifera*, *Bellamya unicolor*, *Theodocus niloticus*, and *Mytella* sp. were the most common molluscan species at Damietta sites. Nevertheless, they were not or rarely recorded at Rosetta sites (Table 5). *Chironomus* spp. were the most Arthropod species recorded at all sites of Damietta and Rosetta branches. *Ischnura* sp. and *Trichoptera* spp. were recorded at Damietta sites, while they were rarely recorded at Rosetta sites (Table 5).

Generally, Damietta Branch showed the frequent presence of the families such Neritidae, which is a bioindicator of moderate water quality, and family Unionidae, a bioindicator of good water quality (Mouthon and Charvet 1999). *Corbicula consobrina* was recorded at D2, D4, R4, and R6, where this species indicates moderate water quality (Khalil et al. 2016). Furthermore, the most resistant species to pollution (*Limnodrilus* spp. and *Chironomus* sp.) were frequently recorded in the Rosetta Branch, and the less resistant species to pollution were absent. Yap et al. (2006) reported that *Limnodrilus* spp. are pollutant-resistant worms, and they can live in the bad water quality ecosystem. Aston (1973) mentioned that *Limnodrilus* sp. is predominant in heavy sewage polluted water bodies and low dissolved oxygen conditions. Al-Shami et al. (2010) found *Chironomus* spp. with high

densities in six rivers in Malaysia changed from highly to moderately polluted water. On the contrary, the dominance of (*Limnodrilus* spp. and *Chironomus* sp.) in Damietta Branch can be explained on the basis of that, while these species are pollutant resistant, and they also can survive in good water quality.

Seasonal variations

Seasonal variation showed clear differences between the distribution of macrobenthic invertebrates in both Damietta and Rosetta branches (Fig. 3). In the Damietta Branch, macrobenthic invertebrates attained their maximum average density (1878 Org./m²) during winter and the lowest one (43 Org./m²) during summer. While the highest average density (614 Org./m²) of macrobenthic invertebrates in Rosetta Branch was recorded during spring, and the lowest of 57 Org./m² was recorded during winter (Fig. 3).

The highest seasonal average density of Annelida was observed during Winter (1048 Org./m²) in Damietta Branch and during spring and summer in Rosetta Branch being 485 and 455 Org./m², respectively. Mollusca and Arthropoda recorded their highest average density in Damietta Branch during winter being 298 and 532 Org./m², respectively, while they peaked during autumn in Rosetta Branch. The present results are similar to Saad et al. (2015) which found that the maximum occurrence of macrobenthic invertebrates was recorded during spring and the minimum occurred during winter. Also, it partially coincided with El-Damhogy et al. (2017) who found that the highest average number of macrobenthic invertebrates was recorded during spring, while the lowest was recorded during summer. So, the variations of seasonal

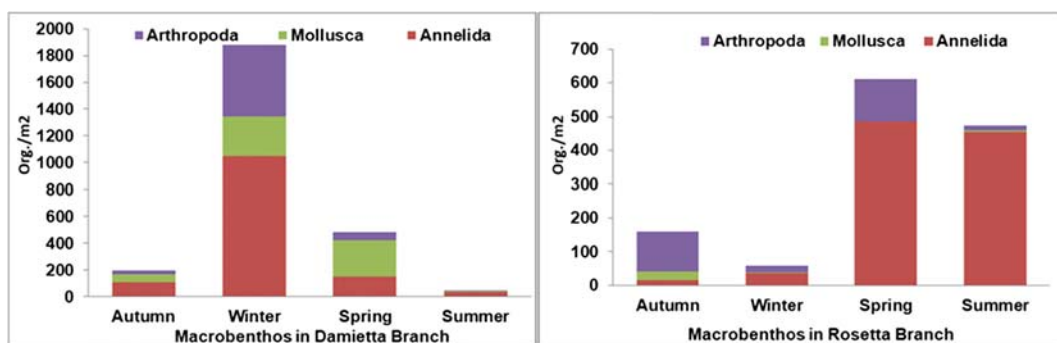


Fig. 3 Seasonal variations of macrobenthic groups in Damietta and Rosetta branches

distribution of macrobenthic invertebrates in both Damietta and Rosetta branches indicate wide differences between the environmental conditions and habitats of the two branches, where the Rosetta Branch receives huge quantities of sewage, agricultural, and industrial drainage (Hegab 2010), while there is no significant pollution in Damietta Branch.

