



## Efficacy of *Phragmites australis* in the removal of heavy metals from the contaminated El-Qabouty junction canal of Lake Manzala, Egypt

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### ABSTRACT

The present investigation was carried out to assess the spatial and seasonal variations in heavy metals concentrations in water, sediments as well as belowground and aboveground parts of the dominant macrophyte *Phragmites australis* along contaminated El-Qabouty junction Canal. Analyses of 12 heavy metals content (Br, As, Co, Ni, Fe, Cr, Hg, Zn, Cd, Pb, Se, Mn) in water, hydrosol and plant samples were collected from two sites along El-Qabouty Canal and seasonally analyzed using XRF. The results recorded the highest concentrations of Co, Mn, As, Cr and Fe in water with 9.73, 9.79, 24.89, 26.38 and 47.57 mg/l, respectively in spring season at the southern site nearby industrial drain output. Seasonally, the pollutant content was lower in winter. Higher concentrations of Co, Cr, Hg, Ni, Pb, Se and Zn were recorded in belowground parts for *P. australis* at the norther site of the canal in summer. The bioaccumulation factors (BF) of heavy metals were more than one and in the order Hg>Se>Br>Pb>Zn>Mn with values 174.38, 106.26, 52.30, 18.49, 7.21, 2.98, respectively. The translocation factors (TF) of As and Cd were 15.97 and 12.58, respectively. The obtained results and indices indicated that *P. australis* can grow and tolerate in highly contaminated waste water and is a good candidate to serve as hyper-accumulator, phyto-stabilizer and bio-monitors of heavy metals.

### Key words:

*Phragmites australis*, heavy metals, phytoremediation, junction canal, Lake Manzala.

### 1. INTRODUCTION

Water pollution by heavy metals is one of the most serious environmental hazards in many countries around the world, including Egypt [1]. The most anthropogenic sources of water contaminated metals are industrial, petroleum contamination and sewage disposal [2], [3]. Moreover, environmental pressures caused by heavy metal releases from industry to air and water bodies expanded with time [4]. The release of despicably treated urban sewage and industrial effluents containing heavy metals into lakes have become a serious environmental problem, as the consumption of polluted lake water that contains heavy metals postures a threat to human health through bioaccumulation in ecological food chains [5]. In aquatic ecosystems contaminated by heavy metals, unlike organic contaminants, cannot be devastated by biological processes; as they concentrate in bottom sediments, then travel up the food chain, and often biomagnifying at higher trophic levels [6].

Heavy metal removal may be processed via chemical precipitation, coagulation–flocculation, adsorption, ion exchange, membrane filtration and other advanced oxidation strategies that require excessive capital, working and management costs [7]. Henceforth, it was once necessary to advocate an economic and eco-friendly technology to do away with these heavy metals and improve the wastewater quality[8].

The nature and growth forms of macrophytes enable them to be as natural absorbers of heavy metals and other different nutrients [9]. Removal of heavy metals from wastewater and polluted sediments by macrophytes has been pronounced as a low cost and effective technology[10]. Their roots, rhizomes and shoots are efficient absorbers for heavy metal ions through the direct absorbance, deposition and accumulation [11, 12] .

Behavior and distribution of many macrophytes are frequently corresponded with water quality and sediment properties[13, 14]. They possess several mechanisms of heavy metal tolerance and a sophisticated network for maintenance of metal homeostasis in both water and sediments [15]. In addition, the microbiota associated with their roots, play a major role in detoxification of toxic metal ions [16]. They can accumulate high levels of heavy elements from water and sediments through their well-developed root system, tolerance to toxicity, highly productive biomass, and stationary nature [17]. Therefore they can accumulate pollutants at high levels irrespective of their content in the environment [11].

Various macrophyte species show different behavior regarding their ability to accumulate elements in their organs [12] . According to different capacity for metal uptake, species of relatively high ability to accumulate metals in the aboveground tissues could be good candidates for phytoextraction [18]. Other species, with strong ability to reduce metal translocation from roots to shoots, could be considered as phytostabilizers of metal-polluted environments [19] .

The macrophyte *Phragmites australis* is the major component of reed stands along the shores of lakes and wetlands in Egypt [20, 21] . It grows on soils with different pH, salinity, fertility, and texture [22] . Its network of emergent stems emerge from a belowground network of rhizomes that play a role in clonal spread of the plant [23]. *P. australis* considered ideal for phytoremediation due to its high growth rate and biomass production, deep fibrous root system, adaptability to a wide range of climatic conditions, and great capacity for metals accumulation [24, 25].

Lake Manzala is the largest and the foremost vital fisheries resource along the Mediterranean coast of Egypt [26] . It is subjected to continuous pollution hazards due to the inflow of huge amounts of wastewater, agricultural drainage and industrial wastes through several canals at its southern and western parts [27]. One of these canals is El-Qabouty canal, which receives wastewater from the industrial and investment zones of Port Said with different industry of chemicals, paints, dyes, textiles and others. The discharge of such industrial wastewater that are untreated, partially treated or treated may affect the water quality, hydrosol properties and macrophytic vegetation along the shores and banks of El-Qabouty Canal. Previous studies focused on pollution in Lake Manzala, However, there has been little previous research carried out for evaluation heavy metals concentrations at El-Qabouty Canal in contaminated water, sediments and existing macrophytic vegetation as reported by Ibrahiem et al., (2012) and El morsi et al., (2017) [28 , 29] . Therefore, the aim of the current study was to evaluate spatial and seasonal variations in heavy metals concentrations in water, sediments as well as belowground and aboveground parts of the dominant macrophyte *P. australis* along contaminated El-Qabouty Canal. Such evaluation will also assess the efficacy of *P. australis* as phytoremediation for industrial wastewater.

## 2. MATERIALS AND METHODS

### 2.1- Study area

The two selected sites were selected to represent spatially different degrees of pollution from the discharged outlet of the industrial area along the EL Qabouty junction canal, Port Said (Figure 1). The

first site (Site 1) was about 4 km far away from the outlet pipe at the Northern Site of El- Qabuty canal (NSQ), while the second one (Site 2) was nearby the discharge outlet Southern Site of El-Qabuty canal (SSQ).

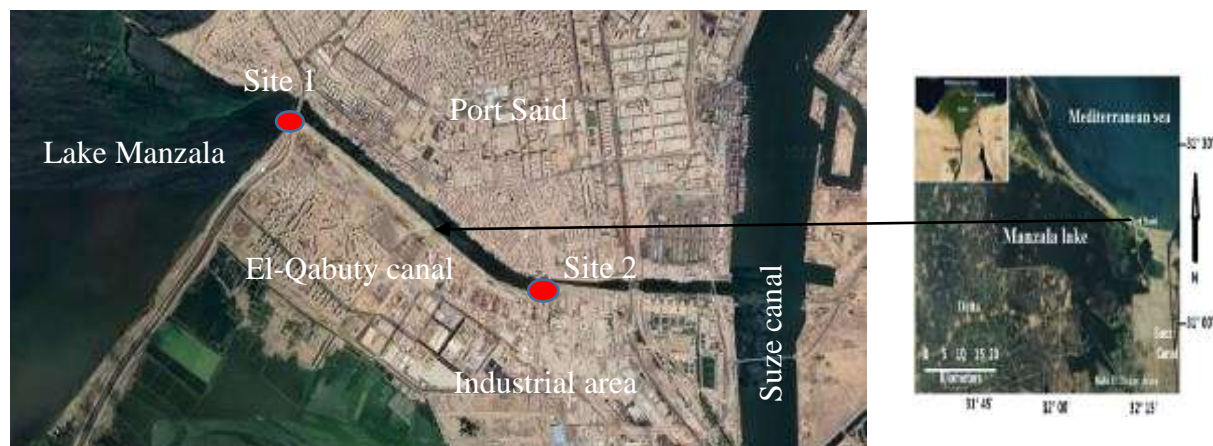


Figure 1. The location of sampling sites northern and southern of El-Qabouty junction canal in Lake Manzala at Port Said, Egypt.

## 2.2- Water and soil samplings

At each selected site, sampling was done seasonally (summer, winter and spring) during 2018. One liter of water samples was collected separately at depth of 0.5–1m and kept in acid-cleaned polyethylene bottles from the two selected sites along the canal. Then, the samples were filtered using a Whatman glass microfiber filter (No.1) and acidified with 65% concentrated Nitric acid and preserved for further analysis.

Hydrosol samples were collected from the canal bottom by using core sampler according to Boyd and Tucker (1992) [30], at the same selected sites of water and *P. australis* samplings. They transferred in cleaned plastic bags to the laboratory where they were air-dried. Soil clods and aggregates are pulverized by means of wooden mortar and pestle to reduce particle size, then they passed through 2.0 mm and 0.5 mm stainless steel sieve after screening.

