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Characterization of Chemical Water Quality in the Nile River, Egypt

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ABSTRACT

Providing safe and secure water to people around the world, and promoting sustainable use of water are fundamental objectives. Quality of water is the property that tells whether water is polluted or not and assessing water quality is a very complex subject. Rivers are the most important freshwater resource for man life. Civilization related activities e.g. manufacturing, mining, construction, runoff from agricultural areas, and discharge of treated and untreated sewage transportation are among the major reason for deteriorating the water quality, especially in developing countries). This is the case for the River Nile in Egypt which considered the principal artery of life in Egypt comprising about 97% of the existent water supplies. The Nile water quality is characterized by high nutrients concentrations (maximum of nitrates, 0.63 mg/L; nitrite, 0.472 mg/L; ammonia, 2.83 mg/L; total nitrogen, 3.48 mg/L; phosphates, 0.461 mg/L; total phosphates, 0.53 mg/L; sulfates, 62.57 mg/L and silicates, 3.50 mg/L) at some locations (e.g. El-Nasria). This is obviously influenced by the quality of water coming from El-Nasria Pumping Station. A recognizable depletion in Hydrogen ion concentration (pH) and dissolved oxygen (DO) was recorded at this site. High concentrations of total dissolved salts (TDS) with maximum level of 524.00 mg/L, Sulphate Chlorides and other conductible salts highly impacted the Nile water conductivity (EC). The Nile water near Mansoura City tends to shift to the alkaline side of the pH range due to the existence of carbonates and bicarbonates. Variations in pH and alkalinity were found to be controlled by the level of CO₂ liberated through the nitrification process undertaken within the system followed nutrients and phytoplankton peaks. The mathematical statistical estimation of Water Quality Index (WQI) were help to categorize the Nile water quality at this segment to be ranged from medium/fair to poor quality status. Results refereed to Site 4 (El-Nasria) as the highest polluted site throughout the study long in response to excessive and unrecompensed activities at some villages nearby as well as the wastewater runoff. The study recommended (i) divert the polluted water away off the River Nile; (ii) a better treatment technique to be applied to wastewater pumped to El-Nasria site via El-Nasria Pumping Station. Application of a reliable and continuous monitoring methodology along the whole River is a crucial demand to mitigate health problems outbreaks or any aquatic ecosystem disorders.

Keywords: The River Nile, Water quality Index, Physico-Chemical analysis, Mansoura City, GIS, heavy metals, nutrients.

INTRODUCTION

Water is vital to the existence of all living organisms, but this valued resource is increasingly being threatened as human populations grow and demand more water of high quality for domestic purposes and economic activities. Providing safe and secure water to people around the world, and promoting sustainable use of water resources are fundamental objectives of the Millennium Development Goals; MDGs³⁰. Water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter. Rather, it is variable in both time and space and requires routine monitoring to detect spatial patterns and changes over time. There is range of chemical, physical, and biological

components that affect water quality and hundreds of variables could be examined and measured. Some variables provide a general indication of water pollution, whereas others enable the direct tracking of pollution sources.

Quality of the drinking Water is a crucial demand as it is an essential substance upon which all life depends; however the world's finite supply of freshwater has been subjected to increasing pressures over the last 50 years. Surface water sources (such as rivers and lakes) only constitute 0.0067% of the total world water⁴³. By 2025, if the current trends of life/water use persisted, the demand for freshwater is expected to rise by 56% more than what is currently available⁶⁰. This enhances the ultimate need for sustainable development or/and use of natural water resources worldwide, particularly fresh-water ones.

The River Nile is one of the world longest rivers and is the donor of life to Egypt and represents the principle freshwater resource that meets nearly all demands for drinking water and irrigation^{58,9}. The River Nile flows from south to north with 6,850 kilo meters long and over 35 degrees of latitude. Its catchment basin covers approximately 10 % of the African continent, with an area of 3 106 Km², and spreads over 10 countries from Uganda in the south to Egypt in the north. Passing through Kenya, Tanzania, Rwanda, Burundi, DR Congo, Zaire, Ethiopia, and Sudan⁴². BY the beginning of fifties of the Nineteenth century, heavy industries were introduced to Egypt along the Nile (i.e. in Delta, Cairo and Alexandria) of which, chemicals, food, metal products, and textiles industries are the most prominent activates³⁶. Undoubtedly, this industrial revolution has dramatically affected the Nile water quality. These industrial pollutants exhibited deleterious effects on structure and function of the resident biological communities. Low water quality was determined within the downstream water of Damietta and Rosetta branches^{24,4,5,53,54,2}. The international community has recognized the links between ecosystem and well-being particularly, as human populations expand and place ever greater pressure on natural environments³⁰. However, the ability to properly track progress toward minimizing impacts on natural environments and improving access of human to safe water depends on the availability of data that document trends at both space and time dimensions.

Monitoring the Nile River is therefore crucially targeted for better management and sustainable development of this valuable life artery not only for Egypt but also for the other 10 countries. The main objective of this research is to provide an overview of the major components and characteristics of the Nile surface water quality at a segment of the River Nile near Mansoura City. The study is focused on analysing some water quality attributes and integrated their inter-linkage in response to man-made activities around the study area. Application of a mathematical integrated analysis (Water Quality Index; WQI) and the spatial mapping (ArcGIS) helped to generate a series of maps scoring and describing the Nile water status. This study would help in proposing new recommendations and solutions to enhance the Nile water quality, to minimize the impacts of the continuously developed man-made activities and/or to mitigate health problems outbreaks.

MATERIALS AND METHODS

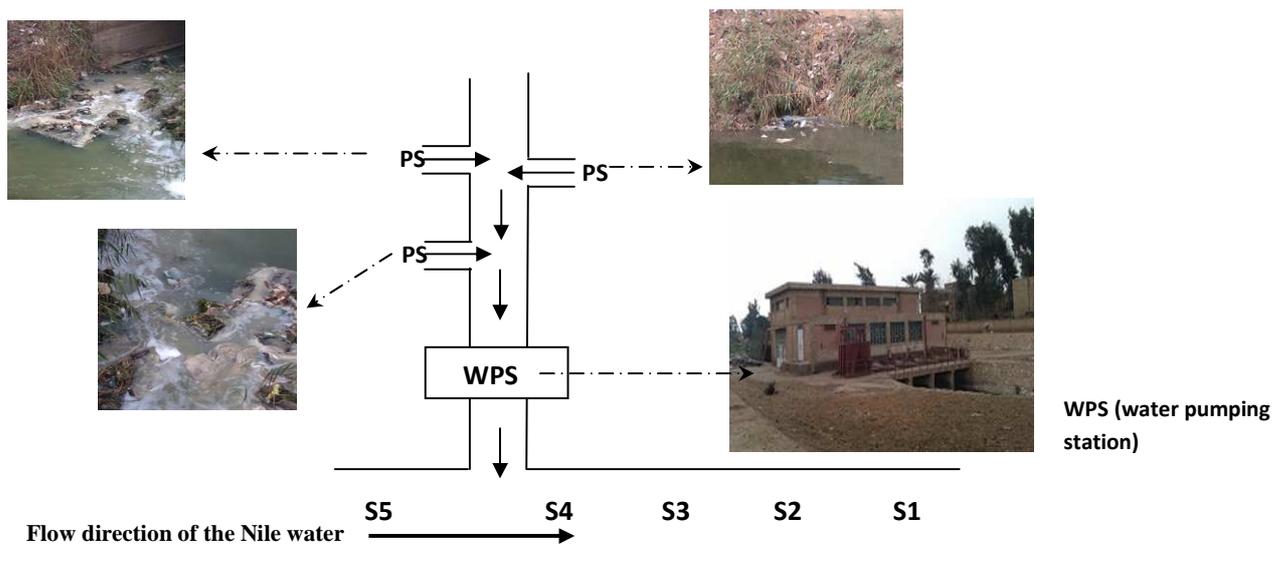
Study Area

Five sampling sites were selected lengthwise the study segment of Damietta branch. These are distributed between Aga town (31°03'41.34"N, 31°34'84.45"E) at the south and Mansoura city (30°92'33.15"N, 31°22'25.57"E) at the northern part of the River Nile (Figure 1). This section of the Nile River is typically bounded by variable land uses that have direct and indirect impact on the water quality. This includes agriculture, urban, industrial and others. It worth mentioning that El-Nasria sampling site is receiving water from El-Nasria Pumping Station.

