International Journal of Water Resources and Arid Environments 4(2): 146-153, 2015
ISSN 2079-7079

Environmental Impacts of Industrial Wastewater Effluents on Water Quality of Nile River

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Abstract: Nile River pollution has increased in the past few decades due to the increase of wastewater disposal into the river without appropriate treatments. El Sail storm water canal in Aswan city, which is the starting point of the river in Egypt, discharges into the Nile around 56000 m^3/day of the industrial and domestic wastewater. The main objective of this study is to evaluate the effects of these wastes on the quality of drinking water taken from the Nile in this area especially at the nearest drinking water stations. Results showed that the river has the self-purification capability for diminishing or removing some constituents of El Sail water canal such as salts and nutrients, while it failed with others such as Mn and Fe. An urgent and proper treatment must be applied for this canal water before the disposal into the Nile.

Key words: Nile River · Drinking water quality · Wastewater disposal

INTRODUCTION

The water budget of Egypt from Nile River is 55.5 x 10^9 m^3 /year. Other surface water resources are estimated at 0.5 x 10^9 m^3 / year. This comes up to 56.0 x 10^9 m^3 /year as a total. Nile water comprises about 97% of the renewable water supplies in Egypt, thus it is believed there that Nile River is the sole source of life [1]. The rising living standards and population growth have put more stress on water resources. With the increasing population from 20 million in 1952 to 38 million in 1977 to up 90 million in recent days, the availability of water has been an impacting factor on the life in Egypt especially when the Nile yield also has been subjected to dramatic changes from year to another. Egypt has been listed among ten countries that are threatened by the demand of water by the year 2025 [2].

Thus, it is very important to explore new resources to face this water demand. Reuse water from wastewater of irrigation, domestic and industry activities is suggested as a supporting solution for water shortage problems. It has become a national policy to maximize the reuse of drainage water by mixing it with irrigation canals. In sequence, increased industrial growth together with intensified agriculture has a direct effect on water quality [3]. About 350 industries are discharging their sewage-water either directly into the Nile or through the municipal system. As a result, many canals may be contaminated with pollutants from industrial and domestic sources [2]. The pollutants in river systems migrate with water flow, any factors that may affect this flow are also likely to influence the migration of contaminants in water. The transport of contaminants is subject to physical, chemical and biological activities, such as contaminant density, adsorption and desorption, retardation, degradation and chemical-biological reactions [4]. It is known that, the availability of water is also constrained by its degraded quality which limits its use for specific purposes.

El Sail storm water canal in Aswan city, which is considered a starting point of the Nile River in Egypt, discards around 56000 m3/day of the industrial and domestic wastewater into the river [5]. The canal is currently polluted by domestic and industrial wastewater and municipal solid waste during its journey through Aswan City up to the Nile. The KIMA Industries discharged wastewater into the El Sail canal leading it to the Nile. Industrial wastewater effluents of KIMA Company, which is a factory producing ammonium nitrate coated with limestone powder fertilizer have great awful effects on the water quality in this stream and successively on the quality of the Nile water. The Sail stream delivers a huge amount of water having dark colours and very bad odour to the river indicating that the drain waters may have a health hazard to the public living in this area.

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The main objective of this study is to evaluate the effect of these wastes on the quality of drinking water especially near water stations on the Nile in Aswan city. This work includes experimental and mathematical modelling studies for the movement and fate of the pollutants from the source into the river. The experimental work involved collecting samples from the intersection point of El Sail stream and the river. Samples were also collected from drinking water stations before and after the intersection position. Therefore, the contaminant migration was monitored from the source into the surrounded area in the direction and opposite direction of the Nile stream.

The work adopted also a mathematical model, which assesses migration of the constituents from their sources into water. This model is based on dispersion and advection processes. The model was used to validate the experimental measurements of the constituents of the drinking water stations after the position of the pollution source. Modelling calculations were based on measurements of initial pollutant concentrations from the source and the adopted process concept.