## 2.3- Plant sampling

Six samples of *P. australis* were harvested individually from the same water and sediment locations during the three seasons for every site. The plant parts were washed thoroughly several times using distilled water. Then they transferred in cleaned plastic bags to the laboratory, where they separated into aboveground and underground parts. Then, each part was dried at 80 C° and ground into fine powder by laboratory blender for further analysis.

## 2.4- Physiochemical and heavy metal analysis

For each site and season, water and hydrosol were analyzed for their physiochemical characteristics. Biochemical oxygen demand of water (BOD) was estimated according to Rodger B. Baird et al.

(2017) [31]. Hydrogen ion concentrations (pH) of water and hydrosol were determined by electrical pH meter (Adwa, Romania). Electrical conductivity (EC) and total dissolved solids (TDS) were measured using Ec and TDS meter (Cole-parmer model ChicagoII.60648). Determination of organic matter content was evaluated by loss on ignition method according to Condie, (1993) [32]. Leaf water content (LWC) and specific leaf area (SLA) of *P. australis* were investigated following Rawson et al., (1987) [33]. The chlorophylls and carotenoids were measured following the procedures of Dudek et al. (2014) [[34]].

For each site and season, the concentrations of heavy metals (Br, As, Cd, Co, Cr, Fe, Hg, Mn, Ni, Pb, Se and Zn) were measured in water, hydrosol and *P. australis* parts using (XRF) X-ray fluorescence spectrometers [Thermo Scientific ARL PERFORM'X Spectrometers (X-UQ-Helium)].

### 2.5- Heavy metal uptake and accumulation

Heavy metals concentration in soils and *P. australis* parts was calculated on the basis of dry weight. For each element, the bioaccumulation factor (BF) was computed by dividing its total content in below-ground portions by total content in soil (Brooks 1998) [35].

$$BF = C_{\text{Below-ground}} / C_{\text{Soil}}$$

The translocation factor (TF) was calculated [35, 36]. TF is the ratio of metal concentration in above-ground parts and its concentration in below-ground portions.

$$TF = C_{\text{Above-ground}} / C_{\text{Below-ground}}$$

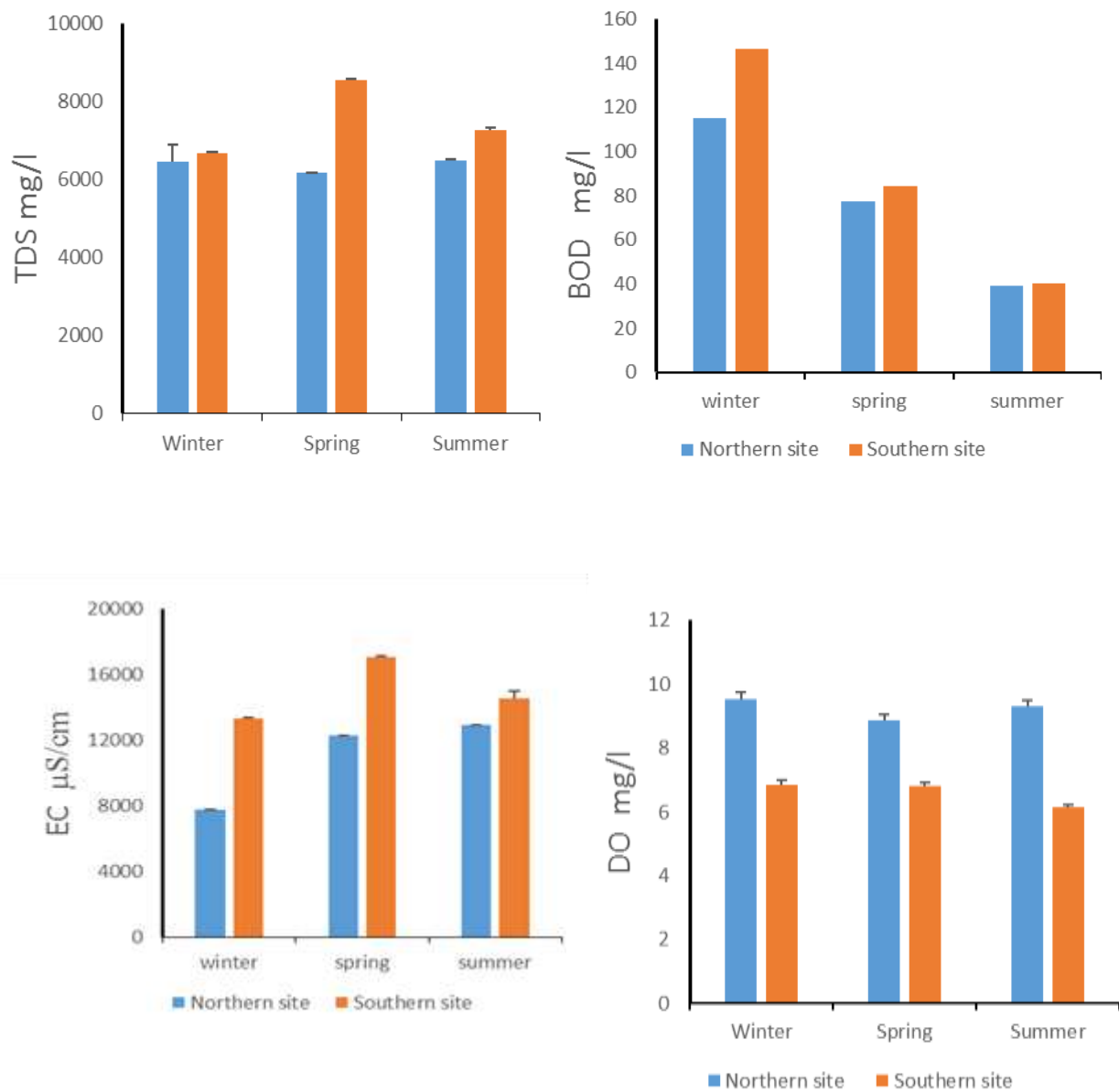
### 2.6- Data analysis

All statistical analyses were conducted using SPSS version 16.0 for Windows. One-way analysis of variance was used to determine the significance of fluctuation in water and sediment quality measures across time (ANOVA). The Pearson's coefficient (r) was used to determine correlations between nutrient and heavy metal concentrations in plant organs and water or sediment samples.

## 3. RESULTS

### 3.1- Physicochemical characteristics of water

The physicochemical characters of water for both sites NSQ and SSQ of the contaminated El-Qabuty junction canal during different seasons are presented in Figure 2. The results show that highest mean values for pH was 9.21 in SSQ at summer season, while pH mean ranged from 7.19 to 8.97 in NSQ. Total dissolved solids (TDS) of water showed the highest value (8540 mg/l) at SSQ in spring season compared to their counterparts at NSQ, while the lowest values were in summer and winter (6460 and 6480 mg/l, respectively) in NSQ. Electric conductivity (EC) varied greatly between sites and seasons. EC' water of SSQ illustrated the highest values 17090  $\mu\text{S}/\text{cm}$  at spring opposed to NSQ which showed the lowest mean values at 7760  $\mu\text{S}/\text{cm}$  in winter. The highest value of DO was 9.54 mg/l in NSQ during winter and its lowest value was 6.16 mg/l at SSQ in summer. Biochemical oxygen demand (BOD) of SSQ showed the highest value (146.6 mg/l) at winter and the lowest value (39.1 mg/l) at summer.



**Figure 2.** Seasonal variation of physicochemical parameters of water for northern (NSQ) and southern (SSQ) sites of El-Qabauty junction canal.

### 3.2- Physicochemical characteristics of hydrosol

The physicochemical characters for hydrosol of both sites NSQ and SSQ of the contaminated El-Qabauty junction canal are shown in Table 1. Soil's pH had the highest value (9.46) at SSQ site during summer season, while its lowest value was 8.4 at NSQ in winter. In spring, soil of SSQ had the highest values for TDS, NaCl and Ec (2143 mg/g, 8.033 % and 4283.33 µS /cm, respectively) compared to NSQ site soil with the lowest values (236.66 mg/g, 0.97% and 473.66 µS /cm, respectively). Chloride concentrations showed significant difference between the two sites along the study period. The values of chlorides ranged from 9.99 mg/g to 17.483 mg/g in SSQ soil during winter and from 0.8885 mg/g to 9.922 mg/l in NSQ soil. Soil organic matter content of SSQ ranged from 5.171% to 1.255% was higher than those of their counterparts of NSQ site soil ranged from 0.622% to 2.478%.

