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Journal of Biological Studies
ISSN 2209-2560

JBS
An Open Access Peer Reviewed Journal

Seasonal variation of certain nutrients and micro components of water and four hydrophytes in different polluted sites, Nile River, Aswan, Egypt

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Received 20 September 2020; Accepted 28 November 2020; Published online 02 March 2021

Abstract

The chemical composition of hydrophytes is affected by many environmental and physiological factors. The content of certain nutrients and micro components in the tissues of four hydrophytes, Persicaria senegalensis L., *Ceratophyllum demersum* L., *Potamogeton crispus* L. and *P. perfoliatus* L., was investigated over four seasons. These hydrophytes were collected from different sites in the Nile River in Aswan subjected to domestic-like, industrial and agricultural pollutions and non-polluted conditions. The plant tissues were digested and nitrate (NO_3^-), phosphate (PO_4^{3-}), sulfate (SO_4^{2-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), fluoride (F^-) and bromide (Br^-) were measured using atomic absorption spectroscopy. The distribution of the different hydrophytes was related to different levels or types of pollution. *Persicaria senegalensis* was the most tolerant of the pollution conditions that appeared in all sites during all seasons. Both pollution and seasonal variability affected the concentration of different nutrients in the tissues of the studied hydrophytes. In general, the concentration of all nutrients increased in the polluted conditions. The concentrations of NO_3^- and PO_4^{3-} were low comparing to other nutrients in both water samples and plant tissues. The highest concentrations of SO_4^{2-} were detected in summer for all studied hydrophytes. The highest concentrations of Ca^{2+} and Mg^{2+}in *P. senegalensis* were measured in autumn and spring, respectively. The seasonal maxima of the concentrations of Ca^{2+} and Mg^{2+} of *C. demersum*, *P. crispus* and *P. perfolitas* were detected in winter, spring and autumn, respectively. In conclusion, *Persicaria senegalensis* was proven to have the widest range of tolerance of water quality, suggesting it could be a more reliable bio-indicator than the other three hydrophytes.

Keywords: *Ceratophyllum demersum*; Hydrophytes; Mineral nutrient; Nile River; *Persicaria senegalensis* L.; Pollution; Seasonal variability

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1 Introduction

Pollution of aquatic ecosystems is a significant global problems (Chakravarty et al. 2010). In Egypt, increased anthropogenic activities and new projects have led to increased pollution of the waters of the Nile and its tributaries (Goher et al. 2019). Hydrophytes show significant potential as bio-indicators of environmental changes (Lacoul and Freedman 2006). They also show significant potential as fodder, food, sources of medicine, etc. They alter water quality by modifying the temperature, pH, alkalinity, dissolved oxygen (DO), biological oxygen demand (BOD) as well as levels of dissolved nutrients (McVea and Boyd 1975).

Each hydrophyte species is distinguished by its unique biochemical tolerance of various environmental conditions. Therefore, monitoring the presence or absence of each species helps to characterize its adaptative range (Kadono 1982). Persicaria senegalensis is commonly distributed weed in the Nile River, and a member of the Polygonaceae (Srivastava 2014). It grows in shallow wetlands, and has the potential to block small water bodies (Zahran and Willis 2003). *Ceratophyllum demersum* L. (Coontail) is a deeply submerged hydrophyte belonging to the Ceratophyllaceae (Arber, 2010). *Potamogeton crispus* and *P. perfoliatus* are in the Potamogetonaceae, and are found in fresh and brackish streams (Täckholm and Boulos 1974). These four hydrophytes show great potential as bio-indicators of water quality (Ghavzan et al. 2006) and they may also function as “bio-filters” due to their ability to absorb pollutants)Fawzy et al. 2012; Lone et al. 2014). In addition, they show several biological activities including acting as antimicrobial, antioxidant and anti-cancer agents (Metwally et al. 2020).

Few previous studies have focused on the effects of different pollutants on the mineral nutrient profile of hydrophytes. Problems with the pollution of aquatic ecosystems have attracted the attention of ecologists, and many researchers have explored the relationship between the pollution of water bodies and hydrophytes. In the present study, the effect of pollution and seasonal variation on certain macronutrients and micro-components of water and these four hydrophytes was studied.

2 Materials and Methods

Study area and sampling regime

In the period from May 2016 to May 2017, water and plant samples (three replicates for each) were collected once in each of four seasons (spring, summer, autumn and winter) from four sites representing non-polluted and different polluted conditions. Site 1 (24°04’328"N, 032°52’279"E) is in the main channel of the Nile River near Saluga and Ghazal Islands represented non-polluted conditions; Site 2 (24°24’644"N, 032°54’825"E) is located near Isis Island in the main channel of the Nile received domestic-like wastes from the Isis Hotel; Site 3 (24°07’023"N, 032°54’058"E) received industrial effluents from Kima fertilizer factory and Site 4 (24°27’685"N, 032°54’299.00"E) is El-Mansouriya drainage canal was polluted with agricultural effluent (see Figure 1).

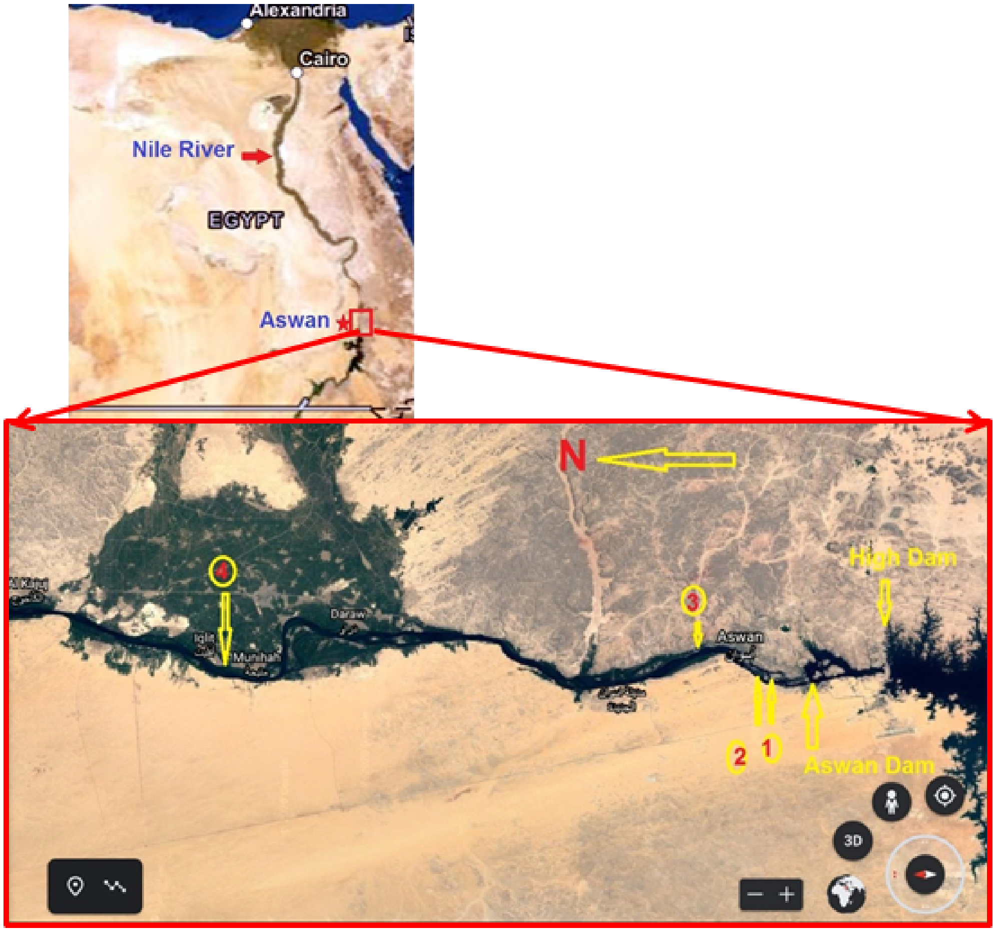


Figure 1. Maps show the location of the four contrasting study sites.