Fig. 1: Map shows the study segment of the River Nile and the five sampling sites



Meet Khamis (S1), Nawsa El-Bahr (S2), Meneit Samanod (S3), El-Nasria (S4) and Abo Sair (S5) near Mansoura City. The digrame (below) shows the water sources, flow, and direction before entering the main River body



N.B. PS = Multiple lateral point sources of polluted and wastewaters that drain in the River Nile.

Sampling Procedure

Water samples were collected once a month from March, 2011 to February, 2012. Sampling process was regularly starts at 9.00 am and lasts for approximately two-three hours to undertake water sampling process out of five sites covering the study segment. Surface water samples (1 m) were collected using non-metallic water sampler and kept in dark until reach the laboratory. Samplers were soon sent to the laboratory (faculty of Sciences at Mansoura University) where all analyses and investigations were undertaken.

Sample analyses

Analyses of physical and chemical characteristics of water sampled were carried out according to the standard methods for examination of water^{10,11}. Water temperature was measured using mercury thermometer. Electric conductivity (EC) was measured by YSI model 33 S.C.T. meter. Total dissolved salts (TDS) were determined by CORNING (Cole-Parmer model Check-mate 90). Hydrogen ion concentration (pH) was measured using a HORIZON ECOLOGY CO. PH meter Model 5995. Concernin dissolved oxygen (DO), it was determined by the modified Winkler⁶³ method as described by Wood⁶⁴. Welch⁶² method was used to determine total alkalinity where the method adopted, by Diehl et al.²³ was used to measure total hardness. Chloride, dissolved reactive phosphorus (DRP), sulfate and Reactive silica was determined by the methods descried in APHA¹⁰. Nitrate - N was determined using the method described by Barnes and Folkard¹⁴ and Dewis and Freitas²². Nitrate-N was determined by the method described in Golterman (1969). Ammonia-N, was determined by the method descried in APHA¹¹. Total dissolved nitrogen and phosphorus were measured by the modified⁴⁵ method as described by D'Elia et al.,²¹. Biological Oxygen Demand was determined according to the methods descried in APHA¹⁰. Analysis of the heavy metals followed the direct aspiration into an air-acetylene flame using atomic absorption spectrophotometer type BUCK Scientific ATOMIC ABSORPTION SPECTROPHOTOMETER model ACCUSYS 211.

Water Quality Index (WQI)

WQI is a 100 point scale that was used to summarize results from different physico-chemical measurements using computer program created by the National Sanitation Foundation, USA. The used parameters are: DO, pH, temperature, PO₄, NO₃ and TDS. This index transforms huge amount of data to a single number, which then used to rank water into one of five descriptive categories of water qualities ranged from very bad conditions (0-25), to excellent conditions (90-100).

To spatially show the monthly changes in water quality and eutrophication status together with the changes among sites, a series of 12 maps representing the Nile water quality (expressed as WQI values) were produced using ArcGIS 9.2 package. The built-in statistical simulation model in the GIS package (the Inverse Distance Weighted method, IDW) was used to interpolate the monthly spatial distribution of WQI. The mechanism of the IDW method is based on averaging the parameter values at each location and the neighborhood considering the geographical distance between the stations and assuming that there is no environmental changes between the stations (ESRI 2007). For more accuracy the triple replicate values, rather than the mean value, for each of the six parameters were used in calculating the WQI at each site (ESRI 2007). Triple values, rather than the mean value, for each of the six parameters were considered in calculating the WQI at each site.

Statistical Analyses:

Correlation (predictive statistics) was carried out using STATGRAPHICS (STSC, ver. 4.2) program. The correlation coefficients are considered significant at the 95% confidence level ($p \leq 0.05$). Also Bary-Curtis similarity index in cluster analyses was carried out using the Past program (multivariate statistical package, ver. 1.72). Correlations among determined parameters are shown in table (2).

Table 2: Correlation coefficient between the different Physico-Chemical parameters

Parameters	Temperature	PH	T.D.S	E.C	Chloride	Total Alkalinity	Total Hardness	D.O	Saturation	Ammonia	Nitrate	Nitrite	Total N	Reactive P	Total P	Sulfate	Silica	Fe	Zn	Cu	Co	Pb	WQI	
Temperature	1.00																							
PH	-0.68	1.00																						
T.D.S	-0.19	-0.10	1.00																					
E.C	-0.17	-0.07	0.99	1.00																				
Chloride	-0.46	0.16	0.91	0.89	1.00																			
Total Alkalinity	-0.73	0.69	0.46	0.46	0.65	1.00																		
Total Hardness	-0.49	0.19	0.84	0.83	0.90	0.73	1.00																	
D.O	-0.55	0.49	-0.50	-0.50	-0.27	0.16	-0.18	1.00																
Saturation	-0.58	0.64	-0.53	-0.52	-0.26	0.27	-0.17	0.95	1.00															
Ammonia	0.14	-0.15	0.62	0.64	0.47	0.20	0.41	-0.54	-0.56	1.00														
Nitrate	0.03	-0.28	0.57	0.56	0.43	-0.01	0.36	-0.46	-0.50	0.45	1.00													
Nitrite	-0.13	-0.06	0.79	0.79	0.70	0.33	0.72	-0.48	-0.47	0.45	0.39	1.00												
Total N	0.04	0.14	0.60	0.62	0.57	0.52	0.48	-0.55	-0.45	0.74	0.30	0.32	1.00											
Reactive P	0.01	-0.28	0.84	0.83	0.68	0.15	0.68	-0.56	-0.60	0.56	0.66	0.78	0.39	1.00										
Total P	-0.19	-0.06	0.85	0.82	0.79	0.49	0.83	-0.43	-0.43	0.55	0.48	0.73	0.58	0.85	1.00									
Sulfate	0.15	-0.24	0.83	0.85	0.67	0.15	0.54	-0.64	-0.66	0.66	0.47	0.71	0.57	0.69	0.57	1.00								
Silica	0.43	-0.42	-0.45	-0.45	-0.53	-0.68	-0.59	-0.23	-0.16	-0.28	0.01	-0.26	-0.37	-0.22	-0.42	-0.26	1.00							
Fe	0.08	-0.07	-0.16	-0.16	-0.19	-0.25	-0.23	-0.08	-0.07	-0.15	0.07	-0.14	-0.15	-0.07	-0.17	-0.09	0.33	1.00						
Zn	-0.21	0.03	0.13	0.14	0.11	0.03	0.08	-0.11	-0.10	0.13	0.32	0.18	-0.04	0.21	0.08	0.20	0.12	0.27	1.00					
Cu	-0.41	0.26	0.20	0.15	0.22	0.30	0.35	0.13	0.20	-0.03	-0.19	0.19	0.00	0.20	0.28	0.04	-0.06	0.02	0.48	1.00				
Co	0.04	0.06	-0.10	-0.08	-0.12	-0.07	-0.10	0.15	0.10	0.14	-0.15	0.04	-0.06	-0.09	-0.02	-0.08	-0.06	0.03	-0.09	-0.04	1.00			
Pb	-0.15	0.20	0.00	0.00	0.08	0.10	0.10	0.07	0.08	0.02	-0.06	0.03	0.00	0.01	0.03	-0.06	0.04	0.05	-0.17	-0.07	-0.23	1.00		
WQI	-0.05	0.10	-0.83	-0.85	-0.70	-0.22	-0.64	0.53	0.54	-0.61	-0.57	-0.74	-0.55	-0.82	-0.73	-0.79	0.29	0.05	-0.03	0.08	-0.01	0.05	1.00	