Table (1): Mean  $\pm$  standard error of seasonal variation of hydrosol characteristic at El-Qabauty junction canal. Northern site in (1stline) and southern site bold in (2ndline). Values with the same small letters in the same rows do not significantly different at  $p < 0.05$  according to LSD used for seasonal variations. Values with capital letters in same columns do not significantly different at  $p < 0.05$  according to LSD used for site variations.

	Winter	Spring	Summer
pH	8.40 <sup>aA</sup> $\pm$ 0.1 <b>8.44<sup>A</sup><math>\pm</math>0.25</b>	8.61 <sup>aA</sup> $\pm$ 0.05 <b>8.72<sup>A</sup><math>\pm</math>0.46</b>	8.63 <sup>a</sup> $\pm$ 0.05 <b>9.46<math>\pm</math>0.1</b>
EC $\mu$ S /cm	854 <sup>aA</sup> $\pm$ 16.28 <b>1070.33<sup>A</sup><math>\pm</math>62.73</b>	473.66 <sup>a</sup> $\pm$ 42.19 <b>4283.33<math>\pm</math>422.3</b>	761 <sup>a</sup> $\pm$ 112.22 <b>1825.33<math>\pm</math>88.696</b>
TDS mg/g	425.66 $\pm$ 9.24 <b>535<math>\pm</math>30.53</b>	236.66 $\pm$ 21.18 <b>2143<math>\pm</math>0.21</b>	380.33 $\pm$ 56.44 <b>913<math>\pm</math>44.6</b>
NaCl %	1.47 <sup>aA</sup> $\pm$ 1.33 <b>2.06<sup>A</sup><math>\pm</math>1.33</b>	0.97 <sup>a</sup> $\pm$ 0.07 <b>8.033<math>\pm</math>0.57</b>	1.53 <sup>a</sup> $\pm$ 0.2 <b>3.5<math>\pm</math>0.152</b>
OM %	2.478 <sup>a</sup> $\pm$ 1.01 <b>4.434<sup>a</sup><math>\pm</math>3.52</b>	0.622 <sup>a</sup> $\pm$ 0.01 <b>5.171<sup>a</sup><math>\pm</math>1.73</b>	0.721 <sup>a</sup> $\pm$ 0.98 <b>1.255<sup>a</sup><math>\pm</math>0.16</b>
Cl mg/g	9.922 <sup>A</sup> $\pm$ 1.673 <b>17.483<sup>A</sup><math>\pm</math>7.503</b>	0.885 $\pm$ 0.42 <b>9.99<math>\pm</math>0.852</b>	3.647 <sup>A</sup> $\pm$ 0.01 <b>10.889<sup>A</sup><math>\pm</math>0.01</b>

EC=Electrical conductivity, TDS=Total dissolved solids, OM%=Organic matter, Cl=Chloride.

### 3.2.1- Correlations between water and soil parameters

Pearson correlations between water and soil variables are shown in Table 2. The results revealed that water pH had significant positive correlations with soil EC, TDS and NaCl ( $r = 0.549$ ,  $0.549$  and  $0.546$ , respectively), while DO, EC, TDS of water have significant correlations with all soil parameter except pH and Cl. Water BOD showed positively significant correlations with soil Cl ( $r = 0.602$ ).

Table (2) Correlation coefficients between water and soil variables at junction canal (El-Qabauty). \*\* = Significant at  $p < 0.01$ , \* = Significant at  $p < 0.05$ .

soil \ water	pH	EC	TDS	NaCl	Cl
pH	0.154	0.549*	0.549*	0.546*	0.134
DO	-0.408	0.582*	-0.582*	-0.596**	-0.467
Ec	0.333	0.722**	0.722**	0.745**	0.095
TDS	0.266	0.961**	0.961**	0.964**	0.248
BOD	-0.104	-0.016	-0.017	0.024	0.602**

DO=Dissolved oxygen, Ec=Electrical conductivity, TDS=Total dissolved solids, BOD= Biochemical oxygen demand.

### 3.3- Heavy metal concentrations in water

The results of heavy metal concentrations of water at NSQ and SSQ sites along El-Qabauty junction canal during the different seasons are represented in Table 3. In spring, the SSQ had the highest concentrations of Co, Mn, As, Cr and Fe were 9.73, 9.79, 24.89, 26.38 and 47.57 mg/l, respectively. However, the same site recorded the highest values of Zn (2.12 mg/l) and Pb (61.54 mg/l) during winter. Summer had the lowest mean values for the majority metal concentrations, except for Cd, Ni, Hg and Se with higher values (0.03, 0.08, 12.83 and 12.94 mg/l, respectively) at SSQ.

**Table (3):** Mean values± standard error for seasonal variation of heavy metal concentrations in water at northern site in (NSQ, first line) and southern site in bold (SSQ, second line) of El-Qabuty junction canal compared to food and Agriculture Organization (FAO) for heavy metals in wastewater [38].

Metals	Winter	Spring	Summer	Maximum level of FAO
As	0.01 <sup>A</sup> ±0 <b>0.01<sup>Aa</sup>±0</b>	6.24 <sup>a</sup> ±0.05 <b>24.89<sup>Aa</sup>±0.14</b>	0.01A <sup>a</sup> ±0 <b>0.04<sup>Aa</sup>±0</b>	0.10
Br	89.99±0.01 <b>104.13±0.1</b>	174.23±1.58 <b>115.17±0.17</b>	150.75±0.17 <b>121.03±0.06</b>	-
Cd	<0.01 <sup>Aa</sup> ±0 <b>0.02<sup>Aa</sup>±0</b>	<0.01 <sup>Aa</sup> ±0 <b>0.01<sup>Aa</sup>±0</b>	<0.01 <sup>Aa</sup> ±0 <b>0.03<sup>Aa</sup>±0</b>	0.01
Co	0.01 <sup>A</sup> ±0 <b>0.08<sup>Aa</sup>±0.01</b>	3.68±0.14 <b>9.73<sup>a</sup>±0.14</b>	0.29±0.17 <b>3.04<sup>a</sup>±0.01</b>	0.05
Cr	0.01 <sup>A</sup> ±0 <b>18.04<sup>Aa</sup>±0.14</b>	1.42±0.14 <b>26.38±0.17</b>	7.86±0.16 <b>24.37<sup>a</sup>±0.17</b>	0.10
Fe	5.04 <sup>Aa</sup> ±0.16 <b>25.09<sup>Aa</sup>±0.14</b>	19.81±0.14 <b>47.57±0.17</b>	3.01 <sup>Aa</sup> ±0.06 <b>6.25<sup>Aa</sup>±0.06</b>	5.00
Hg	<0.01 <sup>Aa</sup> ±0 <b>7.65<sup>A</sup>±0.14</b>	<0.01 <sup>a</sup> ±0 <b>10.52±0.17</b>	<0.01 <sup>a</sup> ±0 <b>12.83±0.06</b>	0.0005
Mn	<0.01 <sup>Aa</sup> ±0 <b>5.13<sup>Aa</sup>±0.14</b>	<0.01 <sup>a</sup> ±0 <b>9.79±0.17</b>	<0.01 <sup>Aa</sup> ±0 <b>7.66<sup>Aa</sup>±0.14</b>	0.20
Ni	<0.01 <sup>Aa</sup> ±0 <b>0.05<sup>A</sup>±0.01</b>	<0.01 <sup>Aa</sup> ±0 <b>0.02<sup>Aa</sup>±0.01</b>	<0.01 <sup>Aa</sup> ±0 <b>0.08<sup>Aa</sup>±0.01</b>	0.20
Pb	38.26±0.01 <b>61.54±0.1</b>	17.37±0.14 <b>50.65±0.17</b>	26.60±0.17 <b>31.14±0.06</b>	5.0
Se	<0.01 <sup>A</sup> ±0 <b>0.15<sup>Aa</sup>±0.01</b>	<0.01±0 <b>3.64<sup>a</sup>±0.14</b>	<0.01±0 <b>12.94<sup>a</sup>±0.17</b>	0.02
Zn	0.12±0.01 <b>2.12±0.1</b>	0.15 <sup>A</sup> ±0.01 <b>1.58<sup>Aa</sup>±0.14</b>	0.89±0.17 <b>1.16<sup>a</sup>±0.17</b>	2.00

Values with the same small letters in the same rows do not significantly different at  $p < 0.05$  according to LSD used for seasonal variations. Values with capital letters in same columns do not significantly different at  $p < 0.05$  according to LSD used for site variations.