General physico-chemical properties and chemical analyses of water

Analyses of specific physico-chemical characteristics, including temperature, pH, transparency, dissolved oxygen (DO), total dissolved salts (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), and total hardness were performed to evaluate water quality at each site following Barrows and Simpson (1962); Gillam (1941). NO_3^-, PO_4^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Cl^-, Br^- and F^- were measured in the water samples using atomic absorption spectroscopy (model iCE3000seriesAAspectrophotometer) the concentration of each ion was expressed as (ppm). Total hardness [(calcium (Ca^{2+}) and magnesium (Mg^{2+})] was determined following Gaines et al. (1984).

Collection and analysis of plant materials

Plant samples were collected from each field site, and were washed carefully with tap water to remove any debris. Then, they were separated into leaves and stems. The samples were air-dried and ground to a fine powder which was used for further analyses. The dried, powdered plant tissues were digested using mixture of acids (HNO_3 : HCl) (3:1). Then, NO_3^-, PO_4^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Cl^-, Br^- and F^- were measured using atomic absorption spectroscopy (model iCE3000seriesAAspectrophotometer) and the concentration of each ion was expressed as (µg/g dry mass).

Statistical analysis

All data are presented as means ± standard deviation. A one-way- ANOVA was used to assess the significance of any differences in concentration according to season. Turkey pairwise comparisons were used to identify which seasons (if any) showed statistically significant differences. Two-way analysis of variance (ANOVA; from the software Minitab version 18.1) was used to assess the relative significance of pollution and season on nutrient profile of the four hydrophytes. Pearson's correlations were performed using Minitab (version 18.1) to achieve the correlation of the parameters of water and plant analyses.

3 Results

Water samples

Temperature, pH, DO, transparency, COD, BOD, TDS and total hardness of the water in the four sites in each of the four seasons were evaluated and their results are shown in Figure 2 as the mean value of water samples collected in different seasons at the selected sites. The mean water temperature differed among seasons, and was significantly ($p < 0.05$) affected by particular types of pollution, according to the two-way ANOVA. Temperature ranged from 18.0°C to 23.2°C in spring, 21.0°C to 24.0°C in summer, 15.0°C to 16.0°C in autumn and 15.0°C to 17.0°C in winter in all the sampling sites (Figure 2).

In the present study, the pH of water did not differ between seasons, but it was significantly affected by pollution type in most seasons. The pH values were slightly alkaline, with the highest pH (8.1) being recorded in spring, at Site 3, which is subjected to industrial pollution; the lowest value (7.36) is associated with agricultural pollution (at Site 4) in winter (Figure 2).

Water transparency was significantly influenced by both season and pollution. Site 3, exposed to industrial pollution, showed the lowest transparency in all seasons. In contrast, the highest transparency values were seen at the uncontaminated site (Site 1, Figure 2). In winter, there were highly significant differences according to pollution type (Figure 2), but in summer, the transparency range was limited.

In the present study, DO was markedly lower in Site 3 in all four seasons. The highest DO values were measured in spring (f-value= 55.00; $p < 0.001$, Figure 2). Water conductivity and TDS exhibited similar response and they varied significantly in association with both season, and the type of pollution occurring at a site ($p < 0.001$). The highest values for conductivity and TDS were seen in summer, with increases being associated with pollution ($p < 0.001$). In winter and autumn, water conductivity and TDS followed the same pattern as in the other seasons, but, with lower values (Figure 2). The values of BOD differed significantly according to season, and the level of pollution at a site. The BOD was significantly higher at Site 3 in all seasons, with a peak in summer (Figure 2). The COD values were significantly affected by season, and the level of pollution at a site, with significantly higher values at Site 3 in all seasons, and with the highest values in summer (Figure 2).

Total hardness was calculated based on the concentrations of Ca^{2+} and Mg^{2+}. Site 3 showed the highest values for total hardness compared to the other three sites. In addition, spring and summer showed a wide range of values for total hardness (Figure 2).

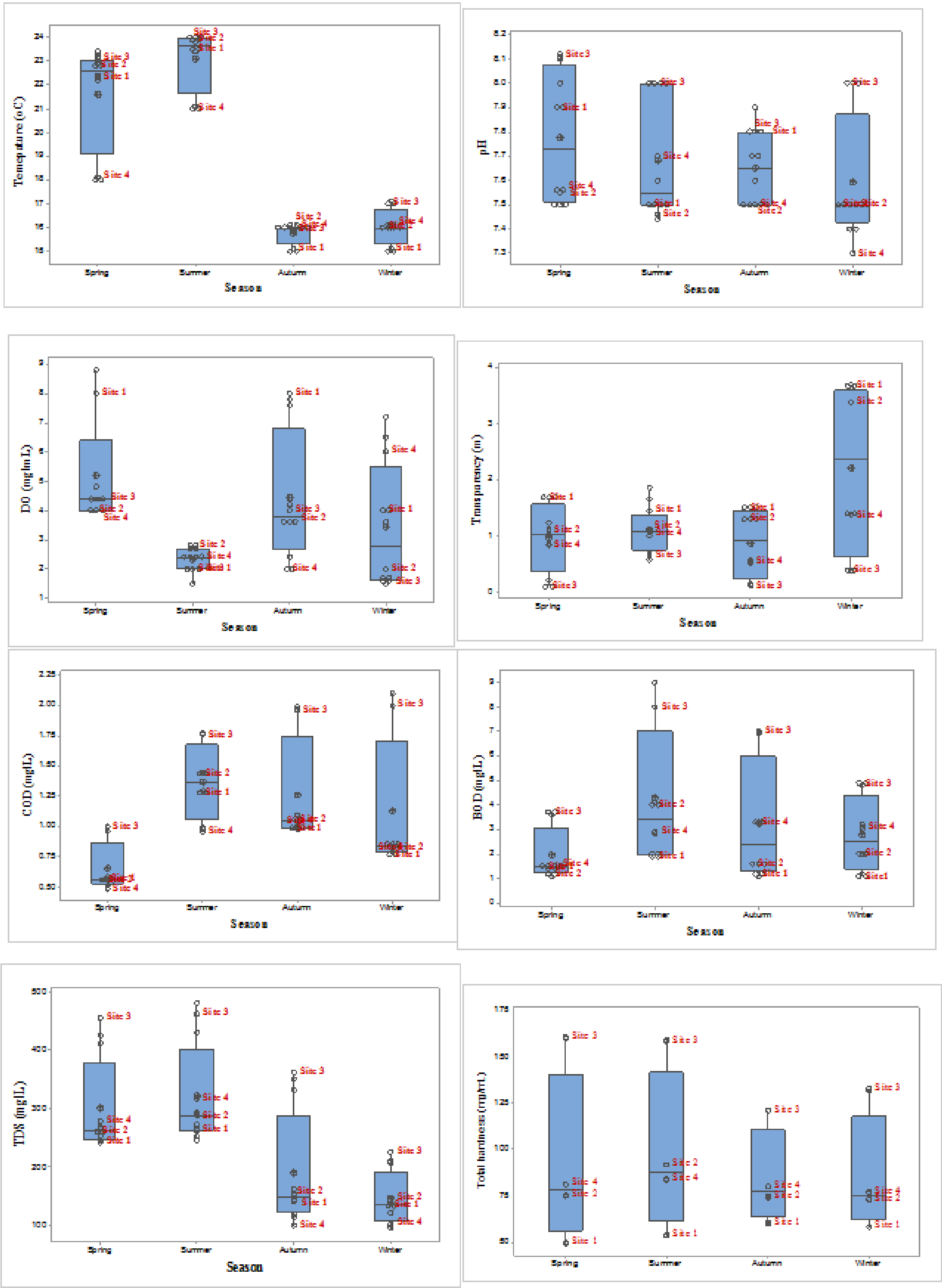


Figure 2. The physico-chemical characteristics of the water samples collected from the different sites