Biotic indices

Biomonitoring is the most suitable method for the ecological studies to control the water quality changes because the living organisms are very good biosensors of the abiotic and biotic characteristics of water (Kholodkevich et al. 2008).

The BMWP and NBPI indicated that the water quality of the Damietta Branch was within the moderate class with a score of 60 and 65, respectively. Site D1 recorded the highest scores of 75 and 85 of BMWP and NBPI, respectively, while site D3 recorded the lowest scores of 42 and 41 for BMWP and NBPI, respectively (Table 6). BMWP and NBPI scores were ranged between 25 and 29 at R4 and 10 and 8 at R1, respectively, which indicate that the water quality of Rosetta Branch was varied from polluted to extremely polluted classes (Table 6).

BMWP showed a highly significant regression ($p < 0.0001$; $R^2 = 0.83$ and 0.87) with Canadian WQI for drinking and aquatic life uses, respectively, while the regression between BMWP index and CWQI for the irrigation usage was not significant ($p < 0.203$) (Fig. 4). Moreover, the relation between NBPI index and the applied chemical indices showed the same results, where NBPI showed a highly significant regression ($p < 0.0001$; $R^2 = 0.767$ and 0.808) with drinking and aquatic life indices, respectively, while the regression between NBPI index and irrigation index was not significant ($p < 0.249$).

The results of the biotic indices (BMWP and NBPI) rather coincided with that obtained by chemical indices. These results confirm the validity of BMWP and NBPI indices to assess the water quality of the study area. BMWP index is widely applied and valid to evaluate water quality in several countries around the world (the UK, Spain, Portugal, Turkey, Poland, Latin America, and others) (Ruiz-Picos et al. 2017). Furthermore, this index was modified to NBPI, and it was tested for evaluating the water quality of the Nile River (Fishar and Williams 2008). Fishar and Williams (2008) found a highly significant regression between the biotic indices (BMWP and NBPI) and Nile Chemical Pollution Index. Also, they mentioned that both BMWP and NBPI are given the actual image of the water quality of the Nile

Table 6 Biotic indices (NBPI and BMWP) scores and water quality classes for the studied sites in Damietta and Rosetta branches of Nile River, Egypt

Site	BMWP		NBPI	
	Score	Class	Score	Class
D1	75	Moderate	85	Moderate
D2	54	Slightly polluted	53	Slightly polluted
D3	42	Polluted	41	Polluted
D4	64	Moderate	77	Moderate
D5	67	Moderate	69	Moderate
Average	60	Moderate	65	Moderate
R1	10	Extremely polluted	8	Extremely polluted
R2	7	Extremely polluted	10	Extremely polluted
R3	11	Extremely polluted	11	Extremely polluted
R4	25	Very polluted	29	Very polluted
R5	13	Extremely polluted	13	Extremely polluted
R6	20	Very polluted	23	Very polluted
Average	14	Extremely polluted	16	Very polluted