MATERIALS AND METHOD

The experimental program contains collecting 500 ml sample water from the Nile at four suggested positions which are shown in Fig. 1. The proposed positions were chosen to cover the pollution source point of El Sail canal intersection with the Nile and one position for a drinking water station before the pollution source point, called Gabel Tagog station and two positions for other drinking water stations after the source point and in the direction of the Nile flow, namely Al Shadeda and Abo Alreesh stations. The distances of these three stations from El Sail canal intersection point are 5.1, 1.2 and 2.4 km respectively. Therefore, the contaminant migration could be monitored from the source into the surrounded area in the direction and opposite direction of the Nile stream and also on the two sides of the river, as shown in Fig. 1. The water samples were collected at winter time in January-2012 and summer time in July-2012. Two batches were collected at the beginning and middle of each month. Each batch had three samples from each position. Thus, the samples of each batch are 12 in total and the overall samples for the four positions are 48 samples in winter and summer months. Samples from El Sail canal were collected exactly before the mixing point of the canal water with the river water. All water samples were kept into a one-litter polyethylene bottle in ice box and analysed in the laboratory. Each sample was analysed to determine physical and chemical values, namely, turbidity, temperature, pH and conductivity, TDS, Fe, Mn, Ca, Mg, SO_4, Cl, NO_3, NO_2 and NH_3.

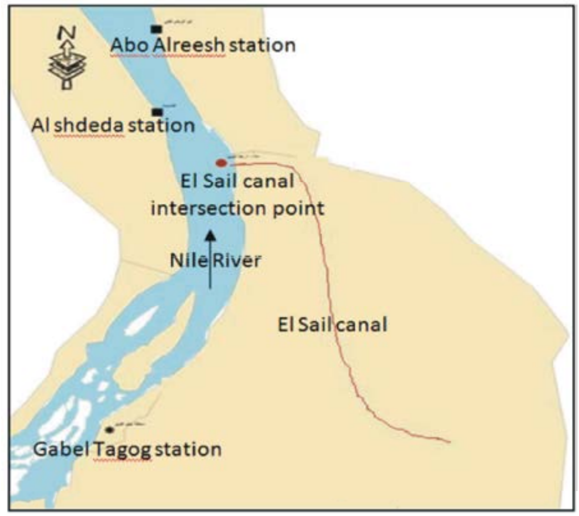

Fig. 1: A map showing the four suggested points for sample collection.

For turbidity and total dissolved solid measurements, HI 983308-01Pronto TDS Meter and HI 88703, Precision Turbidity Bench-top Meter were adopted. Temperature and pH by were measured by a dry mercury thermometer and Orion Research Ion Analyser 399A pH meter respectively. The electrical conductivity of the water samples (μScm-1) was measured by using conductivity meter model (S.C.T.33YSI). Fe^{2+} and Mn^{2+} were measured using atomic absorption model (Perkin Elmer 3110 USA). Cations namely Ca^{2+} and Mg^{2+} were determined by EDTA titrimetric method. While anions namely, SO4 and Cl^- were measured by turbidimetric and argentometric methods respectively. Concentrations of NO2, NO3 and NH3 were determined using the colorimetric techniques.

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RESULTS

Each value of the results presented herein is the average of six readings because, as mentioned above,

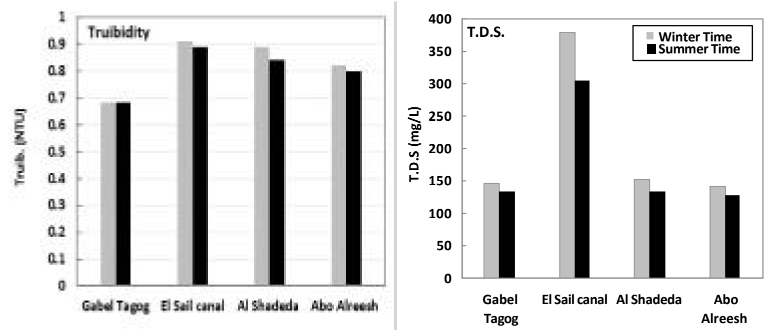

Fig. 2: Average values of turbidity and total dissolved solid for the four suggested positions in winter and summer times