### 3.4- Heavy metal concentrations of hydrosol

The results showed significant seasonal and spatial variations in the concentrations of heavy metals Table 4. The mean concentrations of Br, Cr, Fe, Mn, Ni, Pb, and Zn of winter season attained the highest values in SSQ with the concentrations of 108.74 mg/kg, 181.75 mg/kg, 63379.80 mg/kg, 1014.04 mg/kg, 93.64 mg/kg, 30.09 mg/kg and 184.92 mg/kg, respectively. The spring and summer showed the lowest values in concentrations of most elements during study; but summer of SSQ attained the highest values of As, Co, Hg, Se and Cd with concentrations of 41.67 mg/kg, 21.87 mg/kg, 41.12 mg/kg, 8.00 mg/g, and 14.25 mg/kg, respectively.

**Table (4):** Mean  $\pm$  standard error of seasonal variations of heavy metal concentrations in hydrosol (mg/kg dry wt) at northern (NSQ) and southern (SSQ) sites of El-Qabouty junction canal in reference to the corresponding values of World Average Soil (WAS)[[39], [40]]. Northern site in 1<sup>st</sup> line and southern site bold in 2<sup>nd</sup> line.

Element mg/kg	winter	spring	summer	WAS mg/kg
As	6.69 <sup>Aa</sup> $\pm$ 0 <b>2.74<sup>Aa</sup><math>\pm</math>0</b>	5.64 <sup>Aa</sup> $\pm$ 0 <b>2.00<sup>Aa</sup><math>\pm</math>0</b>	20.83 <sup>Aa</sup> $\pm$ 0.01 <b>41.67<sup>Aa</sup><math>\pm</math>0.01</b>	6.83
Br	36.48 <sup>Aa</sup> $\pm$ 0.01 <b>108.7<sup>Aa</sup><math>\pm</math>0.06</b>	5.59 <sup>Aa</sup> $\pm$ 0 <b>64.08<sup>Aa</sup><math>\pm</math>0.01</b>	24.84 <sup>Aa</sup> $\pm$ 0.01 <b>41.15<sup>Aa</sup><math>\pm</math>0.01</b>	10
Cd	2.00 <sup>Aa</sup> $\pm$ 0 <b>4.01<sup>Aa</sup><math>\pm</math>0</b>	1.25 <sup>Aa</sup> $\pm$ 0 <b>2.03<sup>Aa</sup><math>\pm</math>0</b>	17.11 <sup>Aa</sup> $\pm$ 0.01 <b>14.25<sup>Aa</sup><math>\pm</math>0.01</b>	0.4
Co	8.82 <sup>Aa</sup> $\pm$ 0 <b>10.95<sup>Aa</sup><math>\pm</math>0</b>	5.60 <sup>Aa</sup> $\pm$ 0 <b>4.57<sup>Aa</sup><math>\pm</math>0</b>	19.92 <sup>Aa</sup> $\pm$ 0.01 <b>21.87<sup>Aa</sup><math>\pm</math>0.01</b>	11.3
Cr	78.26 <sup>a</sup> $\pm$ 0.02 <b>181.7<math>\pm</math>0.01</b>	55.91 <sup>Aa</sup> $\pm$ 0.01 <b>72.02<sup>Aa</sup><math>\pm</math>0.02</b>	56.20 <sup>Aa</sup> $\pm$ 0.01 <b>74.84<sup>Aa</sup><math>\pm</math>0.01</b>	59.5
Fe	27639 <sup>a</sup> $\pm$ 4.98 <b>63379<math>\pm</math>13.58</b>	11235 <sup>Aa</sup> $\pm$ 0.58 <b>32859<sup>Aa</sup><math>\pm</math>10.69</b>	10966 <sup>Aa</sup> $\pm$ 0.01 <b>21184<sup>Aa</sup><math>\pm</math>0.01</b>	35000
Hg	5.26 <sup>Aa</sup> $\pm$ 0 <b>10.46<sup>Aa</sup><math>\pm</math>0.01</b>	16.64 <sup>Aa</sup> $\pm$ 0 <b>56.01<sup>Aa</sup><math>\pm</math>0</b>	0.60 <sup>a</sup> $\pm$ 0 <b>41.12<math>\pm</math>0.01</b>	0.26
Mn	556.2 <sup>a</sup> $\pm$ 0.06 <b>1014<math>\pm</math>0.11</b>	319.7 <sup>a</sup> $\pm$ 0.03 <b>595.7<sup>a</sup><math>\pm</math>0.16</b>	332.6 <sup>aA</sup> $\pm$ 0.01 <b>460.8<sup>Aa</sup><math>\pm</math>0.01</b>	488
Ni	30.03 <sup>a</sup> $\pm$ 0.01 <b>93.64<math>\pm</math>0.02</b>	14.38 <sup>Aa</sup> $\pm$ 0 <b>53.07<sup>aA</sup><math>\pm</math>0.01</b>	39.06 <sup>Aa</sup> $\pm$ 0.01 <b>50.32<sup>Aa</sup><math>\pm</math>0.01</b>	29
Pb	1.56 <sup>a</sup> $\pm$ 0 <b>30.09<math>\pm</math>0.02</b>	17.52 <sup>Aa</sup> $\pm$ 0 <b>8.12<sup>Aa</sup><math>\pm</math>0</b>	6.05 <sup>Aa</sup> $\pm$ 0 <b>17.22<sup>Aa</sup><math>\pm</math>0</b>	27
Se	1.43 <sup>Aa</sup> $\pm$ 0 <b>6.04<sup>Aa</sup><math>\pm</math>0</b>	2.89 <sup>Aa</sup> $\pm$ 0 <b>1.74<sup>Aa</sup><math>\pm</math>0</b>	1.10 <sup>Aa</sup> $\pm$ 0 <b>8.00<sup>Aa</sup><math>\pm</math>0</b>	0.5
Zn	65.49 <sup>a</sup> $\pm$ 0.01 <b>184.9<math>\pm</math>0.06</b>	24.34 <sup>a</sup> $\pm$ 0 <b>122.5<math>\pm</math>0.02</b>	48.9 <sup>Aa</sup> $\pm$ 0.01 <b>77.6<sup>Aa</sup><math>\pm</math>0.01</b>	70

Values with same small letters in same rows do not significantly different at  $p < 0.05$  according to LSD used for seasonal variation, where are values with capital letters in same columns do not significantly different at  $p < 0.05$  according to LSD used for site variation.

### 3.5- Physiological characteristic of *Phragmites australis*:

The seasonal variation in the properties of leaves for *P. australis* appeared in the Table 5. The results revealed significant differences in the measured attributes of the two sites over the study time. The largest values of chlorophylls a, b, total carotenoids and total pigments were 2.74 mg/g, 0.620 mg/g, 0.701 mg/g and 3.961 mg/g, respectively in NSQ site at winter compared to the other seasons. Specific leaf area in SSQ in spring attained the greatest area (195.43  $cm^2 / g$ ) and the highest water content (248.06%) opposed to corresponding values in the winter and summer.

#### 3.5.1- Correlation between physiological characteristic of *Phragmites australis* and hydrosol parameters

Correlation between hydrosol variables and *P. australis* at the studied sites are represented in Table 6. It has been found that SLA, Chl a, Chl b, total cartonoid and total pigments showed no significant correlations with soil variables. Leaf water content (WC) has negative correlation with all parameters and heavy metals of soil. All heavy metals has no correlation except Cd had significant correlation



with *P. australis* leaf water content, chlorophyll a and total carotenoid ( $r = 0.529, 0.296$  and  $0.598$ , respectively).

Table (5): Mean  $\pm$  standard error of seasonal variations of *Phragmites australis* leaf attributes (mg/g f.wt) at El-Qabouty junction canal. Northern site (NSQ) in 1<sup>st</sup>line and southern site (SSQ) bold in 2<sup>nd</sup>line. Values with the same small letters in the same rows do not significantly different at  $p < 0.05$  according to LSD used for seasonal variations, where are values with capital letters in the same columns do not differ significantly at  $p < 0.05$  according to LSD used for site variations.