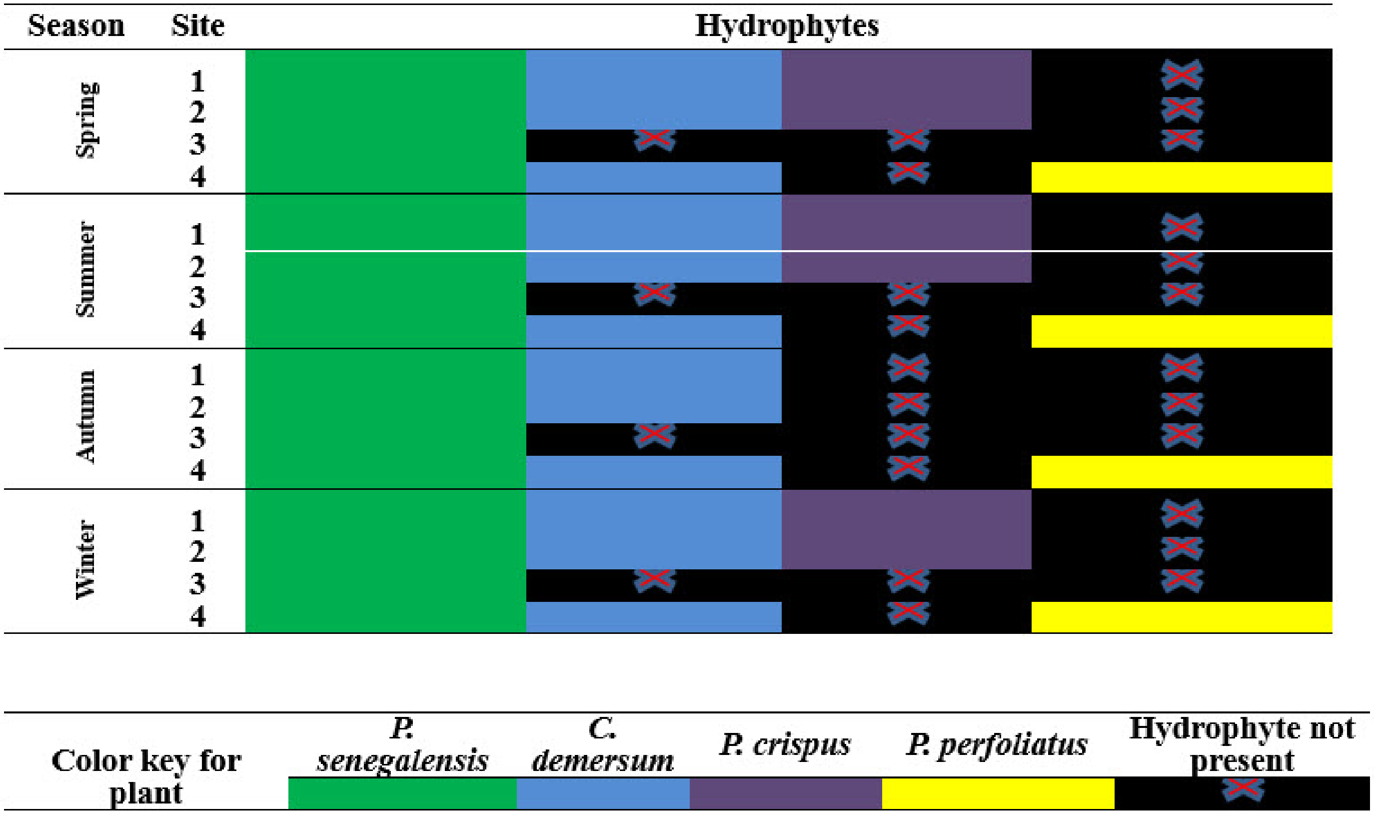
The concentrations of NO_3^-, PO_4^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Cl^-, Br^- and F^- in the water samples of the different sites are depicted in Table 1. Seasonal variation and pollution type significantly influenced the concentration of NO3- (f-value= 15.87; p-value< 0.001 and f-value= 5.57; p-value< 0.001, respectively). In spring, Site 3 exhibited the highest concentration (1.89 ppm) of NO_3^- which was nearly 6-folds of its concentration in Site 4 or Site 1 in the same season (Table 1). The seasonal variation had a significant effect on the mean concentration of PO_4^{3-}, however, there was no significant influence due to the pollution type (f-value= 11.58; p-value< 0.001 and f-value= 2.15; p-value= 0.108, respectively). All the values in the spring season were low in comparison to the other seasons. Site 3 had the highest values in all seasons except in winter. The lowest value (0.05 ppm) was recorded in Site 1 in the spring (Table 1). The mean concentration of SO_4^{2-} was significantly affected in response to both seasonal variation and pollution type (f-value= 6.64; p-value< 0.001 and f-value= 22.97; p< 0.001, respectively). In Sites 2 and 3, SO_4^{2-} exhibited maximum concentrations (36.23 and 39.25 ppm, respectively) in comparison to other sites in winter. The mean concentration of Ca^{2+} was not affected due to seasonal variation (f-value= 1.83; p-value = 0.158) but it was significantly influenced by pollution type (f-value= 182.61; p-value< 0.001) as indicated by two-way ANOVA. In all seasons, the highest values were recorded in Site 3, while, the lowest values were detected in the Site 1 (Table 1). Both of seasonal variation and pollution type had a significant effect on mean Mg^{2+} concentration (f-value= 11.69; p< 0.001 and f-value= 170.85; p<0.001, respectively). The Mg^{2+} concentrations exhibited lower values (of about half-folds) in comparison with Ca^{2+} (Table 1). For Mg^{2+}, the highest value (16.8 ppm) was measured in summer at Site 3. The mean content of Cl^- was significantly affected due to variation of seasons and pollution type (f-value= 7.78; p-value< 0.001, f-value= 8.80; p-value< 0.001, respectively). The ratio between the highest and lowest values was moderately the same during all seasons. The highest value (8.2 ppm) was recorded in Site 3 in autumn (Table 1). Both Br^- and F^- exhibited similarly ranged values and they were affected in response to the seasonal variation and the pollution type (f-value= 14.17; p-value< 0.001 and f-value= 17.56; p< 0.001, respectively) for Br^- and (f-value= 162.57; p-value< 0.001 and f-value= 81.36; p-value< 0.001, respectively) for F^- (Table 1).

Distribution and presence/absence of the four plant species

The presence or absence of each of the four hydrophyte species, tracked over the four seasons, and their responses to pollution are illustrated in Table 2. *Persicaria senegalensis* and *C. demersum* were present in all seasons; the only difference between the two species was their presence in Site 3. Potamogeton crispus was only found in Sites 1 and 2, however, it was absent in autumn; *P. perfoliatus* was only found in Site 4, where it was present throughout the year.