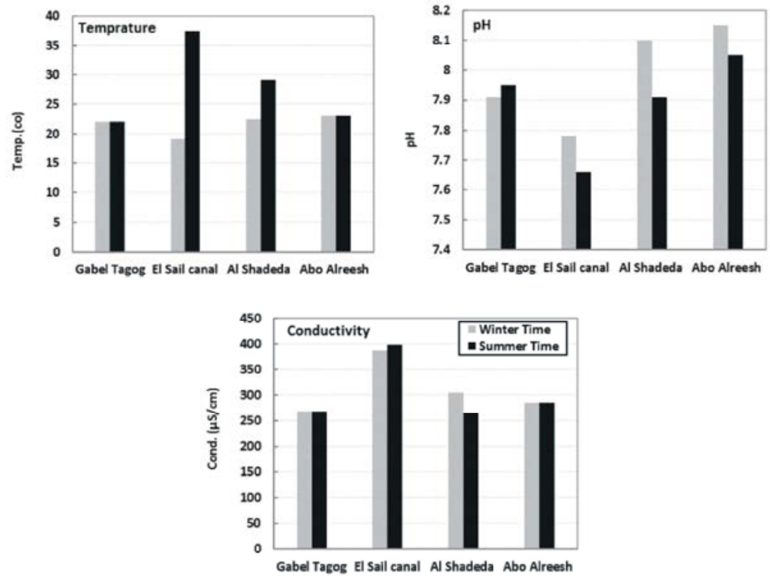

Fig. 3: Average values of temperature, pH and conductivity for the four suggested positions in winter and summer times

three samples were collected two times per month. The following sections exhibit the experimental results of the four positions at the winter and summer times.

Physical Parameters: Fig. 2 presents the average values of turbidity and total dissolved solid for the four suggested positions in winter and summer times. Results showed a high level of turbidity and total dissolved solid (TDS) from El Sail canal. Consequently, this increases the turbidity level of the two drinking water stations after El Sail canal in comparison to the Gabel Tagog station which is before the pollution source point. However, in spite of the high concentration of TDS of pollution source, its concentration in the stations after the pollution source is nearly equal to that of the station before it. This indicates to the ability of the Nile River current to dilute the wastewater and make self-purifications.

Fig. 3 presents the average values of temperature, pH and conductivity for the four suggested positions in winter and summer times. Temperature of the Nile water is between 19 and 23 in the winter and 32 and 38°C in the summer. The high temperature of the El Sail canal water in summer increased the temperature of the nearest drinking water station, Al Shadeda. Results revealed that pH and conductivity of water at stations after the pollution source point increased, however, they are still within the permissible limit. pH values were in the alkaline side (7.6-8.15). Conductivity maintained positive correlation with many parameters like, for instance, with T.D.S discussed above and Cl^-, SO_4 and Ca^{2+} which will be discussed latter.

Results of Fe^{2+} and Mn^{2+} concentrations showed that El Sail canal water contained a high level of these heavy metals and consequently this affected significantly on the content of these elements in the water of the two drinking stations after the canal, as shown in Fig. 4.

The same result was obtained in the case of Ca^{2+} and Mg^{2+} as presented in Fig. 5. The canal water has a high concentration of Ca^{2+} and Mg^{2+}. The concentrations of Mg^{2+} in drinking water stations showed low values

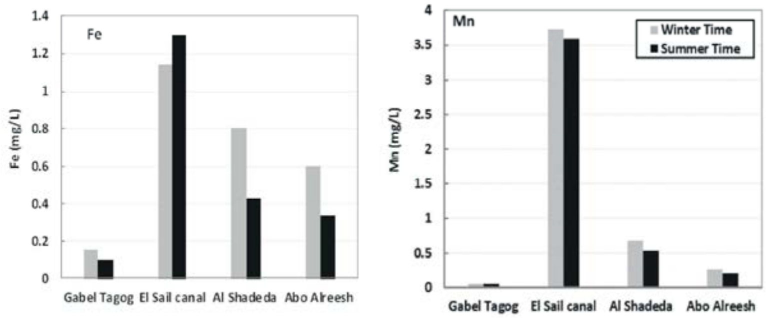

Fig. 4: Average concentrations of Fe and Mn elements for the four suggested positions in winter and summer times.

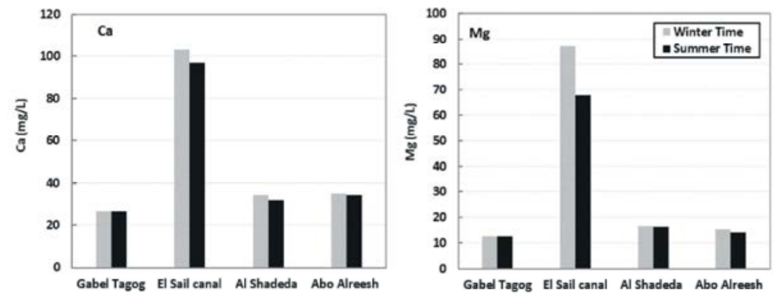

Fig. 5: Average concentrations of Ca and Mg elements for the four suggested positions in winter and summer times.