	Winter	Spring	Summer
Chl a	2.74 $\pm$ 0.192	1.412 <sup>Aa</sup> $\pm$ 0.168	1.524 <sup>Aa</sup> $\pm$ 0.324
	<b>1.9<sup>a</sup><math>\pm</math>0.67</b>	<b>1.522<sup>Aa</sup><math>\pm</math>0.111</b>	<b>1.715<sup>Aa</sup><math>\pm</math>0.152</b>
Chl b	0.620 $\pm$ 0.084	0.312 <sup>Aa</sup> $\pm$ 0.048	0.363 <sup>Aa</sup> $\pm$ 0.084
	<b>0.336<sup>a</sup><math>\pm</math>0.009</b>	<b>0.383<sup>Aa</sup><math>\pm</math>0.047</b>	<b>0.484<sup>Aa</sup><math>\pm</math>0.044</b>
TC	0.701 <sup>A</sup> $\pm$ 0.039	0.413 <sup>A</sup> $\pm$ 0.045	0.622 $\pm$ 0.072
	<b>0.595<sup>A</sup><math>\pm</math>0.033</b>	<b>0.369<sup>A</sup><math>\pm</math>0.035</b>	<b>0.627<math>\pm</math>0.15</b>
TP	3.961 $\pm$ 0.299	2.137 <sup>Aa</sup> $\pm$ 0.26	2.609 <sup>Aa</sup> $\pm$ 0.335
	<b>2.831<math>\pm</math>0.094</b>	<b>2.273<sup>A</sup><math>\pm</math>0.163</b>	<b>2.826<sup>A</sup><math>\pm</math>0.143</b>
WC (%)	198.17 <sup>Aa</sup> $\pm$ 9.3	248.06 <sup>A</sup> $\pm$ 14.7	167.52 <sup>Aa</sup> $\pm$ 23.82
	<b>140.47<sup>Aa</sup><math>\pm</math>37.3</b>	<b>202.7<sup>A</sup><math>\pm</math>5.87</b>	<b>126.48<sup>Aa</sup><math>\pm</math>3.86</b>
SLA <sup>cm<sup>2</sup>/g</sup>	142.16 <sup>A</sup> $\pm$ 30.3	166.81 <sup>Aa</sup> $\pm$ 13.23	156.64 <sup>Aa</sup> $\pm$ 20.92
	<b>183.43<sup>Aa</sup><math>\pm</math>13.9</b>	<b>195.43<sup>Aa</sup><math>\pm</math>12.11</b>	<b>119.37<sup>A</sup><math>\pm</math>5.18</b>

Chl a = chlorophylls a, Chl b= chlorophylls b, TC= total carotenoid, TP= total pigment, WC%=water content, SLA<sup>cm<sup>2</sup>/g</sup> = specific leaf area.

Table (6): Correlation coefficients between *Phragmites australis* and hydrosol variables in El-Qabouty junction canal, Port Said. \*\* = Significant at  $p < 0.01$ , \* = Significant at  $p < 0.05$ .

<i>P. australis</i> soil	WC	SLA	Chl a	Chl b	total carotenoid	total pigment
pH	-0.101	-0.261	-0.234	0.042	0.079	-0.150
EC	-0.036	0.28	-0.182	0.029	-0.406	-0.289
TDS	-0.036	0.28	-0.182	0.03	-0.406	-0.289
As	-0.388	-0.466	0.046	0.212	0.15	0.226
Br	-0.146	0.288	0.136	0.051	0.028	0.071
Cd	<b>-0.529*</b>	-0.344	<b>0.296*</b>	0.064	<b>0.598**</b>	0.061
Hg	-0.139	0.134	-0.225	0.014	-0.372	-0.305
Pb	0.207	0.198	-0.102-	-0.334	-0.004-	-0.156
Cr	-0.463	0.103	0.225	-0.042	0.04	0.161
Mn	-0.315	0.226	0.304	0.027	0.022	0.207
Ni	-0.427	0.152	0.077	-0.080	0.046	0.02
Zn	-0.261	0.336	0.121	0.072	0.061	0.04
Se	<b>-0.560*</b>	-0.262	-0.116	0.058	0.11	0.101
Fe	-0.224	0.259	0.268	-0.017	0.005	0.172

### 3.5.2- Heavy metals in *P. australis* organs

The concentrations of heavy metals in both aerial and underground parts of *P. australis* were presented in Table 7. The results showed significant differences between aerial and underground parts in the two studied sites at the different seasons. Heavy metal concentration of underground parts in NSQ site occurred in the following order Fe > Mn > Br > Zn > Cr > Ni > Pb > Se > Hg > As > Co > Cd, while the order of heavy metal in aerial parts was as follow Fe > Mn > Br > Zn > Cr > As > Hg > Ni > Se > Cd > Co > Pb. In SSQ site, the heavy metals of underground part was enriched with Fe as the most metal followed by Mn > Br > Zn > Cr > Ni > Hg > Pb > Se > As > Cd > Co and the concentrations of elements for aerial parts in the same site were as follow Fe > Mn > Br > Zn > Cr > Ni > Hg > Pb > As > Co > Se > Cd. Iron recorded its highest concentration in the underground part in SSQ site at dry season with value 11472.01 mg/kg, while its lowest value was 1429.42 mg/kg in the aerial part at the same site. The highest concentration of Mn was 1432.59 mg/kg in the underground part of SSQ site in winter; while its lowest concentration was 292.88 mg/kg at NSQ site during summer. Cd concentration ranged from 19.25 mg/kg in underground parts in SSQ site at summer while the lowest value was 0.10 mg/kg in spring at NSQ site. Notably, the underground parts at NSQ site attained the highest values of most metals such as Co, As, Cr, Hg, Ni, Pb, Se, and Zn with concentrations 101.05 mg/kg, 67.37 mg/kg, 159.96 mg/kg, 104.63 mg/kg, 150.18 mg/kg, 110.95 mg/kg, and 229.09 mg/kg, respectively during summer season. It must be recorded that Br and As are the only metals which their concentrations in aerial parts were higher than in the underground parts.

### 3.5.3- Bioaccumulation and translocation of heavy metals in *P. australis*.

The cited results in Table 8 revealed that Bioaccumulation Factors (BF) and Translocation Factors (TF) of considered heavy elements varied greatly between sites. Except Co and Fe, the BF of all metals was found to be high in dry seasons than winter season. The Bioaccumulation Factor of different metals ranged from 174.38 for Hg to 2.35 for Cd.

As regard to Translocation Factor (TF), Co, Fe, Hg and Zn recorded values < 1 at the two sites in all studied seasons. On the other hand, the TF of Pb, As, Br, Cd and Mn showed higher values of TF compared to the other metals. The BF of Cr and Ni had values <1 in the SSQ during spring but TF for both metals recorded values >1 (1.23 and 1.13, respectively). Notably, Results revealed that BF of AS and Cd were 0.15, 0.06 respectively but their TF recorded 15.97 and 12.82 respectively.

**Table (7):** Mean  $\pm$  standard error of seasonal variations of heavy metal concentrations in *Phragmites australis* (mg/kg dry .wt) along El-Qabouty junction canal compared to critical ranges of metals in plants (mg/kg) [[39]]. Northern site (NSQ) in 1<sup>st</sup> line and the southern site (SSQ) bold in (2<sup>nd</sup>line).