		Concentration (ppm)							
Season	**Site**	**NO_3^{1-}**	**PO_4^{3-}**	**$^{2-}SO_4$**	**Ca^{2+}**	**Mg^{2+}**	**Cl^{1-}**	**Br^{1-}**	**F^{1-}**
Spring	1	0.350(±0.01)^{c}	0.05(±0.00)^{c}	12.00(±1.50)^{b}	11.25(±0.10)^{c*}	5.20(±0.00)^{c}	5.71(±0.20)^{b}	0.40(±0.00)^{a}	0.40(±0.00)^{c}
	2	0.430(±0.02)^{b}	0.06(±0.00)^{c}	10.22(±0.94)^{c}	18.26(±0.00)^{b}	7.20(±0.00)^{bc}	6.51(±0.10)^{a}	0.30(±0.00)^{b}	0.60(±0.00)^{b}
	3	1.890(±0.02)^{a}	0.74(±0.03)^{a}	25.37(±1.23)^{a}	39.22(±0.00)^{a}	15.20(±0.10)^{a}	5.22(±0.30)^{c}	0.40(±0.00)^{a}	0.71(±0.00)^{a}
	4	0.321(±0.02)^{c}	0.13(±0.03)^{b}	9.23(±0.25)^{d}	18.51(±0.01)^{b}	8.50(±0.00)^{b}	5.81(±0.33)^{b}	0.31(±0.00)^{b}	0.40(±0.00)^{d}
Summer	1	0.010(±0.00)^{d}	0.63(±0.02)^{d}	1.86(±0.71)^{b}	10.02(±0.00)^{d}	6.90(±0.00)^{c}	5.00(±0.10)^{c}	0.21(±0.00)^{c}	0.30(±0.00)^{c}
	2	0.063(±0.00)^{c}	6.49(±0.05)^{b}	18.98(±1.47)^{b}	24.09(±0.00)^{b}	7.71(±0.01)^{b}	5.90(±0.30)^{b}	0.30(±0.10)^{b}	0.50(±0.00)^{b}
	3	0.140(±0.00)^{b}	7.08(±0.03)^{a}	20.63(±1.15)^{a}	35.93(±0.00)^{a}	16.82(±0.10)^{a}	6.11(±0.30)^{a}	0.41(±0.20)^{a}	0.61(±0.00)^{a}
	4	0.151±0.00^{a}	1.37(±0.02)^{c}	8.25(±0.81)^{c}	19.62(±0.10)^{c}	8.53(±0.10)^{b}	5.10(±0.10)^{ab}	0.30(±0.02)^{b}	0.30(±0.00)^{c}
Autumn	1	0.003(±0.00)^{c}	2.13(±0.32)^{b}	4.92(±0.14)^{c}	13.61(±0.10)^{d}	6.40(±0.00)^{c}	6.12(±0.10)^{c}	0.11(±0.10)^{c}	0.10(±0.00)^{b}
	2	0.082(±0.00)^{b}	4.10(±0.0)^{a}	4.17(±0.06)^{c}	18.44(±0.00)^{c}	6.91(±0.10)^{c}	5.30(±0.30)^{b}	0.20(±0.10)^{b}	0.10(±0.00)^{b}
	3	0.094(±0.00)^{a}	4.53(±0.06)^{a}	18.91(±0.38)^{a}	29.51(±0.10)^{a}	11.51(±0.00)^{a}	8.22(±0.30)^{a}	0.40(±0.00)^{a}	0.50(±0.00)^{a}
	4	0.095(±0.00)^{a}	1.36(±0.15)^{c}	10.27(±0.31)^{b}	19.72(±0.00)^{b}	7.50(±0.00)^{b}	3.95(±0.14)^{d}	0.10(±0.00)^{c}	0.10(±0.00)^{b}
Winter	1	0.001(±0.00)^{d}	2.71(±0.08)^{b}	0.83(±0.02)^{d}	14.08(±0.00)^{c}	5.61(±0.00)^{c}	4.31(±0.30)^{ab}	0.11(±0.00)^{c}	0.10(±0.00)^{b}
	2	0.005(±0.00)^{c}	2.03(±0.05)^{b}	36.23(±1.12)^{b}	18.25(±0.00)^{b}	6.70(±0.10)^{bc}	5.30(±0.30)^{a}	0.20(±0.10)^{b}	0.10(±0.00)^{b}
	3	0.020(±0.00)^{a}	1.63(±0.32)^{c}	39.25(±1.09)^{a}	32.95(±0.30)^{a}	12.20(±0.10)^{a}	4.90(±0.10)^{b}	0.30(±0.10)^{a}	0.30(±0.10)^{a}
	4	0.010(±0.00)^{b}	3.76(±0.25)^{a}	9.10(±0.10)^{c}	18.27(±0.00)^{b}	7.60(±0.00)^{b}	3.40(±0.50)^{c}	0.10(±0.00)^{d}	0.10(±0.00)^{b}

Table 2. Concentrations of the different macronutrients and micro elements (ppm) of the water from the selected sites during different seasons. Values are shown in mean ± SD (n=3).



Season	Site	Hydrophytes			
Spring	1	🟩	🟦	🟪	✗
	2	🟩	🟦	🟪	✗
	3	🟩	✗	✗	✗
	4	🟩	🟦	✗	🟨
Summer	1	🟩	🟦	🟪	✗
	2	🟩	🟦	🟪	✗
	3	🟩	✗	✗	✗
	4	🟩	🟦	✗	🟨
Autumn	1	🟩	🟦	✗	✗
	2	🟩	🟦	✗	✗
	3	🟩	✗	✗	✗
	4	🟩	🟦	✗	🟨
Winter	1	🟩	🟦	🟪	✗
	2	🟩	🟦	🟪	✗
	3	🟩	✗	✗	✗
	4	🟩	🟦	✗	🟨

Color key for plant	***P. senegalensis***	***C. demersum***	***P. crispus***	***P. perfoliatus***	**Hydrophyte not present**
	🟩	🟦	🟪	🟨	✗

Table 2.The occurrence (absence/presence) of the investigated hydrophytes in the four sites during the different sites

The concentrations of different ions in plant leaves and stems

The nutrient content of the four plant species growing at four different sites during four different seasons is described in Table 3. The mean concentrations of the measured nutrient minerals in the leaves and stems of the hydrophytes were significantly influenced ($p < 0.05$) by season and pollution type.

Nitrate concentrations

In the leaves of P. senegalensis, the mean concentration of NO_3^- was affected by season and pollution type. The highest concentration (96.6 µg/g dry mass) was seen in Site 3 in spring, while the lowest concentration (25.3 µg/g dry mass) was seen in Site 1, also in spring (Table 3). With reference to stems, both season and pollution type affected the mean concentration of NO_3^-. In the leaves of C. demersum, season and pollution type had significant effects on the mean concentration of NO_3^-. The highest concentration (122.1 µg/g dry mass) was seen in autumn in Site 4, and the lowest concentration (34.8 µg/g dry mass) was seen in Site 1, in spring (Table 3). The mean concentration of NO_3^- in the leaves of *P. crispus* was affected by both season and pollution type. In the stems, in contrast, the mean P. crispus concentration did not differ significantly between seasons (Table 2). The highest concentration of P. crispus in the leaves of *P. perfoliatus* (81.9 µg/g dry mass) was seen in autumn, while the lowest concentration (34.5 µg/g dry mass) was seen in spring. With reference to its stems, the highest concentration (78.1 µg/g dry mass) was seen in autumn, while the lowest concentration (24 µg/g dry mass) was seen in winter (Table 3).

Phosphate concentrations

The effect of seasons and pollution types on the mean content of PO_4^{3-} in the leaves *P. senegalensis* was measured, and there was noticeable variation in response to pollution in summer (Table 3). In the stems of this species, the mean concentration of PO_4^{3-} was affected by both season and pollution type. As with the leaves, pollution had its most striking effect in summer (Table 3). Season and pollution type had the same effect on the mean concentration of PO_4^{3-} in the leaves of *C. demersum*, and the effect of pollution was particularly evident in summer and winter (Table 3). As with the leaves, stems showed a very similar effect for season and pollution type on the mean concentration of C. demersum (Table 3). The mean concentration of *C. demersum* in the leaves of *P. crispus* varied according to season and pollution type, with a wide range of values in summer due to pollution. In the stems, similar to the pattern in leaves, the mean concentration of PO_4^{3-} was affected by both season and pollution type (Table 3). In the leaves and stems of *P. perfoliatus*, the highest values of PO_4^{3-} concentration (56.5 and 41.1 µg/g dry mass, respectively) were seen in spring, while the lowest values (3.4 and 2.6 µg/g dry mass, respectively) were seen in autumn (Table 3).