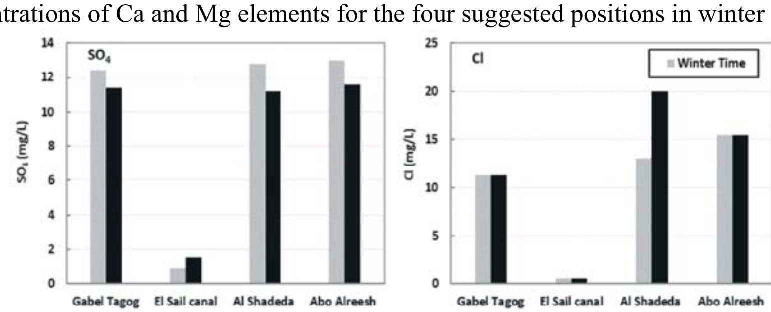

Fig. 6: Average concentrations of SO_4 and Cl elements for the four suggested positions in winter and summer times.

(15.6-18.2 mg/L) compared with Ca^{2+} concentrations (32-35 mg/L). This is perhaps due to the preferential behaviour of dissolved CO_2 as it reacts with Ca^{2+} salts than with Mg^{2+}, thus converting large quantities of Ca^{2+} into soluble bicarbonates [6].

In addition, it is noted that the concentrations of elements were higher at the nearest station, Al Shadeda than Abo Alreesh station as the increase in the distance of the pollutant migration reduced its effect. This refers to the ability of the Nile on the self-purifications.

Fig. 6 presents the average values of SO_4 and Cl^- concentrations for the four suggested positions in winter and summer times. The experimental results revealed that the concentration of SO_4 and Cl^- are very low in the canal water and thus there is no effect from the canal on the Nile water. Though the values of SO_4 and Cl^- are high in the Nile River, they are still within the allowable values.

Nutrients: Experimental results presented in Fig. 7 showed that El sail canal had a high level of NO_2, NO_3 and NH_3 concentrations. This is due to the activity of KIMA Company which discharges its wastewater in this canal leading it to the Nile. As the company produces mainly ammonium nitrate coated with limestone powder fertilizer. NH_3 showed significant positive correlation with temperature during summer, as the increase in temperature increases NH_3 formation [7]. In addition, NH_3 was negatively correlated with pH as shown earlier in Fig. 3. The disposal of the canal water in the Nile increased significantly the amount of NO_2, NO_3 and NH_3 in the positions of Alshadeda and Abo Alresh stations. NH_3 is one of the most important pollutants because it can be toxic, causing lower reproduction and growth, or death animal and plants. The neutral, unionized form NH_3 is highly toxic to fish and other aquatic life.

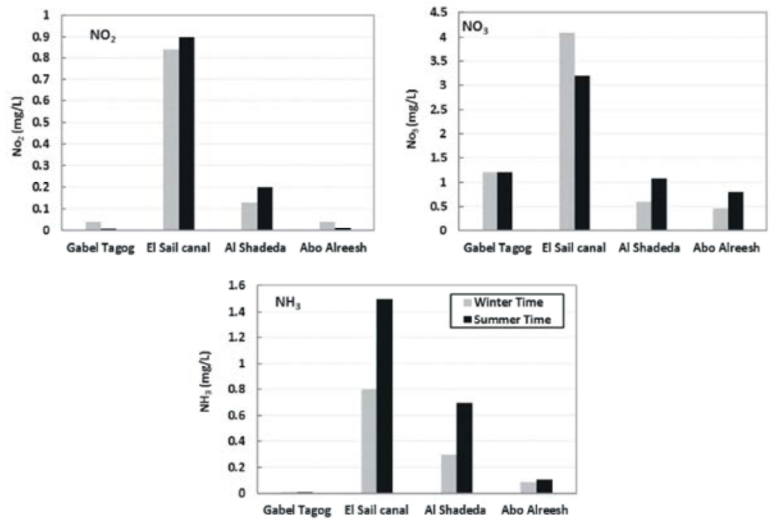

Fig. 7: Average concentrations of NO_3, $NO_2$and NH_3 elements for the four suggested positions in winter and summer times.