Metal mg/kg	Critical ranges in plants	Winter		Spring		Summer	
		Above	Below	Above	Below	Above	Below
AS	5 - 20	15.97 <sup>Aa</sup> $\pm$ 3.35 <b>5.23<sup>A</sup> <math>\pm</math>2.44</b>	1.05 <sup>Aa</sup> $\pm$ 0 <b>4.22<sup>A</sup> <math>\pm</math>0</b>	35.06 <sup>Aa</sup> $\pm$ 6.69 <b>7.30<sup>A</sup> <math>\pm</math>4.21</b>	29.50 <sup>Aa</sup> $\pm$ 17.03 <b>16.69<sup>A</sup> <math>\pm</math>4.31</b>	41.32 <sup>Aa</sup> $\pm$ 5.83 <b>3.85<sup>A</sup> <math>\pm</math>0</b>	101.05 $\pm$ 58.34 <b>20.72 <math>\pm</math>10.13</b>
Br	---	117.56 <sup>Aa</sup> $\pm$ 2.36 <b>54.44<sup>Aa</sup> <math>\pm</math>4.40</b>	97.83 <sup>Aa</sup> $\pm$ 24.52 <b>103.31<sup>Aa</sup> <math>\pm</math>12.51</b>	360.34 <sup>b</sup> $\pm$ 37.3 <b>253.24<sup>b</sup> <math>\pm</math>41.9</b>	292.42 <sup>b</sup> $\pm$ 22.69 <b>180.37<sup>bc</sup> <math>\pm</math>20.93</b>	115.39 <sup>a</sup> $\pm$ 5.83 <b>383.41<sup>c</sup> <math>\pm</math>10</b>	259.82 <sup>Ab</sup> $\pm$ 58.34 <b>276.12<sup>Ab</sup> <math>\pm</math>10.13</b>
Cd	5 - 30	4.16 <sup>Aa</sup> $\pm$ 0.10 <b>2.04<sup>Aa</sup> <math>\pm</math>0</b>	3.00 <sup>aA</sup> $\pm$ 0 <b>4.23<sup>Aa</sup> <math>\pm</math>0</b>	0.10 <sup>aA</sup> $\pm$ 0 <b>2.03<sup>Aa</sup> <math>\pm</math>1.17</b>	0.20 <sup>aA</sup> $\pm$ 0 <b>4.70<sup>Aa</sup> <math>\pm</math>0</b>	12.85 $\pm$ 5.8 <b>2.25<sup>a</sup> <math>\pm</math>0</b>	1.48 <sup>a</sup> $\pm$ 0 <b>19.25 <math>\pm</math>10.12</b>
Co	15 - 50	0.79 <sup>Aa</sup> $\pm$ 0 <b>0.43<sup>Aa</sup> <math>\pm</math>0</b>	2.87 <sup>Aa</sup> $\pm$ 1.88 <b>1.07<sup>Aa</sup> <math>\pm</math>0</b>	0.87 <sup>Aa</sup> $\pm$ 0 <b>1.08<sup>Aa</sup> <math>\pm</math>0</b>	2.49 <sup>Aa</sup> $\pm$ 0 <b>3.67<sup>Aa</sup> <math>\pm</math>0</b>	11.58 <sup>Aa</sup> $\pm$ 5.83 <b>4.93<sup>Aa</sup> <math>\pm</math>0</b>	67.37 $\pm$ 67 <b>5.64<sup>a</sup> <math>\pm</math>0</b>
Cr	5 - 30	40.38 <sup>Aa</sup> $\pm$ 2.73 <b>30.17<sup>Aa</sup> <math>\pm</math>8.68</b>	81.33 <sup>Aa</sup> $\pm$ 14.19 <b>54.83<sup>Aa</sup> <math>\pm</math>3.85</b>	25.15 <sup>Aa</sup> $\pm$ 11.11 <b>51.62<sup>Aa</sup> <math>\pm</math>15.29</b>	51.59 <sup>Aa</sup> $\pm$ 23.92 <b>41.88<sup>Aa</sup> <math>\pm</math>2.03</b>	70.54 <sup>Aa</sup> $\pm$ 5.83 <b>44.97<sup>Aa</sup> <math>\pm</math>10.13</b>	159.96 <sup>A</sup> $\pm$ 58.34 <b>134.93<sup>A</sup> <math>\pm</math>10.13</b>
Fe	1000 - 3000	1538.04 <sup>Aa</sup> $\pm$ 141.42 <b>1470.75<sup>Aa</sup> <math>\pm</math>54.27</b>	6949.38 <sup>Ab</sup> $\pm$ 1269 <b>9294.45<sup>Ab</sup> <math>\pm</math>1610</b>	1429.42 <sup>Aac</sup> $\pm$ 231.6 <b>3483.04<sup>Aac</sup> <math>\pm</math>373.1</b>	4104.16 $\pm$ 326.4 <b>11472.01<sup>ac</sup> <math>\pm</math>3222</b>	2049.60 <sup>Aac</sup> $\pm$ 5.83 <b>1989.06<sup>Aac</sup> <math>\pm</math>10.13</b>	4360.41 <sup>Aabc</sup> $\pm$ 58.34 <b>7469.67<sup>ba</sup> <math>\pm</math>10.13</b>
Hg	1 - 3	7.24 <sup>Aa</sup> $\pm$ 1.77 <b>24.98<sup>Aa</sup> <math>\pm</math>11.20</b>	33.37 <sup>Aa</sup> $\pm$ 9.69 <b>48.06<sup>Aa</sup> <math>\pm</math>2.83</b>	18.50 <sup>Aa</sup> $\pm$ 2.81 <b>0.87<sup>A</sup> <math>\pm</math>0</b>	33.39 <sup>Aa</sup> $\pm$ 2.57 <b>2.49<sup>A</sup> <math>\pm</math>1.43</b>	13.11 <sup>Aa</sup> $\pm$ 5.83 <b>35.35<sup>Aa</sup> <math>\pm</math>10</b>	104.63 <sup>A</sup> $\pm$ 58.34 <b>73.07<sup>A</sup> <math>\pm</math>10</b>
Mn	400 - 1000	846.42 <sup>Aa</sup> $\pm$ 146 <b>471.55<sup>Aa</sup> <math>\pm</math>52.65</b>	747.07 <sup>a</sup> $\pm$ 0.07 <b>1432.59 <math>\pm</math>523</b>	520.44 <sup>Aa</sup> $\pm$ 55.32 <b>489.80<sup>Aa</sup> <math>\pm</math>51.99</b>	952.81 <sup>Aa</sup> $\pm$ 210 <b>486.69<sup>Aa</sup> <math>\pm</math>126.19</b>	292.88 <sup>A</sup> $\pm$ 5.83 <b>398.81<sup>Aa</sup> <math>\pm</math>10</b>	405.37 <sup>Aa</sup> $\pm$ 58.34 <b>299.40<sup>Aa</sup> <math>\pm</math>10.13</b>
Ni	10 - 100	6.64 <sup>Aa</sup> $\pm$ 2.61 <b>5.64<sup>A</sup> <math>\pm</math>3.08</b>	26.10 <sup>Aa</sup> $\pm$ 6.41 <b>30.48<sup>Aa</sup> <math>\pm</math>5.59</b>	6.47 <sup>Aa</sup> $\pm$ 3.63 <b>11.44<sup>A</sup> <math>\pm</math>2.53</b>	41.41 <sup>Aa</sup> $\pm$ 15.16 <b>10.09<sup>A</sup> <math>\pm</math>0.57</b>	20.47 <sup>Aa</sup> $\pm$ 5.83 <b>39.79<sup>Aa</sup> <math>\pm</math>10.13</b>	150.18 $\pm$ 58.34 <b>80.42 <math>\pm</math>10</b>
Pb	30 - 300	0.23 <sup>Aa</sup> $\pm$ 0 <b>22.99<sup>Aa</sup> <math>\pm</math>2.95</b>	0.46 <sup>Aa</sup> $\pm$ 0 <b>6.08<sup>Aa</sup> <math>\pm</math>3.19</b>	5.11 <sup>Aa</sup> $\pm$ 2.95 <b>0.54<sup>Aa</sup> <math>\pm</math>0</b>	29.36 <sup>Aa</sup> $\pm$ 19 <b>12.22<sup>Aa</sup> <math>\pm</math>7.51</b>	10.11 <sup>Aa</sup> $\pm$ 5.83 <b>31.15<sup>Aa</sup> <math>\pm</math>10.13</b>	110.95 $\pm$ 58.34 <b>47.20<sup>a</sup> <math>\pm</math>0</b>
Se	5 - 30	2.70 <sup>a</sup> $\pm$ 1.57 <b>0.54<sup>a</sup> <math>\pm</math>0</b>	2.98 <sup>Aa</sup> $\pm$ 0 <b>0.62<sup>Aa</sup> <math>\pm</math>0</b>	3.14 <sup>Aa</sup> $\pm$ 1.81 <b>2.08<sup>Aa</sup> <math>\pm</math>1.20</b>	3.12 <sup>Aa</sup> $\pm$ 2.02 <b>3.44<sup>Aa</sup> <math>\pm</math>2.11</b>	14.58 <sup>Aa</sup> $\pm$ 5.83 <b>3.59<sup>Aa</sup> <math>\pm</math>0</b>	106.23 $\pm$ 58.3 <b>21.34<sup>a</sup> <math>\pm</math>10</b>
Zn	100 - 400	121.57 <sup>Aa</sup> $\pm$ 2.31 <b>64.02<sup>Aa</sup> <math>\pm</math>3.23</b>	147.30 <sup>Ab</sup> $\pm$ 15.67 <b>115.08<sup>Ab</sup> <math>\pm</math>15.67</b>	75.56 <sup>a</sup> $\pm$ 6.68 <b>146.87<sup>b</sup> <math>\pm</math>17.03</b>	175.43 <sup>Aabc</sup> $\pm$ 43.12 <b>166.19<sup>Ab</sup> <math>\pm</math>21.03</b>	68.20 <sup>Aa</sup> $\pm$ 5.83 <b>110.78<sup>Ab</sup> <math>\pm</math>10</b>	229.09 <sup>Ac</sup> $\pm$ 58.34 <b>176.53<sup>Ab</sup> <math>\pm</math>10</b>

Values with same small letters in same rows do not significantly different at  $p < 0.05$  according to LSD used for seasonal variation, where are values with capital letters in same columns do not differ significantly at  $p < 0.05$  according to LSD used for site variation.