Sulfate concentrations

Both season and pollution type significantly affected the mean concentration of SO_4^{2-} in the leaves of *P. senegalensis*. In summer, the highest concentration (7580.2 µg/g dry mass) was seen in Site 3, and the lowest value (10.6 µg/g dry mass) was seen in Site 1 in winter (Table 3). In stems, a similar pattern was seen with the highest concentration (6764.9 µg/g dry mass) seen in Site 3, in summer, and the lowest concentration (8.1 µg/g dry mass) in winter in Site 1 (Table 3). There was a wide variation in the mean concentration of SO_4^{2-} in the leaves of *C. demersum* depending on the season, and type of pollution, especially in summer and winter (Table 3). The mean concentration of SO_4^{2-} in stems of *C. demersum* was significantly affected by pollution and seasons (Table 3). The mean concentration of SO_4^{2-} in the leaves of *P. crispus* was somewhat influenced by site pollution, but it was not significantly affected by season (f-value= 0.81; p-value= 0.465) (Table 3). In the leaves and stems of *P. perfoliatus*, the mean concentration of SO_4^{2-} was highest in summer with concentrations of (950.1 and 868.1 µg/g dry mass, respectively), whereas, the lowest values for leaves and stems (32.2 and 25.8 µg/g dry mass, respectively) were seen in autumn (Table 3).

Calcium concentrations

In the leaves of *P. senegalensis*, there was a narrow variation due to pollution and seasons. The highest value (2197.3 µg/g dry mass) was measured in Site 3 in autumn, and the lowest value (931.3 µg/g dry mass) was seen in plants in Site 4, in winter (Table 3). The type of pollution at each site affected the mean concentration of Ca^{2+} in the leaves of *P. crispus*, however, in the stems, there was no significant seasonal variation in Ca^{2+} concentration (f-value = 0.12; p= 0.889). In the leaves of *P. perfoliatus*, the highest concentration of Ca^{2+} (1408.9 µg/g dry mass) was seen in autumn, while the lowest value (1014.4 µg/g dry mass) was seen in summer. The highest concentration (1245.3 µg/g dry mass) in the stems was seen in autumn and the lowest concentration (909.1 µg/g dry mass) was seen in summer (Table 3).

Magnesium concentrations

The highest concentration of Mg^{2+} in the leaves of *P. senegalensis* (1677 µg/g dry mass) was seen in Site 4 in spring, and the lowest concentration (558 µg/g dry mass) was seen in Site 2 in autumn (Table 3). The average concentration of Mg^{2+} in stems was influenced by season and pollution type (Table 3). In the leaves of *C. demersum*, the average concentration of Mg^{2+} was affected by season and pollution type (Table 3). In winter, the highest concentration (1583.4 µg/g dry mass) was seen in Site 2 and the lowest concentration (522.7 µg/g dry mass) was seen in Site 2 in autumn (Table 3). The mean concentration of Mg^{2+} in the leaves and stems of *P. crispus* was affected by season and pollution type (Table 3). In the leaves, the highest concentration (611.9 µg/g dry mass) was seen in Site 2 in spring and the lowest concentration (311.2 µg/g dry mass) was seen in Site 1 in summer. In the leaves of *P. perfoliatus*, the highest concentration of Mg^{2+} (724.7 µg/g dry mass) was seen in autumn, while the lowest value (607.8 µg/g dry mass) was seen in winter. The highest concentration (620 µg/g dry mass) in the stems was seen in autumn and the lowest concentration (323.2.1 µg/g dry mass) was seen in summer.

Chloride concentrations

The mean concentration of Cl^- in the leaves of *P. senegalensis* was significantly affected by pollution; however, there were no differences between seasons. In Site 4, the highest concentration (1085.3 µg/g dry mass) was seen in winter (Table 3). In the stems, the highest concentration (1052 µg/g dry mass) was seen in Site 4 in winter and the lowest concentration (53.7 µg/g dry mass) was seen in Site 2 in spring (Table 3). In the leaves of *C. demersum*, the mean concentration of Cl^- was influenced significantly by both season and pollution type. In Site 4, in spring, the highest concentration (1255.9 µg/g dry mass) was seen, while the lowest concentration (257.6 µg/g dry mass) was seen in Site 1 in summer (Table 3). In stems, the highest concentration (980.2 µg/g dry mass) was seen in Site 4 in the autumn, while the lowest value (155.9 µg/g dry mass) was seen in Site 1 in summer (Table 3). In the leaves of *P. crispus*, the highest concentration of Cl^- (359.1 µg/g dry mass) was seen in Site 2 in spring and the lowest concentration (50.8 µg /g dry mass) was seen in Site 1 in winter (Table 3). The highest concentration of Cl^- in the leaves of *P. perfoliatus* (469.4 µg/g dry mass) was seen in spring, while the lowest concentration (89.9 µg/g dry mass) was seen in autumn. In the stems, the highest concentration (202.4 µg/g dry mass) was measured, whereas, the lowest value (71.1 µg/g dry mass) was measured in autumn (Table 3).

Bromide concentrations

In the leaves of *P. senegalensis*, in winter, the highest concentration (576.1 µg/g dry mass) was seen in Site 3, while the lowest value (90.3 µg/g dry mass) was seen in Site 1 in spring (Table 3). The mean concentration of Br^- in stems was influenced by season and pollution type. The highest concentration (520.5 µg/g dry mass) was seen in Site 3 in winter, while the lowest concentration (60.1 µg/g dry mass) was seen in Site 1 in spring (Table 3). Season and pollution type influenced the mean concentration of Br- in the leaves of *C. demersum.* In winter, the highest concentration (519 µg/g dry mass) was measured in Site 4, and the lowest value (127.9 µg/g dry mass) was seen in Site 2 in spring (Table 3). In the leaves of *P. crispus*, the mean content of Br^- was influenced by season and pollution type (Table 3). The mean concentration of Br^- in stems was affected by pollution type and season (f-value= 133.89; $p < 0.001$). There were significant differences between concentrations in spring and winter (Table 3). In the leaves and stems of *P. perfoliatus*, the highest concentrations of Br^- (395.7 and 376.6 µg/g dry mass in leaves and stems, respectively) were seen in summer; in contrast the lowest values (94.1 and 68.6 µg/g dry mass, respectively, for leaves and stems) were seen in autumn (Table 3).

Fluoride concentrations

Regarding the leaves of *P. senegalensis*, the mean concentration of F^- varied with season and pollution type. The highest value (96.6 µg/g dry mass) was seen in Site 3 in spring, and the lowest value (46.3 µg/g dry mass) was seen in Site 1 in autumn (Table 3). Season and pollution type significantly affected the mean concentration of F^- in stems. Stems followed a pattern that was similar to that for leaves. In spring, the highest concentration (88.5 µg/g dry mass) was seen in Site 3 and the lowest concentration (35.6 µg/g dry mass) was seen in Site 1 in winter (Table 3). The mean concentration of F^- in the leaves of *C. demersum* was affected by both season and pollution type. In Site 4, in spring, the highest concentration (96.1 µg/g dry mass) was seen, while the lowest concentration (54.7 µg/g dry mass) was seen in Site 2 in winter (Table 3). In stems, the mean concentration of F^- was influenced by both season and pollution type. The range (difference between the highest and the lowest values) in summer and autumn was quite similar (26 µg/g dry mass, Table 3). There was a clear effect of both season and pollution type on the mean concentration of F^- in the leaves of *P. crispus*; the concentrations seen in Sites 1 and 2 in spring and summer were quite similar (Table 3). In its stems, in Site 2, in summer, we saw the highest concentration (56.8 µg/g dry mass), while the lowest value (30.8 µg/g dry mass) was seen in Site 1 in spring (Table 3). In the leaves and stems of *P. perfoliatus*, the highest concentrations (82.1 and 72.8 µg/g dry mass, respectively) were measured in summer, while, the lowest concentrations (45.4 and 42.2 µg/g dry mass, respectively) were measured in winter (Table 3).