DISCUSSION

From the experimental results discussed above, El Sail canal has high concentrations of different heavy metals, salts and nutrients which have a significant effect on the water content of the nearest drinking water stations. There were some harmful elements having high concentrations in the nearest stations such as Fe^{2+}, Mn^{2+} and NH_3. However, due to the intense self-purification capacity of the Nile, the effect of the majority of the pollutants diminished or removed completely especially for long distances away from the pollution source. This feature of the Nile was discussed by the work of El-Gohary [8], stating that mid-stream conditions of the Nile are still at a fairly clean level due to dilution and degradation processes. Agrama [9] reported that the River Nile has an intensive self-purification capacity though monitoring BOD. The self-purification capacity of the River Nile after High Dam in Aswan is supposed to be high due to silt-free, less turbid and with considerably less velocity. This feature reduces in the Nile downstream from Aswan dramatically as the Nile water became relatively overloaded with various pollutants. In addition, in spite of the high concentrations of the elements due to canal water disposal, all element concentrations are within the permissible limits which suggested by EU Council Directive 98/83/EC [10] (1998) or by WHO [11] except Fe^{2+} and Mn^{2+} which are above the standard values. Perhaps, this is because heavy metals particularly are hard to be diminished from water by the water flow. Toufeek [12] reported that Pb^{2+} and Cd^{2+} levels exceeded the permissible limits in most sites in Nile River in Aswan. The author reported also that increasing the tourist ships discharging its wastes into the Nile at Aswan and wastewater input of Kema fertilizer factory through El-Sail canal may be the main reason for elevation lead and cadmium concentrations at the studied sites. Results herein revealed also there is no significant change for the concentrations of the elements between winter and summer times expect for NO_2 and NH_3 which they be affected by the temperature arise.

Theoretical Validations

Advection–Dispersion Model: A river is a wide, natural stream of fresh water that flows into a large body of water and it is considered as a good transporter. The basic principle of transport phenomena in general is about exchange of energy, mass or momentum between systems on fluid mechanics. Transport phenomena describes the process that take a system of particles from a non-equilibrium state to an equilibrium state, from an equilibrium state to a non-equilibrium state, or from one non-equilibrium state to another [12].

The advection-dispersion is the most common process for transferring the particles via the river water. In this process, a river redistributes solutes by moving them in the longitudinal, lateral and vertical direction of the current. The surface-water flow is assumed to be steady and uniform. The process for solute movement in the current direction of the river can be described by the following expression:

$$\frac{\partial C}{\partial t} = \frac{D_d}{R}\frac{\partial^2 C}{\partial x^2} - \frac{v}{R}\frac{\partial C}{\partial x} \qquad (1)$$

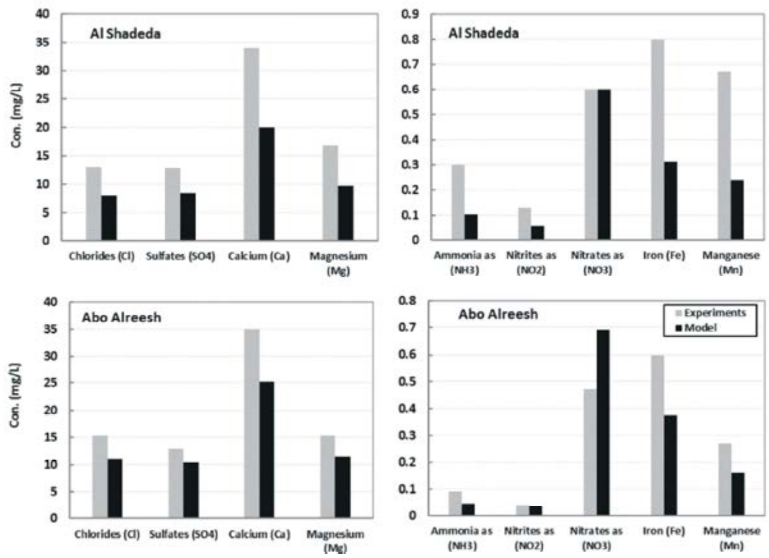

Fig. 8: The modelling results of different constituents in winter time at Al Shadeda and Abo Alreesh stations by Equation 4.

Table 1: Parameter values adopted in equation 4 and 5.