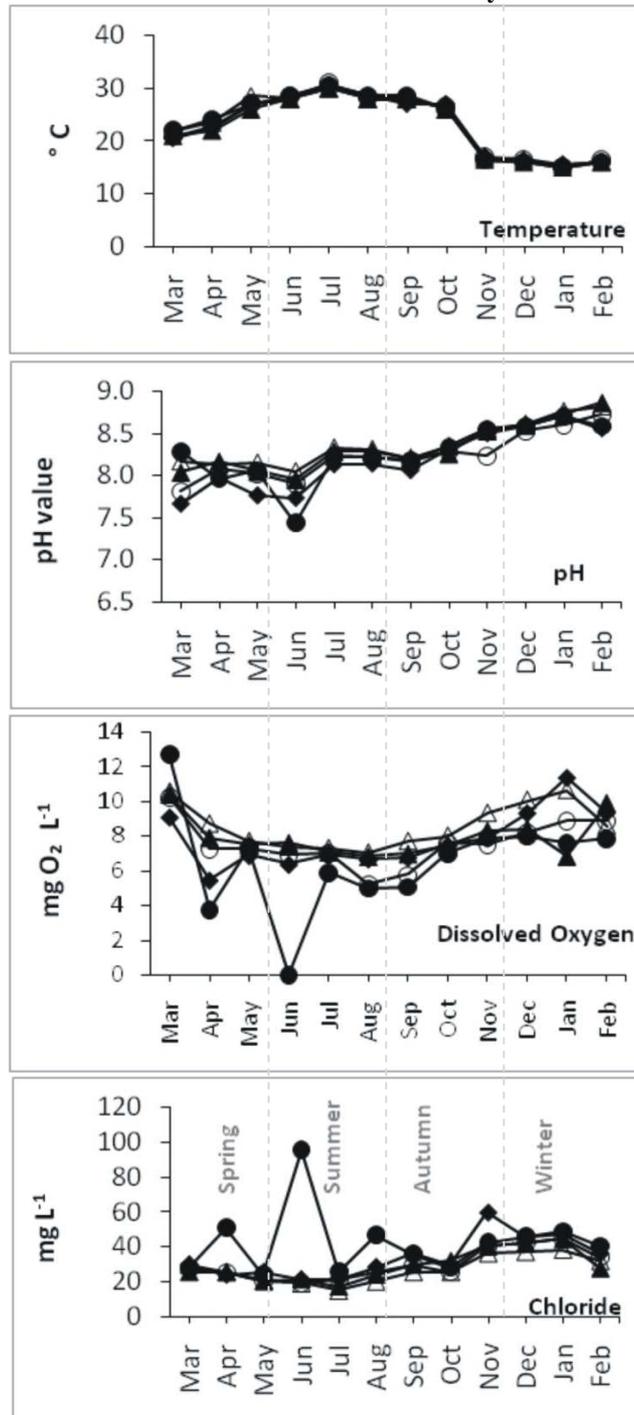
N.B. Significant correlation at probability (p) ≤ 0.05

RESULTS

Temperature and pH

Temperatures of sampled Nile water were conformable to the Egyptian climate with low values during winter season increase towards summer season (figure 2). Temperatures ranged from a lowest value of 15°C (during winter; January, 2012) to highest value 31 °C (during summer; July, 2011). With regards to pH, determined pH values showed a tendency towards alkaline side (figure 2), with no clear seasonal changes during the study period. However, a sudden decrease in pH value (7.44) was recorded at El-Nasria during June 2011.

Fig. 2: Monthly variations in Temperature, pH, dissolved oxygen and chloride along the study segment of the River Nile near Mansoura City



Dissolved oxygen (DO) and Biological Oxygen demand (BOD):

Average dissolved oxygen results ranged from 0.0 to 12.7 mg O₂ l⁻¹ with minimum value at El-Nasria during June, 2011 and maximum values at sampling El-Nasria during March, 2011 (figure 2).. Not unexpectedly, the amount of DO was highly dependent on temperature during the sampling year (2011-2012) with minimum levels during warm months and gradually increased with decreasing temperature (figure 3). DO concentration (figure 4) was generally well-above the concentration below which most fishes die¹⁸ with minimum levels at El Nasria; S4 (mainly in summer) (figure 2).

Fig. 3: Monthly variations in dissolved oxygen versus Temperature along the study segment of the River Nile near Mansoura City during 2011-2012

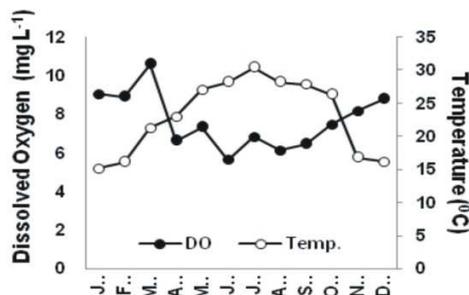
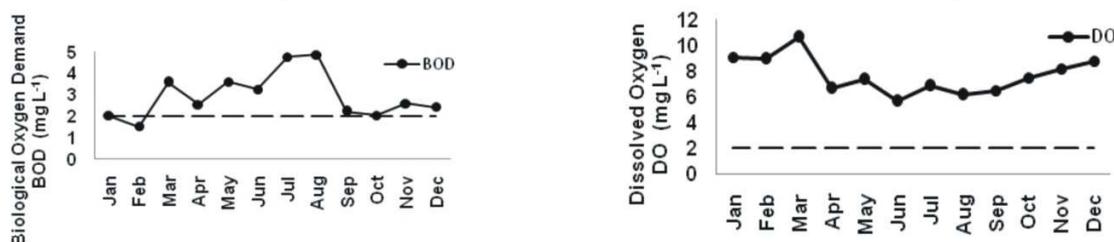


Figure 4: Monthly variations in biological oxygen demand (BOD) and dissolved oxygen (DO) along the study segment of the River Nile near Mansoura City during 2011-2012. Dashed lines represent the BOD concentration below which a system is described as unpolluted and the Do concentration below which most fish die (Chapman, 1996)



Values of oxygen saturation help to give a true picture of dissolved oxygen at the sampling area (table 1) and was correlated strongly positive ($r = 0.95$) with dissolved oxygen. %O₂ ranged between 0.0% and 145.1% (data not plotted) with a minimal % at El-Nasria during Jun, 2011 and a maximal % at Met-Khames (downstream) during January, 2012.

Changes and values in BOD along the sampling sites (figure 4) reflected, to somehow, the degree of organic matter pollution along this segment of the River Nile. BOD concentration was sometimes close to the threshold of unpolluted waters (figure 4); however it was in most months away ahead such value. This is due to the impact of the low quality water at El Nasria (S4), particularly during June, July and August which might be an indicative of organic pollution at this site during these months.

Major Ions in the River Nile

Out of the four major cations, calcium and magnesium were determined (as alkalinity and hardness, in their carbonate form). Meanwhile Chlorides and Sulphates were determined as the major dominant anions (Table 1).

Total alkalinity and Total hardness

Alkalinity is produced by the existence of minerals such as limestone (CaCO₃). Total alkalinity showed distinctive variations throughout the sampling period with regards to time, however, slight spatial changes were recorded along the sampling segment of the Nile River. As some other parameters, S4 showed the highest alkalinity values with two pronounced peaks in April (85.0 mg CaCO₃ L⁻¹) and June (132.5 mg CaCO₃ L⁻¹). As total alkalinity refers to the water's ability to neutralize acids, it correlated significantly with factors increase this ability, for example, total hardness ($r = 0.73$), chloride ($r = 0.65$) and total N ($r = 0.52$).

Hardness refers to the concentration of calcium and magnesium in water with hard water possesses high concentrations of these elements. Total hardness in The Nile River at the studied segment ranged from 41.15 to 111.18 mg CaCO₃ l⁻¹ (table1). The minimum value was recorded at S1 (Met-Khames) while the maximum was recorded at S4 (El-Nasria). Both TDS and total hardness were directly proportioned ($r = 0.78$) due to the fact that hard water is mostly characterized by high levels of TDS than soft water.