4 Discussion

Discussions It is an important approach to evaluate the suitability of water for drinking and aquatic ecosystems (Abdel-Satar et al. 2017). Metwally (2020) performed physico-chemical analyses of water samples to evaluate the water quality at the four sites of the present study. In addition, NO_3^-, PO_4^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Cl^-, Br^- and F^- were measured in water samples. Multivariate data analysis and detailed discussions for their effects on water quality are presented in a separate research article (ready for submission) seriated in a scientific project concerning the ecological and biological potentials of these selected four hydrophytes. Here, the physico-chemical characteristics are briefly designated and the detailed calculations of the pollution indices done by Metwally (2020) described sites as follows: Site 1 ("excellent" water quality); Site 2 ("acceptable" water quality); Site 3 ("polluted"); Site 4 ("slightly polluted").

Water quality affects distribution and development of many hydrophytes and various pollution levels could be distinguished by presence or absence of certain hydrophytes (Agami et al. 1976; Warrier and Saroja 2008; Pérez-López et al. 2009). In the present study, *P. senegalensis* is present at all 4 sites, in all 4 seasons; *C. demersum* is never seen at the polluted site (Site 3), but is present at the rest sites; *P. crispus* is only seen at Sites 1, 2 and only in spring and summer (it is absent in autumn and winter); *P. perfoliatus* is only seen at Site 4, but it is present in all 4 seasons. In the scientific literature, there is no record to study the effect of water quality in the distribution or development of *P. senegalensis* in Egypt. However, Ali and Soltan (1996) studied the effect of three sources of industrial pollution in Aswan on different hydrophytes including *C. demersum*, *P. crispus* and *P. perfoliatus*. Our results are in accordance to their findings where at sites receiving industrial effluents (Kima, Site 3), the three hydrophytes are absent. Potamogeton crispus is associated with highly oxygenated sites (Ali and Soltan 1996; Wu et al. 2009).

Earlier studies of chemical composition of hydrophytes were achieved to estimate their nutrient value and impact on the surrounding aquatic ecosystem (Borsh 1974). The content of macro- and micronutrients in the tissues of hydrophytes changes during the season and is linked to their contents in the surrounding medium (Lytle and Smith 1995; Cao et al. 2007; Ansari et al. 2016). Modifications in the ion contents in the medium can remove some species meanwhile encouraging the growth of other species (Hellquist and Crow 1980). In the present study, increasing the concentrations of nutrients as a result of pollution effluents affected the occurrence and chemical composition of the studied hydrophytes.

Nitrate contamination of drinking water is a global challenge causing serious health problems such blue-baby syndrome (Wakida and Lerner 2005). Accumulation of NO_3^- in plants is significantly influenced by environmental factors and varies during the season (Santamaria et al 2001). In the present study, NO_3^- content was increased in the tissues of *P. senegalensis* and *C. demersum* in autumn and winter than in spring and summer. Likely, Santamaria et al. (1999) found that in vegetables, NO_3^- was accumulated during winter and autumn comparing to the other two seasons. Ceratophyllum demersum was found to be efficient sorbent for NO_3^- and other macro-element from water (Foroughi 2011).

Phosphate promotes the growth of cyanobacteria and photosynthetic algae. When, the concentration of phosphorus in water exceeds 0.03 ppm, eutrophication takes place (Wetzel, 2001; Smith, 2003). In the present study, the content of phosphate was increasing in the tissues of *P. senegalensis* in the polluted conditions (Site 3) except in winter; and in Site 4 in both summer and autumn. *C. demersum* had the same pattern like *P. persicaria* for PO_4^{3-} concentration during the different seasons at Site 1, 2 and 4. There was no positive correlation between the content of PO_4^{3-} in the water and the plant tissue of *P. senegalensis*.

Phosphate is mainly absorbed from the sediments not the water column (Feijoó et al. 2002; Yarrow et al. 2009) and this might explain the unexpected and uncorrelated phosphate content in the studied hydrophytes to that in water. These results are in agreement to those obtained by (Esteves and Suzuki 2010) who studies the nutrient content, e.g, nitrogen and phosphorus of *C. demersum* and Egeria densa grown in the Campelo Lagoon.

Sulfate is one of the main sulphur forms in aquatic ecosystems. In the polluted sites, the concentration of SO_4^{2-} is significantly increased because of acidic deposition (Moore 1992). The existence of SO_4^{2-} in drinking water affects its visual quality. However, World Health Organization does not consider that as instant threat to public health (WHO 2004). In the present study, the concentration of SO_4^{2-} in water was increased from Site 1 to Site 3, then, declined at Site 4 in all seasons. A peak in its concentration was noticed in the polluted site (Site 3) in winter and this is in accordance with the studies done on seasonal variation of the physico-chemical analysis of polluted sites (Patale et al. 2012). In the present study, a strong positive correlation between SO_4^{2-} content in the plant tissue and water was calculated. In all studied hydrophytes, the highest concentrations of SO_4^{2-} were measured in summer. In the previous studies, *C. demersum* was found to be a potent accumulator and indicator for SO_4^{2-} (Ilyashenko et al. 2014).

Calcium and magnesium are considered as the main minerals causing water hardness (Yan et al.

2008). The water hardness might not cause severe health problems; however, it could be resulted in forming deposits on boiler and other household equipment (Suzuki et al. 2002). Calculations of water hardness in the studied sites were reported by Metwally (2020). Here, the contents of the two minerals in water and plant tissues are discussed. Strong positive correlations were calculated between the contents Ca^{2+} and Mg^{2+} in water and their contents in *P. senegalensis* and *C. demersum.* The dynamic uptake of Ca^{2+} which abundantly occurs in natural waters results in its high concentration in the tissues of hydrophytes (Ambasht 1991). In the present study, *C. demersum* had the highest concentrations of Ca^{2+} and Mg^{2+} in winter. *P. crispus* had the highest concentrations of Ca^{2+} and Mg^{2+} in spring. Contrary results are found in previous studies for season maxima of these two nutrients accumulated by hydrophytes in Nile Delta, Egypt; *C. demersum* had the highest concentrations of Ca^{2+} andMg^{2+} in autumn (Shaltout et al. 2009), while, the concentrations of Ca^{2+} and Mg^{2+} in *P. crispus* were highest in autumn (Shaltout et al. 2016). Highest concentrations of Ca^{2+} and Mg^{2+} in *P. senegalensis* were measured in autumn and spring, respectively. Highest concentrations of Ca^{2+} and Mg^{2+} in *P. perfolitas* were measured in autumn. The concentration of Ca^{2+} in the tissue of *C. demersum* was the highest comparing to *P. senegalensis* in Sites 1, 2 and 4 and other hydrophytes when occurred. Similarly, (Younis and Nafea 2015) found that *C. demersum* was the highest in Ca^{2+} accumulation when compared to other hydrophytes.