Parameters	x = the distance (m)	t = the time (sec)	v= Mean Velocity (m/sec)	v* = Shear Velocity, (m/sec)	B= Width, (m)	d = Depth (m)
Al Shadeda	1200	3600	0.3	0.0414	517	5
Abo Alreesh	2400	7200	0.3	0.0414	517	5

where C = the solute concentration; D_d = the longitudinal dispersion coefficient (m^2/s); v = the average flow velocity (m/s); t = the time (sec) ; x = the distance (m); and R denotes the retardation factor

The common analytical solution of Equation (1) for the movement of water in the current direction as follows [14, 15]:

$$\frac{C}{C_o} = 0.5\left[erfc\left(\frac{x - t\frac{v}{R}}{2\sqrt{t\frac{D_d}{R}}}\right) - exp\left(\frac{vx}{D_d}\right) erfc\left(\frac{x + t\frac{v}{R}}{2\sqrt{t\frac{D_d}{R}}}\right)\right] \quad (2)$$

where erfc = complementary error function. Ogata and Banks (1961) reasonably approximate Equation (2) in the following formula (3):

$$C = \frac{C_o}{2}\left[1 - erfc\left(\frac{x - vt}{2\sqrt{D_d t}}\right)\right] \quad (3)$$

The longitudinal dispersion coefficient, $D_{d,}$ in the river can be estimated according to the following equation (4):

$$D_d = \frac{0.011\,(v)^2 (B)^2}{d\,(v)^*} \pm 50\% \quad (4)$$

where v= Mean Velocity; B= Width, (m); d = Depth (hydraulic radius), (m); v* = Shear Velocity, [m/sec]; = $v^* = \sqrt{gds}$; S= Channel Slope (m/m).

In this study, the longitudinal dispersion coefficient was calculated based on Equation 4 and all above mentioned parameters for Nile River at Aswan region were adopted from the work of Abdel-Fattah *et al*. [16].

The model described in Equation 3 was adopted to calculate concentrations of the constituents which transferred by the stream from the pollution source, El Sail canal, to the two followed drinking water stations namely, Al Shadeda and Abo Alreesh. In the simulation, the distances of the two stations from the pollution source are 1.2 and 2.4 km respectively, as mentioned earlier. Simulation time was made at 1 and 2 hours for Al Shadeda and Abo Alreesh respectively. These times were the same for the experimental measurements at these stations. The initial constituent concentration, C_o, applied in the model was the summation of the concentration from the pollution source and the original content of this constituent in the Nile water. The original content was adopted as the concentration at Gabel Tagog station which is before the pollution source. Excel sheet was designated to do all the model calculations. All used parameter are shown in Table 1.

Fig. 8 and 9 present the modelling results for the experimental measurements of heavy metals, salts and nutrients. Results of all constituents showed that in

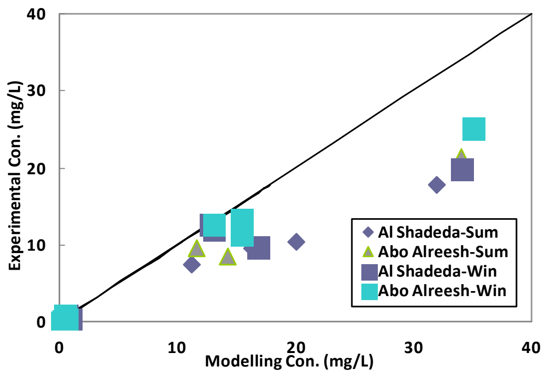

Fig. 9: The modelling against the experimental results for Al Shadeda and Abo Alreesh stations in summer and winter times.

general Equation 3 depicted the experimental measurements fairly; however, the model underestimated significantly the values of Fe, Mn and Ca elements. This is perhaps that the model calculates the longitudinal dispersion only and does not take into account the lateral and vertical dispersion. Due to the broaden width of the river system, the horizontal and vertical directions, which are perpendicular on the flow direction, have significant impacts along with the longitudinal direction of the river. In fact, there are many conditions which may affect the contamination transport and fate in the river flow. This is because the river is not only a pipe-like transferring water downstream but it is a complex system interacting with surrounding areas and conditions. For instance, Field and Leij [17] reported that breakthrough curves in rivers can exhibit multiple peaks due to ?ow occlusion and diversion caused by in-channel features such as islands and pools.

CONCLUSIONS

- El Sail canal has high concentrations of different heavy metals, salts and nutrients.
- Fe, Mn and NH_3 were in high concentration in the water due to El Sail canal disposal and Fe and Mn were above the standard values.
- The effect of the majority of the pollutants diminished or removed completely due to self-purification capacity of the Nile.
- There is no significant change for the concentrations of the elements between winter and summer times expect for NO_2 and NH_3.
- A proper treatment must be applied for El Sail canal water before the disposal into the Nile.

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