Table (8) Translocation factor (TF) and Bioaccumulation factor (BF) of the measured element in *Phragmites australis* along El-Qabouty junction canal. Northern site (NSQ) in bold 1<sup>st</sup> line and southern site (SSQ) in 2<sup>nd</sup>line.

Element	BF			TF		
	Winter	Spring	Summer	Winter	Spring	Summer
AS	<b>0.15</b>	<b>5.23</b>	<b>4.85</b>	<b>15.97</b>	<b>1.19</b>	<b>0.41</b>
	1.46	8.35	0.50	1.31	0.44	0.19
Br	<b>2.68</b>	<b>52.30</b>	<b>10.46</b>	<b>1.20</b>	<b>1.23</b>	<b>0.44</b>
	0.95	2.81	6.71	0.53	1.40	1.39
Cd	<b>1.50</b>	<b>0.20</b>	<b>0.06</b>	<b>1.39</b>	<b>0.50</b>	<b>12.85</b>
	1.75	2.35	1.35	0.29	0.43	0.10
Co	<b>0.32</b>	<b>0.44</b>	<b>3.38</b>	<b>0.28</b>	<b>0.35</b>	<b>0.17</b>
	0.09	0.80	0.26	0.43	0.29	0.87
Cr	<b>1.04</b>	<b>0.92</b>	<b>2.85</b>	<b>0.50</b>	<b>0.49</b>	<b>0.44</b>
	0.30	0.58	1.80	0.55	1.23	0.33
Fe	<b>0.25</b>	<b>1.02</b>	<b>0.40</b>	<b>0.22</b>	<b>0.12</b>	<b>0.47</b>
	0.15	0.12	0.35	0.16	0.85	0.27
Hg	<b>6.35</b>	<b>2.01</b>	<b>174.38</b>	<b>0.22</b>	<b>0.55</b>	<b>0.13</b>
	4.59	0.04	1.78	0.52	0.35	0.48
Mn	<b>1.35</b>	<b>2.98</b>	<b>1.22</b>	<b>1.13</b>	<b>0.55</b>	<b>0.72</b>
	1.41	0.82	0.65	0.33	1.01	1.33
Ni	<b>0.87</b>	<b>2.88</b>	<b>3.84</b>	<b>0.25</b>	<b>0.16</b>	<b>0.14</b>
	0.33	0.19	1.60	0.19	1.13	0.49
Pb	<b>0.29</b>	<b>1.68</b>	<b>18.49</b>	<b>0.50</b>	<b>0.17</b>	<b>0.09</b>
	0.20	1.50	2.78	3.78	0.04	0.66
Se	<b>2.08</b>	<b>1.08</b>	<b>106.23</b>	<b>0.91</b>	<b>1.01</b>	<b>0.14</b>
	0.10	1.98	2.67	0.87	0.60	0.17
Zn	<b>2.25</b>	<b>7.21</b>	<b>4.68</b>	<b>0.83</b>	<b>0.43</b>	<b>0.30</b>
	0.62	1.36	2.27	0.56	0.88	0.63

#### 4. DISCUSSION

The industrial wastes from factories and investments zone of Port Said are discharging in El- Qabouty junction canal. These wastes are not under strict management and consequently may be untreated or partially treated. Therefore, the evaluation of such heavy metal contamination impact on the ecosystem of the canal is critical for monitoring and assessing the potential role of *P. australis* in phytoremediation. Particularly, the impact assessment along the canal could be similar or higher than that of Lake Manzala [41].

Generally, the results of the present study showed that high values of most physiochemical variables and heavy metal concentrations were higher at SSQ site which located nearby the industrial discharge outlet (SSQ). This may be attributed to the nature of area and ensure that the industrial discharge is partially and/or untreated which lead to an increase in the mobilization of the contaminated elements in the canal ecosystem and disturbance of their biogeochemical cycles [42]. Similarly, Madkour (2007) [43] mentioned that El-Qabouty canal has turned into highly eutrophic basin as a result of the continuous release of untreated domestic, industrial and agricultural wastewater.

The results show that pH values are slightly alkaline at both sites, and matches with Salah El Din (2005) [44] in Lake Manzala. The alkalinity along the canal could be attributed to activating air oxygen dissolution by the abundant phytoplankton and photosynthetic activity by aquatic vegetation [45]. The present result also revealed that the seasonal variation in pH has no significance differences which coincides, with Ibrahim (2012) [29]. The higher TDS of water samples was in SSQ site during the dry season which may be attributed to its nearby to the wastes effluent draining point with elevated and concentrated cations and anions during drought Jung (2001) [46]. The highest EC at SSQ site in spring could be reflected it's nearby to the discharge point and the existence of considerable amounts of soluble

inorganic substances as indicated by high TDS in accordance with Salman *et al.*, (2019) [47]. Elmorsi *et al.* (2017) [28] confirmed that electric conductivity (EC) is positively correlated with TDS. On the other hand, the water of El Qabouty junction canal is generally saline water according to classification estimated of Ibrahim (2012) [29].

Dissolved Oxygen (DO) is fundamental for the survival of aquatic life, and hence it serves as an important indicator of ecosystem condition and water quality [48, 49]. The results of the present study showed the lowest DO was in the SSQ site compare to the highest one at the NSQ site which could be related the discharge of large amounts of biodegradable organic compounds near the first site which stimulate the microbial activity with reducing DO that was consistent with Aniyikaiye *et al.*, (2019) [49]. Such high microbial activity at SSQ site is reflected in the obtained results of higher BOD during winter, which reached levels greater than the adopted limits of Egyptian Governmental Law No. 48/1982 (BOD  $\leq$ 10.00 mg/l). On the other hand, the lower temperature during winter may be facilitate oxygen dissolving capacity of water, photosynthesis activity at water surface and anaerobic decomposition of ammonia and organic materials of industrial and municipal effluents that correspond with Abdel -Samei *et al.*, (2007) and Banerjee (2016) [50, 51].

The results of pH in indicated neutral to slightly alkaline of hydrosol, which could be stimulated the metal removal through immobilization in the rhizosphere and absorption by their roots, as well as somewhat by precipitation [52, 5]. Kabata-Pendias, (2011) [53] found that pH of soil is the major factor controlling both total and relative uptake of heavy metals, through its effect on its chemical, physical, and biological qualities [54, 55]. The higher soil electrical conductivity and total dissolved solid at SSQ site during summer and spring may be related to the deposition of chemical compounds from the nearby discharge point and the higher evaporation during warm seasons that agreement with Fritioff *et al.*, (2005) and Shrivastava P. & Kumar R. (2015) [56, 57]. The significant correlation between EC and TDS indicated that the dissolved solids were mainly ionic [58]. This conclusion coincides with Thirumalini and Kurian Joseph (2009) [59] in the fact that TDS – EC correlation ratio may not be same for all water and soil natural and it varies widely with in themselves. DO of water have negative significant correlations with soil's TDS may be due to the concentration of DO is controlled by its consumption by aerobic organisms and plants which is reproduced during photosynthesis. Moreover, DO level mainly affected by the type of nearest water effluents [28]. Cl is found in nature in the form of sodium (NaCl) and potassium (KCl) salts, and it makes up around 0.05 % of the lithosphere. The high Cl'soil contents in El-Qabuty canal recorded during cold period at southern area reflect the contamination from the industrial area that agreed with the high Cl concentration readings are observed at area in the eastern section of Port Said by [60].

The results revealed spatial variations in concentrations of heavy metals (Co, Cr, Fe, As, Cd, Mn, Se, Hg and Ni) in water with higher values during spring and summer. Such spatial and seasonal fluctuations could be due to high temperatures of water and air associated with rising evaporation rate and metal concentrations that is demonstrated by Ouro-Sama *et al.*, (2020) [61]. On the other hand, the increase of heavy metal concentrations of water may be attributed to the mobilization of metals from the hydrosol due to the effect of both high temperature and fermentation of organic materials by microbial activity that agree with the previous studies Kouamenan *et al.*, (2019) [62].

Lead was classified as being potentially hazardous and toxic by The United States Environmental Protection Agency (EPA) to most forms of life [63]. The present results showed extremely high levels for lead at both sites SSQ & NSQ where it represented three to 12 times more the FAO standard limits. Such extremely high Pb concentrations may be due to high discharge of untreated and/or partially treated industrial and agricultural wastes in the canal. Additionally, dust collects a large amount of Pb from gasoline burning in automobiles eventually makes its way into the Lake Manzala and lead to an increase in Pb content [64]. The high content of water Zn concentration could be related to its leaking from the protective plates of fishing boats and the discharge of industrial wastes especially electroplating and synthetic fiber production. The sequence of water heavy metal concentrations was Pb>Fe>Cr>As>Hg which is different from that of Lake Manzala Zn>Cu>Pb>Cd; Bahnasawy, *et al* (2011) [65].