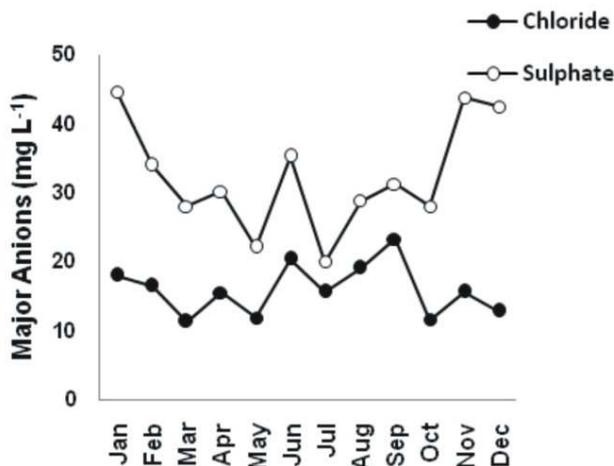
Table 1: Summary statistics of physical and chemical water parameters determined at 5 sites along the River Nile near Mansoura City in 2011/2012

Parameter	Unit	N*	Meet Khamis			Nawsa El-Bahr			Meneit Samanod			El-Nasria			Abo Sair		
			Min*	Max*	Mean*	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Temperature	°C	12	15.5	30.5	23.0	15.0	31.0	23.0	15.0	30.0	23.0	15.0	30.5	23.0	15.5	30.0	23.0
pH	Unit	12	7.66	8.72	8.18	7.81	8.73	8.23	7.95	8.87	8.33	7.44	8.71	8.26	8.05	8.82	8.37
TDS	mg L ⁻¹	12	168.00	222.00	197.75	161.00	234.00	199.67	154.00	225.00	188.92	171.00	524.00	255.08	147.00	216.00	182.92
Conductivity	µmhos.cm ⁻¹	12	466.00	596.00	539.42	460.00	626.00	543.92	443.00	618.00	526.58	483.00	1310.00	679.25	410.00	602.00	504.67
Chloride	mg L ⁻¹	12	21.24	59.47	33.57	19.12	44.60	29.65	16.99	44.60	29.17	23.79	95.58	42.54	14.87	38.23	26.99
Total alkalinity	mg CaCO ₃ L ⁻¹	12	57.50	147.50	97.79	55.00	157.50	99.29	52.50	157.50	98.46	60.00	172.50	114.58	32.50	147.50	92.83
Total hardness	mg CaCO ₃ L ⁻¹	12	41.15	68.06	56.24	44.60	66.83	56.49	44.50	69.30	55.89	47.85	111.38	65.25	45.05	65.59	54.22
DO	mg O ₂ L ⁻¹	12	5.47	11.38	7.80	5.22	10.24	7.56	6.83	10.39	7.93	0.00	12.70	6.50	7.05	10.65	8.59
% of O ₂	%	12	69.75	145.10	97.56	66.56	113.19	94.22	87.08	126.13	99.00	0.00	131.58	80.38	89.90	135.82	107.79
Ammonia- N	mg L ⁻¹	12	0.03	0.29	0.15	0.03	0.35	0.19	0.01	0.28	0.12	0.00	2.83	1.13	0.00	0.09	0.02
Nitrate- N	mg L ⁻¹	12	0.08	0.53	0.17	0.04	0.38	0.13	0.03	0.33	0.13	0.05	0.63	0.22	0.00	0.17	0.08
Nitrite- N	mg L ⁻¹	12	0.03	0.11	0.067	0.03	0.15	0.077	0.02	0.14	0.076	0.03	0.47	0.147	0.00	0.13	0.058
TN	mg L ⁻¹	12	0.13	2.15	1.43	0.05	2.23	1.43	0.40	2.15	1.39	0.45	3.48	2.36	0.43	1.98	1.19
DRP	mg L ⁻¹	12	0.00	0.04	0.019	0.00	0.03	0.014	0.00	0.03	0.008	0.00	0.46	0.099	0.00	0.01	0.006
TP	mg L ⁻¹	12	0.01	0.14	0.07	0.02	0.14	0.08	0.01	0.13	0.08	0.03	0.53	0.17	0.01	0.13	0.07
SO ₄	mg L ⁻¹	12	10.75	17.68	13.45	10.09	16.61	12.95	9.30	16.79	12.96	11.26	62.57	25.17	8.04	15.39	11.11
Reactive silica	mg L ⁻¹	12	0.24	3.50	1.39	0.23	3.34	1.35	0.37	3.32	1.29	0.23	2.80	0.80	0.28	3.27	1.22
Fe	mg L ⁻¹	12	0.08	0.48	0.20	0.10	0.88	0.34	0.08	0.55	0.21	0.06	0.40	0.19	0.02	0.53	0.21
Zn	mg L ⁻¹	12	0.08	1.52	0.35	0.05	4.78	0.65	0.01	2.47	0.55	0.02	6.95	1.32	0.01	0.335	0.13
Cu	mg L ⁻¹	12	0.00	0.02	0.01	0.00	0.05	0.02	0.01	0.02	0.01	0.01	0.07	0.03	0.00	0.027	0.02
Co	mg L ⁻¹	12	0.59	2.67	1.15	0.31	2.98	1.36	0.73	3.63	1.78	0.50	3.79	2.10	0.43	3.50	1.43
Pb	mg L ⁻¹	12	0.05	1.28	0.51	0.20	1.20	0.66	0.27	1.70	0.91	0.17	1.78	0.84	0.17	2.32	0.95

Chlorides and sulphates

Figure 5 shows the variability in anion patterns (Cl & S) of the River Nile near Manoura. Chloride concentration ranged from 14.87 mg l⁻¹ to 95.58 mg l⁻¹ with lowest value (14.87 mg l⁻¹) at S5 (Abo- Seir) and highest value (95.58 mg l⁻¹) at S4 (El-Nasria). Increasing concentrations of chlorides, mostly sodium chloride, increases Salinity of water. Not unexpectedly chloride concentrations hence, maintained strong positive correlations with TDS (r = 0.91), total hardness (r = 0.90), conductivity (r = 0.89).

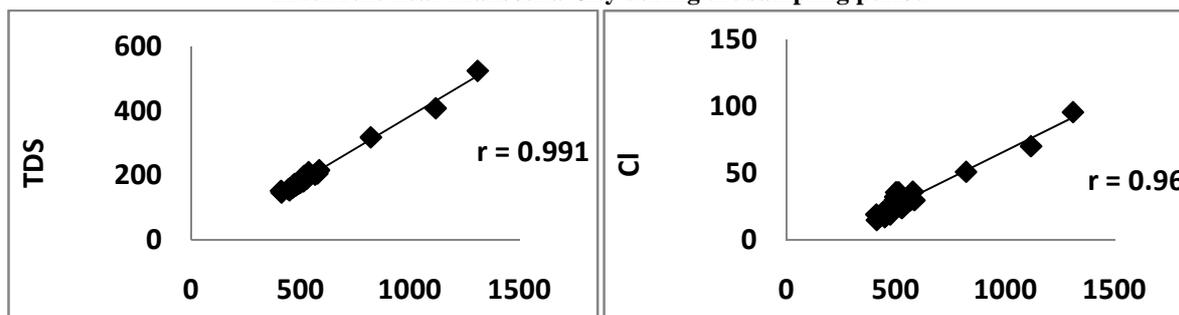
Fig. 5: Monthly variations in major ions (Chlorides & Sulphates) along the study segment of the River Nile near Mansoura City during 2011-2012

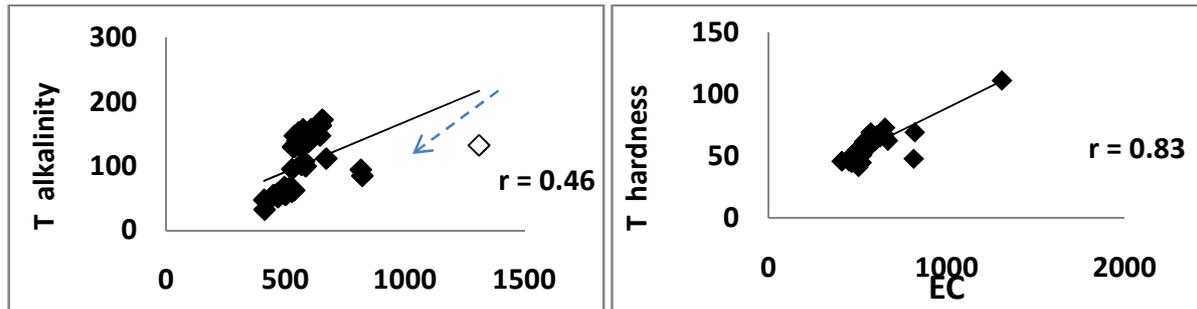


Total Dissolved Salts (TSD) and Electrical Conductivity (EC)