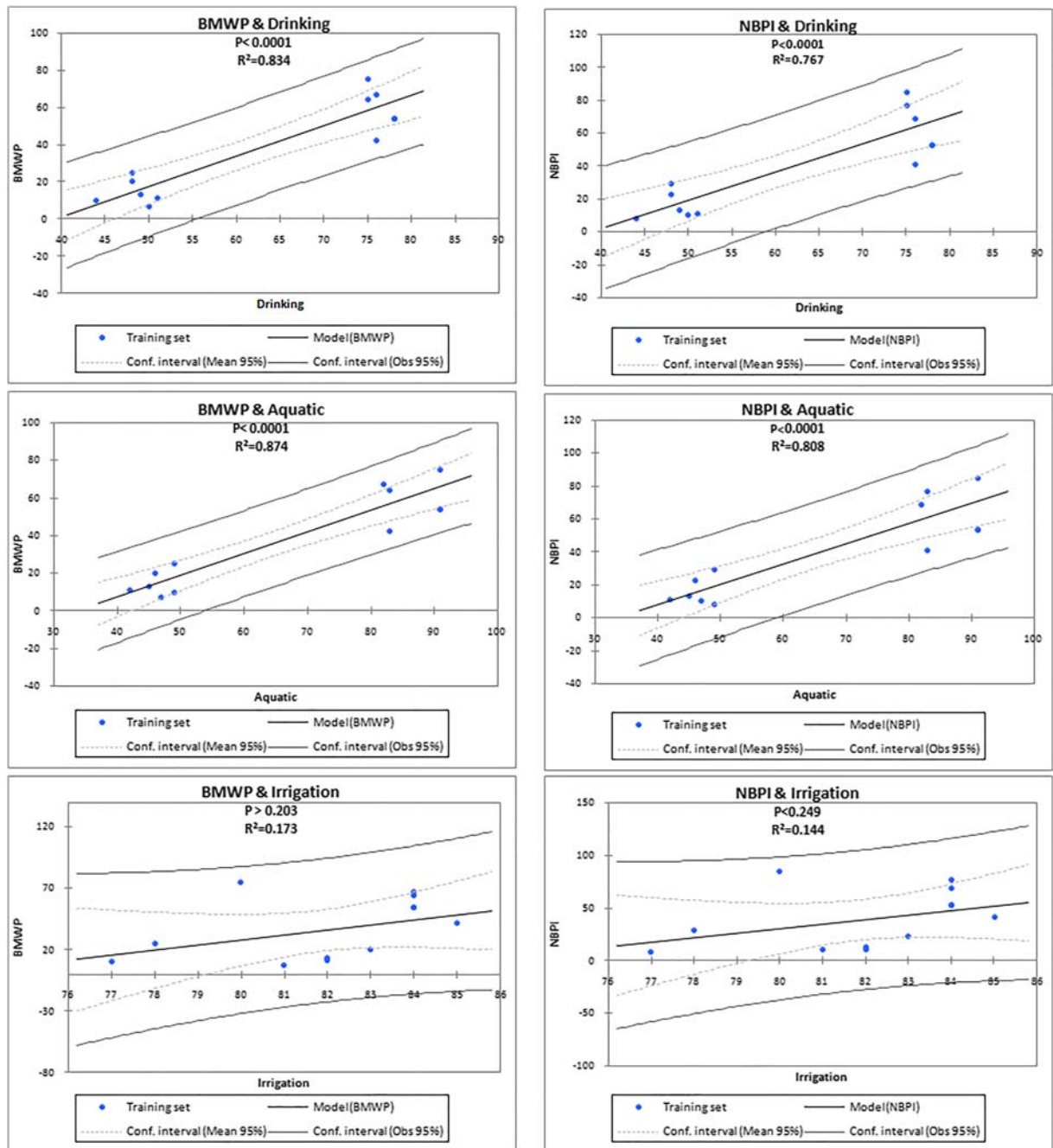


Fig. 4 Regression plots of biological indices (BMWP and NBPI) scores against the chemical indices (CWQI) (drinking, aquatic life, and irrigation) scores of the same sites in Damietta and Rosetta branches of Nile River, Egypt

River. While both biotic indices coincided with the drinking and aquatic life indices, they did not coincide with irrigation index. That may be because each chemical index depends on specific chemical parameters, which differ from index to another. Also, the permissible

limits of the used parameters are varied from index to another, where the permissible limits of water quality parameters of irrigation are higher than that of drinking and aquatic life limits (Hespanhol and Prost 1994; Fewtrell and Bartram 2001). Therefore, the response

degree of macroinvertebrates to the water quality changes of drinking and aquatic life criteria may be clearer than that of irrigation one.

In general, the study proved that BMWP and NBPI indices are valid to evaluate the water quality of the study area and coincided with the CWQI for drinking and aquatic life uses. Water quality assessment by chemical and biological indices indicate that the water of Rosetta Branch is severely degraded and not suitable for drinking and aquatic life utilizations, while the Damietta Branch is suitable for all purposes.

Conclusion

This study applied the biotic indices that depend on macroinvertebrates (BMWP and NBPI) to evaluate the water quality of the two Nile branches, Damietta and Rosetta, in integration with the indices that depend on the chemical analysis (Canadian WQI). The all-chemical parameters except for the dissolved oxygen were much higher and exceed standard levels in Rosetta Branch than in Damietta Branch. On the other hand, the Damietta Branch showed the frequent presence of the families such as Neritidae and Unionidae which are bioindicators of moderate and good water quality. Instead, the most resistant species to pollution (*Limnodrilus* spp. and *Chironomus* sp.) were frequently recorded in the Rosetta Branch. CWQI was matched with biological indices (BMWP and NBPI) and revealed that the water of Rosetta Branch is classified from marginal to poor for the drinking and aquatic life uses, while it is categorized as fair to good for irrigation usage. The water quality of Damietta Branch is classified as fair with respect to drinking water and good to aquatic life and irrigation, which state the deterioration status and the pollution level of Rosetta Branch water compared to Damietta Branch. Also, the study concluded that the BMWP and NBPI indices are valid to evaluate the water quality of the study area.

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