Hydrosol composition is considered a good indicator for heavy metals contamination, as they are rapidly immobilized from water to hydrosol where their adsorption and accumulation occur due to low solubility [66]. Consequently, the present results showed higher concentrations of the measured metals in hydrosol than their counterparts in water.

Metallic ions are commonly associated with organic matter and deposited in hydrosol in wetland environments, which are key sinks and sources for heavy element contamination [66 , 67 , 68]. Heavy metals are linked to the soil, organic matter concentration, pH, and redox potential, all affect the element's ability to escape in stable or ionic form [68]. Metal cations are bonded to negatively charged particles like clay and organic materials in the soil [70]. Metals that detach from soil particles and enter the soil solution become accessible, with the potential to accumulate in plants and other soil-dwelling creatures [71]. Heavy elements like Zn and Ni are more prone to form stable compounds with humic chemicals [69].

The highest concentrations of SSQ hydrosol for Cd, As, Co and Se at summer were probably due to their cycling and deposition at the surface in response to higher temperature and evaporation that accepted with Abu Khatita S. A. et al., (2015) [72]. On the other hand, the lower concentrations during winter could be related to lower evaporation and rainy season which receded the water and soil [73].

The physiological characteristic of the plant may be affected by heavy metal uptake and cause alteration in plant metabolic pathways, such as photosynthesis, respiration, and growth [13]. In this respect, the present results revealed significant increase in pigment concentrations of *P. australis* as a stronger indication of effluent toxicity [74]. Kolotov *et al.* (2003) [75]. Moreover, Hadad, *et al.* (2010) [76] reported that chlorophylls level is an excellent toxicological indication for different metals that are dependent on macrophyte species. The significant increase in chlorophylls a, b, total carotenoid and total pigments at SSQ could be related to the heavy load of industrial effluents which stimulate the above-ground biomass that accepted with previous studies Hadad *et al.*,(2010) and Eid *et al.*,(202) [76 , 22] .

The degree of upward translocation of metals by wetland plants from root tissues to aerial parts is dependent upon the plant species, the specific metal, and a number of environmental conditions [78] . Several plant species undergo serious difficulties for heavy metal uptake due to the antagonistic and synergetic effects [78 , 79].

In the current study, the highest concentration of most heavy metals (Co, Cr, Hg, Ni, Pb, Se and Zn) in below-ground parts (rhizome- root) for *P. australis* indicating that trace metals are largely maintained in the underground organs due to tolerance strategies that prevent harmful levels in underground organs from spreading to aboveground ones that agreement with Aboyeji *et al.*,(2020) and Klink (2017) [80, 24]. On the other hand, the higher levels of Cd, As, Br and Mn in the aerial parts could indicate their translocation and/or deposition through the atmosphere. The highest concentration of Cd was previously recorded nearby El-Qabuty area as a result of urban extension and agricultural disposal especially the phosphatic fertilizers that accepted with Zahran *et al.*, (2015) [82]. Previous research found that defensive strategy of Cd contamination in *P. australis* through increasing antioxidant enzyme activities and potential use for Cd detoxification [82, 83] .

Arsenic (As) is a highly dangerous element found in a variety of species, and its toxicity varies depending on the species. The form (inorganic or organic) and oxidation state of arsenic are affected by pH, redox conditions, surrounding mineral composition, and microbial activities [85]. The current study revealed that concentration of As in under-ground parts of *P. uastralis* at NSQ site exceeded critical ranges (5- 20 mg/kg) of metals that consistent with Pether *et al.*, (2001) [39]. Robinson et al (2006) [86] proved that Arsenic is adsorbed onto the surface of the plant via physicochemical reactions rather than biological uptake, probably as co-precipitation and incorporation with into Fe oxides attached to the surface of the plant.

#### **Bioaccumulation factor (BF) and translocation factor (TF)**

Bioaccumulation process is based on high concentrations of heavy metals in below-ground organs [86- 87]. Most elements recorded BF >1 values indicating that *P. australis* is considered hyper-accumulator species [89] . The BF of studied heavy metals were ordered as Hg > Se > Br > Pb > As > Zn > Ni > Mn > Cr > Cd. In previous study, Rzymiski, et al (2014) [90] recorded that roots of *P. australis* accumulated significantly higher levels of Cr, Cu, Co, Fe, and Ni. Recently Abdelaal et al.(2021) [91] showed that *P. australis* as hyper-accumulators for Fe, Zn, Mn, Co, Cd, Ni and Pb. The difference in the order of metals accumulation at two sites may be attributed to the different sources and intensities of industrial drainage regions and spatial distribution of heavy metals [92] . The BF of most metals was found to be high in dry seasons than winter season may be due to the fact that in rainy season the pollution was lower because of heavy rainfall and flushed out through the canal that is also reported with Mondol *et al.*, (2011) [73]. Such bioaccumulation results have also been reported by other studies of *P. australis* [92, 93] . The lower values of BF in high metal-contaminated hydrosol could be explained by avoiding metal uptake by the plant and/or by

low bioavailability of metals in water and hydrosol. It has been speculated that plant can immobilize heavy metals in unavailable forms through complexation with organic matter and/or precipitation under reducing conditions [95].

In the present study, the TF of Pb, As, Br, Cd and Mn showed higher values of TF compared to the other metals that may be due to heavy metals enter the roots and travel cell to cell through an apoplastic or symplastic pathway. In Apoplast pathway, heavy metal moves through the cell walls and intercellular space of the root cortex, while in the symplastic pathway, heavy metals pass through specialized transporter proteins and are chelated, eventually loading into the xylem at previous studies Maestri *et al.*, (2010) [96]. Certain pathways formed by plants to cope with heavy metals exposure are linked to some stress-signaling molecules, i.e., salicylic acid, ethylene, and nitric oxide [97]. Key elements of maintenance of metal homeostasis in hyperaccumulators plants are chelation and sequestration which result either in removal of toxic metal from sensitive sites or conduct essential metal to their specific cellular destination [98].

TF is used to assess a plant's ability to translocate metals from the underground organs to the aboveground ones [95-96]. The plant recorded TF > 1 for different metals with a sequence of decreasing TF values As > Cd > Zn > Pb > Br > Cr > Mn > Ni. For other elements like Hg and Zn recorded TF < 1 in both studied sites and different seasons; while their BF were more than 1. The obtained results indicated that most of the heavy metals are retained in the underground parts (high BF) of *P. australis* and translocated lesser to shoots (low TF) which suggested its utilization for phytostabilizing of these heavy elements that accepted with Yoon *et al.*, (2006) [99]. Previous results proved that the translocation of some heavy metals by *P. australis* was restricted by the root epidermis or endodermal Casparian strip which serves as a barrier [101]. The division of labor between uptake of roots and shoots is probably associated with the anatomy and morphology of different taxa, characteristic of species differing in growth rate, surface to volume ratio and physiological condition of individual plants [102].

### 5. CONCLUSION

Junction canal (EL-Qabauty) is subjected to an estimated high degree of heavy metal pollution from the waste of many industrial factories. XRF (X-ray fluorescence) is accurate and an excellent technology for qualitative and quantitative analysis of material composition. The present study clearly demonstrates that SSQ site nearby industrial drain output in Qabauty canal is more polluted than NSQ that is relatively far from the source of industrial output. *P. australis* is a good candidate for phytoremediation and has efficacy to extract trace elements to reduce the pollution load that reaches the canal from the industrial zone south of Port Said.

The maximum content of heavy metals in soil and *P. australis* is Fe with concentrations 11472.01 and 63.379 mg/kg, respectively. Heavy metal concentration of underground parts in NSQ site occurred in the following order Fe > Mn > Br > Zn > Cr > Ni > Pb > Se > Hg > As > Co > Cd, while the order of heavy metal in aerial parts was as follow Fe > Mn > Br > Zn > Cr > As > Hg > Ni > Se > Cd > Co > Pb. Heavy metals concentration in the under-ground biomass reaches its maximum values in dry seasons. The underground parts of *P. australis* were found to hyperaccumulate and phytostabilize Hg, Cr, Ni, Pb, Se and Zn. Highest Bioaccumulator factor (BF) of heavy metals were observed in the order Hg > Se > Br > Pb > Zn > Mn. The plant was most efficient in translocating As (TF = 15.97) and Cd (TF = 12.58). It would be best to create clusters i.e. combine the discharged wastewater produced by a group of factories for primary treatment before being discharged. Development, more well-designed and well-documented demonstration projects are necessary to promote phytoremediation as an environmentally friendly and cost-effective technology.

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