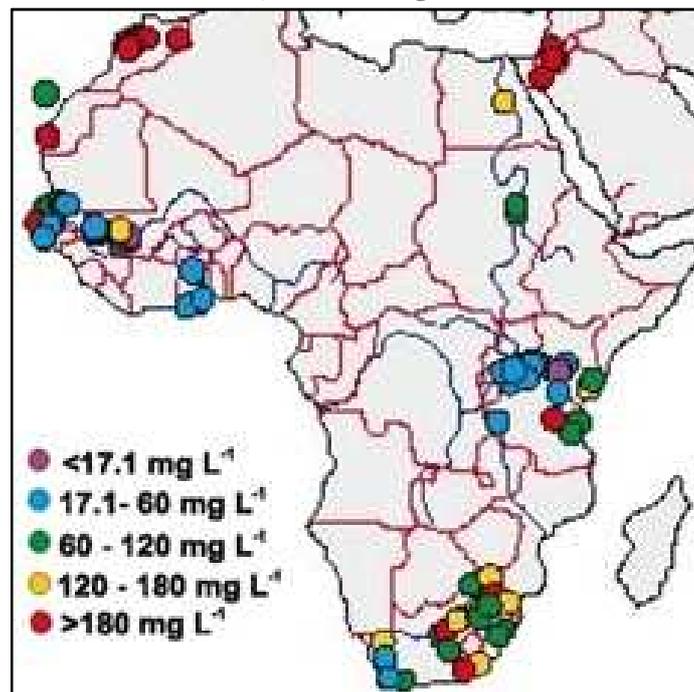
TDS, the measure of the material dissolved in water or/and sediment suspended in the water, showed slight variations throughout the sampling segment of the Nile (table 1). An obvious increase in TDS was however, recorded at S4 (El-Nasria) during April (318.0 mg l⁻¹) and June (524.0 mg l⁻¹), 2011. Similar pattern was recorded with regards to electrical conductivity (EC) with high values (821.0 and 1310.0 μmhos cm⁻¹) at S4 in both months, respectively. As conductivity measures the water’s ability to conduct an electrical current; it increased whenever water purity decreases. This describes the strong significant relationships (figure 6) between EC and not only TDS (r = 0.99) but also, other salts related parameters, e.g. Chlorides (r = 0.96, total hardness, (r = 0.83). This might be attributed to their documented conductivity effect.). The discrepancy observed in the relationship between EC and total alkalinity (r = 0.46) was due to high peak in EC (1310) occurred at El Nasria in June and was not coincident with a peak in total alkalinity. This could be resulted from existence of other highly conductive salts coming along from El Nasria Pumping Station. It is worth mention that water quality of this month was the poorest and water at El Nasria was characterised by bacterial dense patches (pers. Comm.) and undetectable DO concentration (figure 2) resulted from the maceration processes in nearby villages.

Fig. 6: Left: Scatter plot of electrical conductivity (EC) values against values of total dissolved salts (TDS), chloride (Cl), total alkalinity (T alkalinity) and total hardness (T hardness) along the study segment of the River Nile near Mansoura City during the sampling period





Map show the distribution of water hardness in African lakes and rivers as UNEP GEMS/water programme (GEMS, 2000) investigations tell



Nutrients

Monthly changes of all nutrients measured at the sampled segment of The Nile River is presented in figure (7a&b) and table (1). Results showed that nutrients were generally recorded with high levels during spring and summer (the main agriculture season in Egypt) decreasing towards winter. Slight site to site variations in all nutrients (NO_3 , NO_2 , NH_4 , TN and TP) have been observed among the five sites except for S4 (El Nasria) which experiencing relatively high levels of nutrients (2.83 mg NH_4/L , 0.634 mg NO_3/L , 0.472 mg NO_2/L). Minimum nutrient levels were however, determined at S5 (Abo Sair), particularly for NO_3 (undetectable concentration) and NO_2 (0.002). Total nitrogen (TN) experienced an obvious seasonal trend of variation with maximum concentrations during winter (figure 7b). TN fluctuated within a wide range of variations (0.050 to 3.481 mg/L) with maximum levels recorded at S4 (El-Nasria) and minimum levels at S2 (Nawsa El-Bahr).

Values of Total Dissolved Phosphorus (TDP) varied from 0.005 mg/L to 0.533 mg/L (figure 7a) with a trend similar to that recorded for DRP (Dissolved Reactive Phosphorus). Similar to trend of ammonia-N, DRP showed Slight site to site variations with the highest concentration (0.461 mg/L) at El-Nasria site during April and Jun, 2011. The lowest concentration (0.001 mg/L) was however measured at Meneit Samanod (S3). Concentration of reactive silicates ranged from 0.233 and 3.504 mg/L with maximum levels at S1 and S4 (figure 7a). Sulphate had a similar trend to that of reactive silicates with a range varied from 8.037 to 62.570 mg/L. Maximum levels of both attributes were recorded at S1 and S4, respectively; Minimum levels were, however obtained at Abo Sair and El-Nasria, respectively.

Fig. 7(a): Monthly variations in nutrients (nitrates, nitrites, ammonia, phosphates and silicates at the five sampling sites along the study segment of the River Nile near Mansoura City

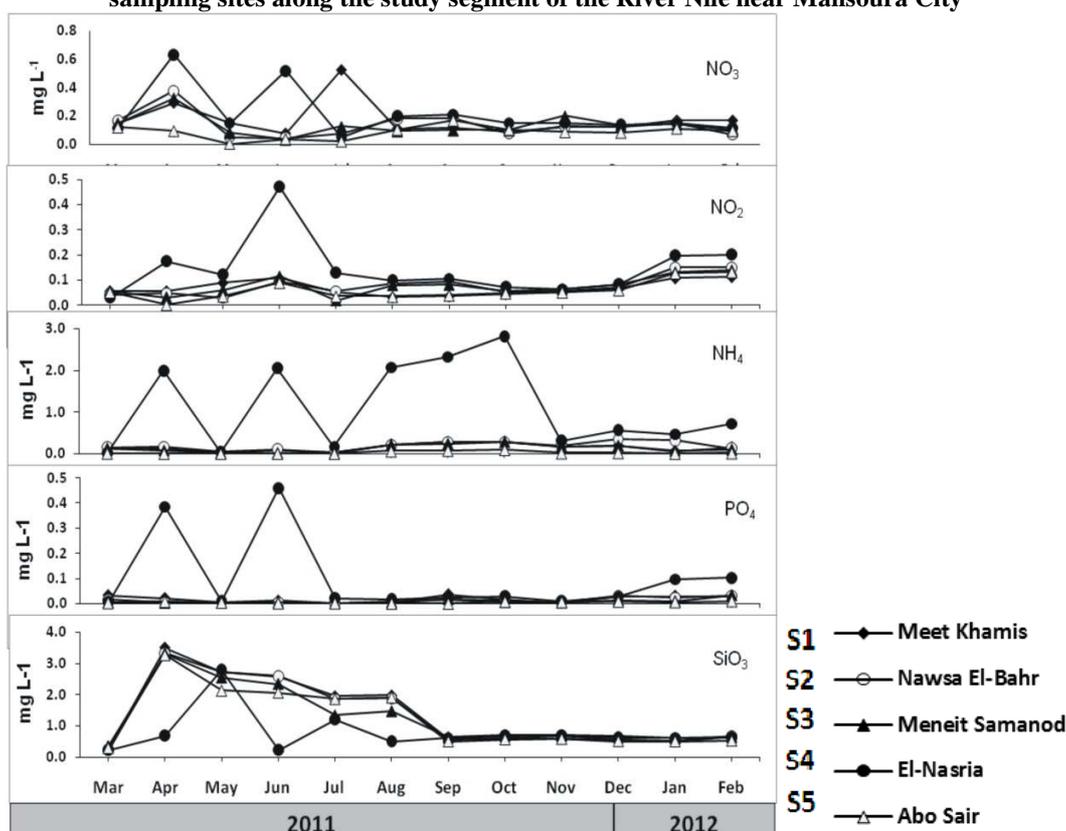
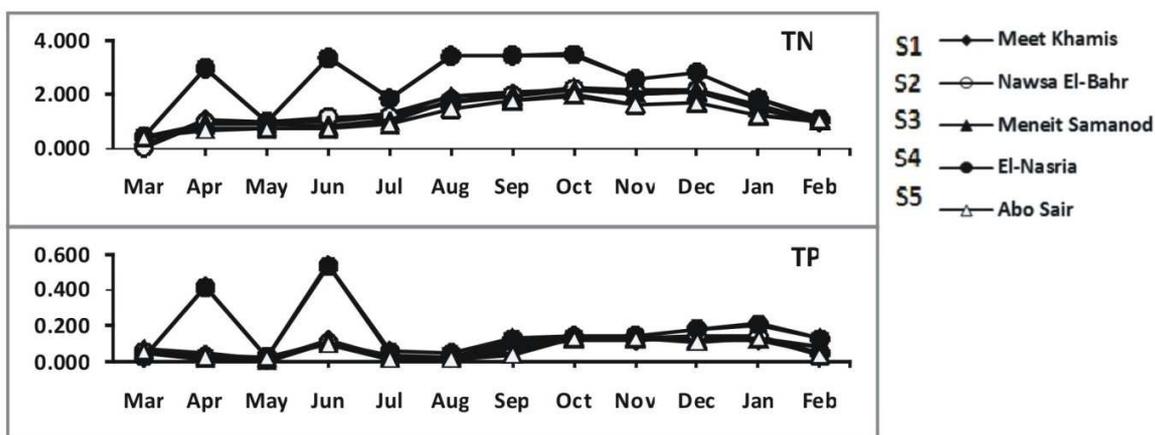