Fluoride and bromide are minor components of natural waters. The optimal concentrations of F^- for human health are ranged from 0.5 and 1.5 ppm. Concentrations > 0.5 ppm inhibit caries of teeth (WHO 1994). The concentration of Br^- in freshwater is practically below harmful levels of the human health (Flury and Papritz 1993). Chloride is one of the important constituents in the natural waters. The Br/Cl ratio is used to distinguish the different sources of these contaminants on the basis (Davis et al., 1998). In the present study, among these three ions, only Br^- content showed a significant correlation to its content in *P. senegalensis.* Similarly, Br^- uptake by some plants was found to be a function of the concentrations of Br^- (Kung 1990).

			Hydrophyte							
			P. senegalensis		*C. demersum*		*P. crispus*		*P. perfoliatus*	
	Season	Site	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
NO$_3$ (µg/g dry mass)	**Spring**	1	25.3(±3.3)^{d}	22.4(±2.7)^{d}	34.8(±1.7)^{b}	28.6(±1.2)^{c}	15.6(±3.6)^{b}	13.21(±3.3)^{b}		
		2	38.5(±2.2)^{c}	32.2(±2.6)^{c}	47.1(±2.3)^{a}	41.6(±0.9^{b}	31.9(±0.6)^{c}	28.9(±1.2)^{a}		
		3	96.6(±2.2)^{a}	90.7(±0.7)^{a}						
		4	48.4(±1.6)^{b}	43.3(±2.2)^{b}	51.1(±0.9)^{a}	47.5(±1.1)^{a}			34.5(±2.8)	27.2(±1.3)
	Summer	1	36.6(±3.9)^{b}	46.8(±3.2)^{b}	52.7(±2.6)^{c}	31.4(±1.6)^{c}	23.1(±2.0)^{b}	10.6(±0.8)^{b}		
		2	43.4(±2.9)^{b}	30.1(±1.3)^{c}	66.7(±1.5)^{b}	55.1(±1.6)^{b}	60.0(±1.14)^{a}	39.9(±1.74)^{a}		
		3	83.0(±2.5)^{a}	64.0(±2.7)^{a}						
		4	74.8(±3.4)^{a}	53.0(±4.2)^{b}	92.1(±6.8)^{a}	82.2(±2.9)^{a}			54.9(±1.4)	42.6(±2.3)
	Autumn	1	74.0(±4.8)^{c}	55.1(±4.5)^{c}	82.8(±3.2)^{b}	80.6(±3.5)^{b}				
		2	84.4(±2.9)^{b}	76.2(±2.8)^{b}	90.6(±0.5)^{ab}	86.9(±5.1)^{b}				
		3	96.5(±1.2)^{a}	87.7(±2.2)^{a}						
		4	93.3(±3.1)^{a}	89.4(±1.7)^{a}	122.1(±26.8)^{a}	97.2(±2.6)^{a}			81.9(±1.5)	78.1(±1.5)
	Winter	1	31.8(±4.2)^{d}	22.0(±1.8)^{c}	49.0(±3.6)^{b}	36.7(±1.2)^{c}	10.9(±0.6)^{b}	9.6(±0.1)^{b}		
		2	42.7(±2.5)^{c}	36.1(±4.2)^{b}	52.4(±1.2)^{b}	46.5(±1.03)^{b}	36.1(±4.2)^{a}	27.1(±2.3)^{a}		
		3	64.4(±2.6)^{a}	54.1(±2.9)^{a}						
		4	54.3(±2.8)^{b}	50.9(±1.7)^{a}	61.7(±1.4)^{a}	55.8(±2.5)^{a}			46.1(±3.4)	24.0(±2.30)

Table 3. Different macronutrients micro elements (µg/ g dry mass) in the leaves and stems of the hydrophytes in the selected sites during different season.

[1] Different letters of data in each season indicate significant difference at $p \leq 005$ (obtained by Turkey pairwise comparison using one-way ANOVA). Table 3. Continued ……

	Season	Site	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
PO_4^{3-}(µg/g dry mass)	Spring	1	24.0(±1.52)^{c}	13.5(±1.9)^{d}	64.2(±2.9)^{c}	46.1(±1.8)^{b}	16.0(±1.8)^{b}	8.59(±0.3)^{a}		
		2	48.1(±6.2)^{b}	33.6(±2.9)^{c}	76.0(±4.1)^{b}	68.5(±2.6)^{a}	48.3(±2.2)^{a}	30.9(±1.6)^{b}		
		3	75.9(±1.7)^{a}	63.7(±1.7)^{b}						
		4	83.6(±1.8)^{a}	71.2(±0.9)^{a}	95.4(±1.3)^{a}	72.8(±2.7)^{a}			56.6(±4.3)	41.1(±3.6)
	Summer	1	1.1(±0.14)^{c}	1.29(±0.6)^{a}	2.5(±0.7)^{b}	2.3(±0.5)^{b}	1.31(±0.5)^{b}	1.1(±0.6)^{b}		
		2	92.4(±3.4)^{a}	80.1(±8.2)^{b}	143.0(±9.2)^{a}	105.0(±6.6)^{a}	74.1(±5.1)^{a}	55.4(±4.7)^{a}		
		3	84.5(±3.5)^{b}	74.2(±2.9)^{b}						
		4	6.5(±0.5)^{c}	5.7(±0.2^{a}	8.2(±0.2)^{b}	7.5(±0.3)^{b}			5.2(±0.2)	4.0(±0.6)
	Autumn	1	1.71(±0.7)^{d}	1.2(±0.3)^{b}	3.5(±0.2)^{c}	2.5(±0.2)^{a}				
		2	8.2(±0.2)^{b}	7.6(±0.4)^{a}	13.8(±1.7)^{a}	11.0(±0.6)^{c}				
		3	10.7(±1.5)^{a}	8.3(±1.0)^{a}						
		4	5.7(±0.2)^{c}	4.6(±0.5)^{b}	7.5(±0.4)^{b}	6.4(±0.3)^{b}			3.4(±0.3)	2.6±0.3
	Winter	1	1.1(±0.1)^{c}	1.1(±0.2)^{c}	4.7(±0.2)^{b}	3.5(±0.2)^{b}	2.4(±0.2)^{b}	1.1(±0.1)^{b}		
		2	2.8(±0.5)^{bc}	2.4(±0.6)^{bc}	5.6(±0.8)^{b}	5.0±0.3^{b}	3.7(±0.4)^{a}	3.1(±0.5)^{a}		
		3	5.5(±0.2)^{b}	3.4(±0.3)^{b}						
		4	23.5(±2.4)^{a}	18.4(±1.3)^{a}	43.8(±1.1)^{a}	40.0(±1.1)^{a}			8.4(±0.2)	7.5(±0.2)