Fig. 7(b): Monthly variations in total nitrogen ((TN) and total phosphorus (TP) at the five sampling sites along the study segment of the River Nile near Mansoura City



Heavy metals

Types, Values and variability at both seasonal and spatial basis of five heavy metals have been determined at the studied segment of The Nile River and data shown in table 3a & b. Cobalt, Lead and Iron were frequently found at the sampling sites however, Zinc and Cupper were recorded with less frequency. Cobalt was recorded in 58 samples during the investigation time. It ranged from 0.306 to 3.79 mg/L . The maximum value and the minimum value were recorded during September, 2011 and December, 2011 respectively. As regard to lead, it was found in 57 samples giving its maximum levels (2.32 mg/L) at El-Nasria during April, 2011. Iron is the next frequently recorded heavy metal; it was recorded in 56 samples being maximum (0.875 mg/L) at Nawsa El-Bahr and minimum (0.021 mg/L) at Abo Sair value. Zinc was recorded within 50 of the collected samples with Maximum value (6.952 mg/L) in February, 2012 at El-Nasria site. Cupper was recorded within only 29 samples and with Maximum values (0.068 mg/L) again in February, 2012 at El-Nasria site.

Table 3 a: Monthly variations in heavy metals (Fe, Zn, Cu, Co and Pb) at the five sites of studied segment of the Nile River (from Aga to Masoura)

Months	Site	Fe	Zn	Cu	Co	Pb
ppm						
March, 2011	S1	0.256	0.796	0.015	1.107	0.154
	S2	0.151	ND*	0.004	2.984	0.630
	S3	0.128	0.064	ND*	0.876	0.940
	S4	0.209	0.020	0.025	3.465	0.850
	S5	0.335	ND*	ND*	2.125	1.060
April, 2011	S1	0.481	1.524	0.006	0.790	ND*
	S2	0.554	4.779	0.026	0.979	ND*
	S3	0.284	1.903	ND*	1.059	0.670
	S4	0.403	2.971	0.030	1.672	0.420
	S5	0.261	0.079	ND*	0.810	2.320
May, 2011	S1	0.215	ND*	0.002	0.781	0.790
	S2	0.376	0.051	0.050	0.430	0.750
	S3	0.100	0.020	ND*	2.008	0.900
	S4	0.164	ND*	ND*	2.862	0.350
	S5	0.122	0.016	ND*	1.172	0.920
June, 2011	S1	0.341	ND*	ND*	2.518	0.051
	S2	0.377	0.125	0.027	2.473	0.230
	S3	0.083	0.022	ND*	3.628	0.720
	S4	0.061	0.056	ND*	0.690	1.160
	S5	0.271	0.011	ND*	0.457	1.650
July, 2011	S1	0.075	0.036	0.000	0.641	0.610
	S2	0.875	0.051	ND*	2.400	1.090
	S3	0.094	0.013	ND*	2.206	0.790
	S4	0.327	2.317	0.015	0.500	0.670
	S5	0.101	ND*	ND*	2.465	0.169
August, 2011	S1	0.118	0.067	ND*	0.885	0.551
	S2	0.433	0.226	0.005	1.700	0.823
	S3	0.090	0.023	ND*	1.450	0.761
	S4	0.213	1.190	0.007	2.150	0.421
	S5	0.530	0.056	ND*	1.650	0.583

Months	Site	Fe	Zn	Cu	Co	Pb
ppm						
September, 2011	S1	0.160	0.095	ND*	1.126	0.460
	S2	ND*	0.353	0.008	1.091	0.600
	S3	0.130	0.033	ND*	0.729	0.750
	S4	0.089	0.052	ND*	3.790	0.170
	S5	ND*	0.099	0.003	0.793	1.080
October, 2011	S1	0.173	0.093	ND*	2.674	0.108
	S2	0.099	0.080	ND*	0.591	0.620
	S3	0.301	0.089	0.009	1.916	0.270
	S4	0.105	0.084	0.009	ND*	1.780
	S5	0.021	0.096	0.027	0.433	1.500
November, 2011	S1	ND*	0.144	0.021	0.725	1.280
	S2	0.154	0.515	0.040	0.500	0.200
	S3	0.546	2.468	ND*	1.148	0.760
	S4	0.311	0.551	0.044	2.275	1.380
	S5	0.095	0.270	ND*	0.716	0.790
December, 2011	S1	0.090	0.076	0.019	0.861	0.752
	S2	0.131	0.271	0.034	0.306	0.435
	S3	0.350	1.342	ND*	1.652	1.216
	S4	0.190	0.290	0.023	2.205	1.231
	S5	0.160	0.302	ND*	2.044	0.451
January, 2012	S1	0.164	ND*	0.018	1.051	0.310
	S2	0.113	0.084	0.026	ND*	0.730
	S3	0.145	ND*	ND*	2.172	1.500
	S4	0.061	0.025	0.005	1.869	1.060
	S5	0.220	0.335	ND*	3.500	0.189
February, 2012	S1	0.103	ND*	ND*	0.585	ND*
	S2	0.521	ND*	ND*	1.500	1.200
	S3	0.245	0.064	0.020	2.554	1.700
	S4	0.118	6.952	0.068	1.599	0.540
	S5	ND*	0.070	ND*	1.053	0.630

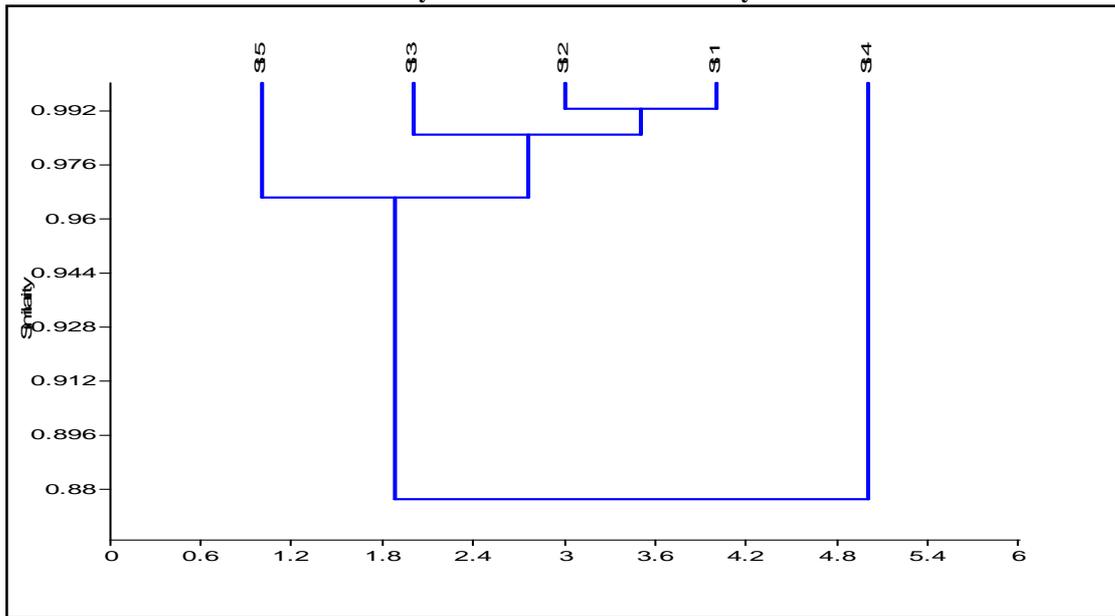
Table 3b: Summary statistics of five main heavy metals as determined at 5 sites along the River Nile near Mansoura City in 2011/2012

sampling sites			Met-Khmis (S1)			Nosia El-Bahr (S2)			Meneit Samanod (S3)			El-Nasria (S4)			Abo-Sair (S5)		
Parameter	Unit	N*	Min*	Max*	Mean*	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Fe	mg L ⁻¹	12	0.08	0.48	0.20	0.10	0.88	0.34	0.08	0.55	0.21	0.06	0.40	0.19	0.02	0.53	0.21
Zn	mg L ⁻¹	12	0.08	1.52	0.35	0.05	4.78	0.65	0.01	2.47	0.55	0.02	6.95	1.32	0.01	0.33 5	0.13
Cu	mg L ⁻¹	12	0.00	0.02	0.01	0.00	0.05	0.02	0.01	0.02	0.01	0.01	0.07	0.03	0.00	0.02 7	0.02
Co	mg L ⁻¹	12	0.59	2.67	1.15	0.31	2.98	1.36	0.73	3.63	1.78	0.50	3.79	2.10	0.43	3.50	1.43
Pb	mg L ⁻¹	12	0.05	1.28	0.51	0.20	1.20	0.66	0.27	1.70	0.91	0.17	1.78	0.84	0.17	2.32	0.95

Statistical analysis (Cluster analysis)

The cluster analysis of sampling sites according to their physico-chemical similarity (Fig. 8) yielded two distinct clusters, one solely composed of S4; El-Nasria, and the other one includes the other four sites. Meet-Khamis (S1) and Nawsa El-Bahr (S2) show high similarity as they are included in the same subgroup followed by Meneit Samanod (S3) then Abo Sair (S5).

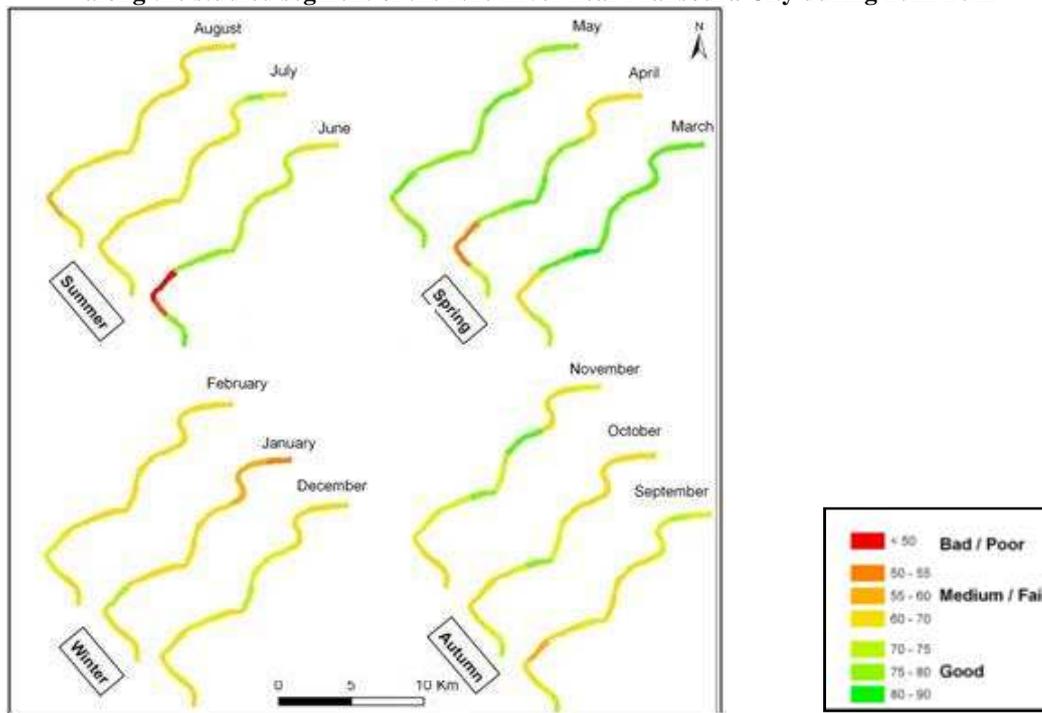
Fig. 8: A dendrogram of clustering the sampling sites, according to physico-chemical characteristics, using Bray-Curtis measure of similarity



Water Quality Index

Apart from S4, WQI values ranged from 65–81 indicated a medium/fair water quality conditions (figure 9). At S4 (El-Nasria) lower WQI values (≥ 45) were calculated, especially during the period from April - September, 2011. Those values of WQI characterized the water quality of the Nile River (from Aga city to Mansoura city) to vary from medium/fair status to bad status. Figure 9 is a descriptive map showing the spatial distribution pattern of the water quality changes along the studied segment of the Nile River within the study period (2011-2012) showing the month-to-month-variations in the river water status.

Fig. 9: A series of GIS map showing the monthly/seasonal variations in water quality (expressed as WQI) along the studied segment of the Nile River near Mansoura City during 2011-2012



DISCUSSION

The future of water quality at local, regional and global scales depends mainly on investments of individuals, communities, and governments at all political levels to ensure that water resources are

protected and managed in a proper manner, and that our good health is the result. Physico-chemical characteristics are as the most important principles in the identification of the nature, quality and status of water for any aquatic (fresh, brackish or saline) ecosystem⁷. The use of specific indices; such as WQI would provide a good indication of the integrate ecological factors⁵⁶.

Nile water (from Aga city to Mansoura city) experienced relatively high levels of the physico-chemical parameters investigated, this signify an inferior state of water quality and vice versa⁵⁹. High concentrations of nutrients were documented at this segment of the River Nile, particularly at El Nasria site (S4). S4 is receiving water from a Water Pumping Station (WPS, see diagram figure 1) which is pumping water rich in agricultural wastes and urbane discharges. Ammonia, for example, was recorded at very low level at all sites except at S4 (El-Nasria). This could be attributed to organic inputs coming from domestic sewage and fertilizers runoff¹⁹. Statistical analysis showed high positive correlations of ammonia with other several pollution attributes, such as: TN ($r = 0.74$), sulphate ($r = 0.66$), conductivity ($r = 0.64$), TDS ($r = 0.62$), DRP ($r = 0.56$) and total p ($r = 0.55$). These significant correlations indicated the impact of sewage discharge and agricultural runoff at this site. Similarly, high nitrate level (figure 7a) was generally determined along the study segment, particularly, at El-Nasria (0.63 mg/L in April and 0.52 mg/L in June). This could be justified by nitrification process through which, ammonia is oxidized into nitrate and nitrite by aerobic bacteria¹. The nitrate peak (0.53 mg/L) recorded at S1 (Meet-Khamis) in May might be due to surface run off, domestic sewage specially washing activities⁵⁵. Meet Khamis is a village dense with population who get used to use of the River as a sink for washing dishes and clothes. This in turn increases the levels of nutrients, particularly, phosphorus and organic matters²⁷. River Nile, at many locations, is accessed by cows and other animals including wildlife such as flocks of ducks and geese, which may cause both soil erosion and direct deposition of animal feces. Deposition of animal faeces could be among the nutrients sources (particularly P) to the lake⁸. This can explain the detection of the higher concentration of orthophosphate in the water during April, 2011 and Jun, 2011⁴⁴. These high P values along the Nile River may be also attributed to industrial and urbane sewage that contains high concentrations of phosphate and ammonia^{47,52}. At shallow sites of the River the well-mixed water would increase P levels from the sediment-release²⁷. Nitrate-N showed positive correlations with DRP ($r = 0.66$), TDS($r=0.57$) and conductivity ($r=0.56$). Similar relationships have been previously recorded^{3,4}.

The pronounced increase in nitrate concentration at El-Nasria (S4) can explain the high oxygen biologically demanding. Dead algae can hence, cause oxygen depletion problems which in turn can kill fishes and other aquatic organisms. Round⁴⁸ previously reported that, in natural habitats the main source of nitrogen are nitrite, nitrate and ammonia salts, which form together the inorganic nitrogen, but in highly polluted waters the organic nitrogen compound may become important. The existence of high level of TN, compared with the inorganic traces, reflect a degree of organic pollution (particularly components of organic nitrogen).

Chloride concentrations in the Nile waters were mostly in the desirable limit (<50 mg/l) except at El-Nasria during June (95.58 mg l⁻¹) and April (50.98 mg l⁻¹). Increase in chloride concentration in Rivers is mainly attributed to the discharge of municipal and industrial wastes⁴⁰ domestic wastes discharged^{50,51}. agriculture activity (e.g. mineral-rich fertilizers) and application of and extensive irrigation^{32,38}. This may justify the relative increase in chloride content at Meet-Khamis (59.5 mg l⁻¹) during November, 2011.

The high levels of sulphate (27.24 - 62.57 mg/L); particularly at El-Nasria (S4) is the result of the excessive use of sulphate-rich fertilizers as well as the domestic wastes³¹. EC values at the study area ranged from 410 to 1310 $\mu\text{mhos cm}^{-1}$ with relatively higher values at El-Nasria during April and June might indicate that this site is receiving large quantities of land run off and/or industrial pollution and suggest potential irrigation problems in case of illegal and unofficial drainage uses adopted from Ayres and Westcott (1985). TDS and EC values revealed positively strong correlation ($r = +0.99$) as the later is the functional property controlled by level of TDS and the conductivity effect of those salts⁵⁸. Similar correlation was previously reported⁵⁸. Water electrical conductivity (EC) is the direct function of its total dissolved salts³⁷ and is used as an index to represent the total concentration of soluble salts in water^{46,35}.

A weak significant relationship was determined between EC and alkalinity. This discrepancy might be a result of the wastewater discharging into the Nile water. Municipal, agricultural or/and industrial discharges can contribute ions to receiving waters and can contain substances that are poor conductors (such as organic compounds) that changing the conductivity of the receiving waters⁵⁷.

The range of Nile Water hardness determined this study (41.15 to 111.18 mg CaCO₃ l⁻¹) was quietly less than what previously determined³⁰ for the upper part of the Nile River (Figure 6b). Water hardness is the parameter that largely influenced by the geology of the surrounded drainage basin and increase with increasing total dissolved solids³. Total hardness showed high significant positive relationship with Chloride (r = 0.88), TDS (r = 0.84), conductivity (r = 0.83), total P (r = 0.83), alkalinity (r = 0.73), nitrite (r = 0.72), DRP (r = 0.68) and sulphate (r = 0.54). Similar conclusion was drowned out by Shinde *et al.*,⁵⁵.

DO concentration was almost within the permissible limits according to the Egyptian law 48/1982 (DO should not be less than 5 mg/l) and was well-above the concentration (2 mg/l) below which fish could die²⁰. El-Nasria site was an exception to that, particularly during April (3.75 mg/l) and June (undetectable concentration). Inadequate DO may contribute to unfavourable environmental conditions in which aerobic bacteria are replaced by anaerobic ones leading to water deterioration and disagreeable odours due to production of gases (H₂S, NH₃ and CH₄) as reported by El-Sherbini *et al.*,²⁸. Depletion in DO might also indicate high organic matter and nutrients load as reported by El-Gamel and Shafik²⁵. In agreement with El-Naggar *et al.*²⁶ and Abd-Ebaky³, dissolved oxygen correlated negatively with sulphate (r = -0.66), DRP (r = -0.60), temperature (r = -0.58), ammonia (r = -0.56) TDS (r = -0.53) conductivity (r = -0.52) and nitrate-N (r = -0.50).

Heavy metals (mainly Iron; Fe & Copper; Cu) were almost within the permissible limits (1 mg/L) according to the Egyptian Law 48/1982. Concentration of lead (Pb) and cobalt (Co) were however higher than the permissible limit (0.05 and 0.05 mg/L) of Canadian water quality guidelines for the protection of aquatic life (CWQGs) and FAO (1985). Zinc experienced many peaks during the period of study that exceed the permissible limits (1 mg/L). Heavy metals are normally added to fresh water streams, rivers and ponds, deliberately as components of herbicides¹⁵ or as by-products of different human activities^{15,61}.

The river water was generally shifted to the alkaline side (7.44 - 8.87) which might be indicative to the presence of carbonates or bicarbonates²⁹. pH and total alkalinity are normally interrelated as investigated by Gupta *et al.*³⁴ and in the Nile water (this work) with a significant relationship (r = 0.69). Both parameters are commonly used to indicate the system's capacity to buffer against acid impacts, which measure the ability of the water body to resist changes in pH. The sudden decrease in pH value (7.44) at El-Nasria during June 2011 might be resulted from the decreased uptake of CO₂ caused by phytoplankton⁶. Alkalinity is known to play an important role in aquatic environment by complex with some toxic heavy metals and reduce their toxicity markedly⁴⁹. Seasonal variations in total alkalinity can be attributed to the lower air and water temperature during cool season that affect the carbonate reactions⁷. The high levels of alkalinity during April (85.0 mg CaCO₃ l⁻¹) and June (132.5 mg CaCO₃ l⁻¹) were mainly due to the high level of nutrients. This might increased the rate of organic decomposition during which CO₂ is liberated and reacts with water to form HCO₃, which increase total alkalinity.

Application of the mathematically calculated WQI is another attempt to assess and conclude that El-Nasria is a wastewater agricultural and urbane discharges receiving station³⁹. This finding adds a rigid support to our assumption about the position, the quality and the treatment efficiency of the water pumped from El-Nasria Pumping Station. Following the Canadian water quality guidelines for the protection of aquatic life (CCME, 2001), Nile water quality ranged between poor to fair status. The multivariate analysis (figure 8) grouped the sampling segment of the Nile River into two distinct clusters, of which, one contain only El-Nasria site reflecting its very poor water quality. The excessive and uncontrolled human activities around El Nasria site is the main cause of the deteriorated water situation at the site. At some villages, farmers are used to dig several artificial canals to be used as sinks for Maceration linen (i.e a process through which the flax vegetation is marinated in water for long time). This process is annually repeated during May-June accelerating the anaerobic activities (due to dense bacterial populations) and

increased organic pollution of the River. This might give reasonable justification for the poor water quality at El-Nasria site. The pictures below (figure 10) show the status of water runoff beyond the maceration canals and just before entering the river through El Nasria pumping station.

Monitoring and assessing the physio-chemical attributes provide describe the chemical pollution of any aquatic systems^{13,41}. Results of this research hence gave a good overview and highlighted the hazards and bad habits impacted the Nile River in Egypt.

Studying physical and chemical properties of the Nile River do not integrate ecological factors and do not necessarily reflect the ecological state of the system. Biological assessments could, however, be a useful alternative for assessing the ecological quality of aquatic ecosystems. Studying the biological communities reflects the integration of environmental effects of all water quality attributes; i.e. water chemistry as well as the physical and geo-morphological characteristics of system⁵⁶. The authors' pretended to conduct another study to explore the potential use of biological assessment as indicator of the water quality of the Nile River and create comparative analysis with the findings of physico-chemical parameters in this research.

Fig. 10: A photos showing the water drainage from lateral canals (that are using for flax maceration) just before reaching El Nasria pumping station (WPS)



CONCLUSIONS

Water quality of the studied segment of the River Nile near Mansoura City is characterized by medium/fair status however it experiences very poor status at some sites. This mean that the Nile water is not always within the standard approved for drinking water by most agencies (e.g. WHO, or/and European Union Water Frame Work Directive). In setting standards, agencies make political and technical/scientific decisions about how the water will be used. It is important for natural water bodies, that environmental lawyers and policy makers work to define legalization that ensure that water is maintained at appropriate quality for its identified use. Monitoring the River Nile water regularly and continuously can helps to understand how this system function which in turn helps to identify the sources and fates of contaminants. This would mitigate outbreak of health disorders and the detrimental impacts on the aquatic ecosystem. Finally, this research recommends the following for this section of the Nile River: i) divert the polluted water away off the River Nile; (ii) apply better treatment technique to wastewater pumped to El-Nasria site via El-Nasria Pumping Station. iii) apply reliable and continuous monitoring mechanism along the whole River. Indeed, this will provide enhanced tools to mitigate health problems outbreaks or any aquatic ecosystem disorders arise from the Nile River.

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