	Season	Site	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
SO_4^{2-} (µg/g dry mass)	Spring	1	3334.2(±817.7)^{b}	2532.9(±485)^{b}	4470.1(±203.5)^{a}	3210.9(±96.6^{a}	2888.6(±92.7)^{a}	2130.5(±169.6)^{a}		
		2	1150.0(±134.4)^{c}	972(±13.8)^{c}	2589.0(±36.5)^{b}	1945.3(±60.9)^{b}	890.1(±16.9)^{b}	818.0(±16.0)^{b}		
		3	6572.5(±302.1)^{a}	5977.7(±176.2)^{a}						
		4	974.9(±13.8)^{c}	902.6(±7.2)^{c}	1794.1(±165.4)^{b}	1125.2(±110.5)^{c}			853.6(±9.7)	750.9(±21.9)
	Summer	1	315.1(±7.6)^{a}	125.8(±10.6)^{d}	464.9(±13.8)^{c}	375.9(±23.3)^{c}	234.9(±12.1)^{b}	117.2(±8.8)^{b}		
		2	5286.4(±307.7)^{b}	4440.6(±415.9)^{b}	6457.9(±101.1)^{a}	5762.7(±69.9)^{a}	4262.5(±69.9)^{a}	3919.6(±132.7)^{a}		
		3	7580.2(±445.3)^{c}	6764.9(±220.2)^{a}						
		4	1003.1(±96.9)^{d}	837.3(±35.4)^{c}	1530.4(±153.7)^{b}	995.8(±28.4)^{b}			950.1(±17.9)	868.1(±27.1)
	Autumn	1	213.2(±76.1)^{b}	125.8(±25.1)^{b}	343.6(±11.7)^{a}	293.7(±20.1)^{a}				
		2	256.5(±44.4)^{b}	185.11(±6.7)^{b}	353.8(±8.1)^{a}	224.8(±25.1)^{b}				
		3	4518.2(±150.7)^{a}	3585.0(±418.9)^{a}						
		4	50.1(±1.9)^{b}	34.8(±1.8)^{b}	72.2(±4.5)^{b}	62.4(±1.5)^{c}			32.2(±0.9)	25.8(±1.8)
	Winter	1	10.6(±1.7)^{d}	8.1(±0.6)^{d}	21.2(±1.1)^{c}	10.5(±0.49)^{c}	8.6(±0.2)^{b}	7.5(±0.4)^{b}		
		2	4490.2(±180.2)^{b}	2970.4(±153.5)^{b}	5403.9(±416.4)^{a}	4648.9(±116.3)^{a}	2396.9±(285.9)^{a}	1453.1(±115.6)^{a}		
		3	6517.9(±465.9)^{a}	5262.6(±299.9)^{a}						
		4	997.7(±178.9)^{c}	629.2(±34.7)^{c}	1474.9(±327.4)^{b}	908.2(±3.1)^{b}			739.6(±31.8)	660.5(±26.7)

Table 3. Continued ……

	Season	Site	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
Ca^{2+} (µg/g dry mass)	**Spring**	1	1210.7(±37.2)^{bc}	958.3(±30.0)^{bc}	2353.1(±201.1)^{a}	1066.5(±56.2)^{b}	1134.9(±141.5)^{a}	864.2(±22.3)^{a}		
		2	1104.7(±104.3)^{c}	862.3(±27.1)^{c}	2595.4(±159.3)^{a}	1259.5(±59.9)^{b}	1259.5(±35.5)^{a}	877.1(±25.7)^{a}		
		3	1978.3(±78.4)^{a}	1762.3(±13.2)^{a}						
		4	1310.7(±56.1)^{b}	1065.7(±83.0)^{b}	2663.8(±148.5)^{a}	1705.8(±158.4)^{a}			1355.3(±145.4)	966.2(±66.2)
	Summer	1	1229.7(±98.8)^{b}	988.0(±98.6)^{c}	1526.3(±147.7)^{a}	1330.1(±76.3)^{ab}	905.4(±18.0)^{a}	755.8(±48.8)^{a}		
		2	1038.3(±61.3)^{c}	893.0(±18.5)^{c}	1633.6(±232.9)^{a}	1448.9(±49.2)^{a}	871.4(±8.22)^{a}	704.2(±76.7)^{a}		
		3	1976.3(±22.1)^{a}	1757.3(±23.9)^{a}						
		4	1304.0(±7.5)^{b}	1206.7(±77.1)^{b}	1723.2(±18.5)^{a}	1118.7(±133.5)^{b}			1014.3(±111.4)	909.1(±98.2)
	Autumn	1	1631.0(±69.6)^{b}	1429.0(±93.5)^{b}	1851.5(±52.0)^{ab}	1659.2(±96.8)^{a}				
		2	1366.0(±46.7)^{b}	1302.3(±43.7)^{b}	1557.5(±176.6)^{b}	1444.7±(267.4)^{a}				
		3	2197.3(±77.9)^{a}	2017.7(±82.9)^{a}						
		4	2210.0(±14.1)^{a}	1919.0(±61.9)^{a}	2105.7(±100.0)^{a}	1425.1(±24.2)^{a}			1408.9(±93.0)	1245.5(±59.6)
	Winter	1	1146.3(±23.9)^{b}	1057.7(±60.7)^{b}	2550.0(±483.5)^{a}	1878.4(±128.2)^{a}	895.4(±30.3)^{a}	680.5(±18.0)^{a}		
		2	1113.3(±15.3)^{b}	1001.7(±20.0)^{b}	2028.6(±211.9)^{a}	1368.8(±60.6)^{b}	868.9(±28.1)^{a}	660.1(±63.1)^{a}		
		3	1888.3(±22.7)^{a}	1702.3(±16.1)^{a}						
		4	931.3(±33.0)^{c}	692.7(±76.8)^{c}	2669.3(±220.3)^{a}	1551.9(±34.7)^{b}			1103.9(±116.3)	933.2±15.4

	Season	Site	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
Mg^{2+} (µg/g dry mass)	**Spring**	1	772.7(±20.0)^{c}	553.7(±29.1)^{c}	1132.8(±116.2)^{a}	936.4(±32.9)^{a}	529.5(±28.4)^{b}	438.8(±16.4)^{a}		
		2	709.0(±12.0)^{d}	527.0(±14.8)^{c}	1242.7(±152.8)^{a}	957.7(±101.3)^{a}	611.9(±22.4)^{a}	430.8±10.1^{a}		
		3	1398.0(±12.8)^{b}	1262.0(±45.5)^{b}						
		4	1677.0(±39.4)^{a}	1530.0(±17.7)^{a}	1334.8(±58.7)^{a}	967.0(±67.5)^{a}			713.7(±19.5)	423.0(.±24.6)
	Summer	1	743.3(±44.2)^{b}	646.3(±47.5)^{b}	615.6(±16.2)^{a}	511.9(±2.1)^{c}	411.7(±1.4^{b}	311.2(±1.7)^{b}		
		2	704.3(±9.1)^{b}	454.7(±38.4)^{c}	823.7(±3.6)^{ab}	771.0(±10.3)^{a}	422.7(±2.4)^{a}	254.0(±23.1)^{a}		
		3	1416.0(±66.7)^{a}	1236.7(±53.7)^{a}						
		4	1444.7(±11.7)^{a}	1340.3(±23.7)^{a}	1002.9(±173.4)^{a}	613.6(±4.9)^{b}			724.7(±4.9)	323.2±3.1
	Autumn	1	674.3(±36.4)^{c}	430.3(±29.3)^{c}	602.8(±4.8)^{b}	421.1(±2.1)^{b}				
		2	558.0(±40.6)^{d}	423.0(±33.9)^{c}	522.7(±4.0)^{c}	422.7(±5.4)^{b}				
		3	1246.7(±26.5)^{b}	1105.0(±5.3)^{b}						
		4	1592.0(±42.7)^{a}	1446.3(±11.5)^{a}	1020.3(±8.3)^{a}	965.9(±2.5)^{a}			712.5(±9.2)	620.0(±5.6)
	Winter	1	748.0(±43.0)^{c}	660.0(±26.9)^{c}	1526.9(±3.9)^{b}	618.6(±1.8)^{c}	440.4(±1.0)^{b}	344.2(±0.9)^{a}		
		2	680.3(±15.5)^{c}	429.7(±36.8)^{d}	1583.4(±6.3)^{a}	682.9(±1.7)^{b}	468.2(±2.7)^{a}	331.7(±3.6)^{b}		
		3	1337.0(±32.9)^{b}	1155.0(±37.6)^{b}						
		4	1444.0(±33.0)^{a}	1257.6(±4.8)^{a}	1356.6(±5.1)^{c}	1254.6(±4.8)^{a}			607.8(±2.3)	593.3(±3.9)

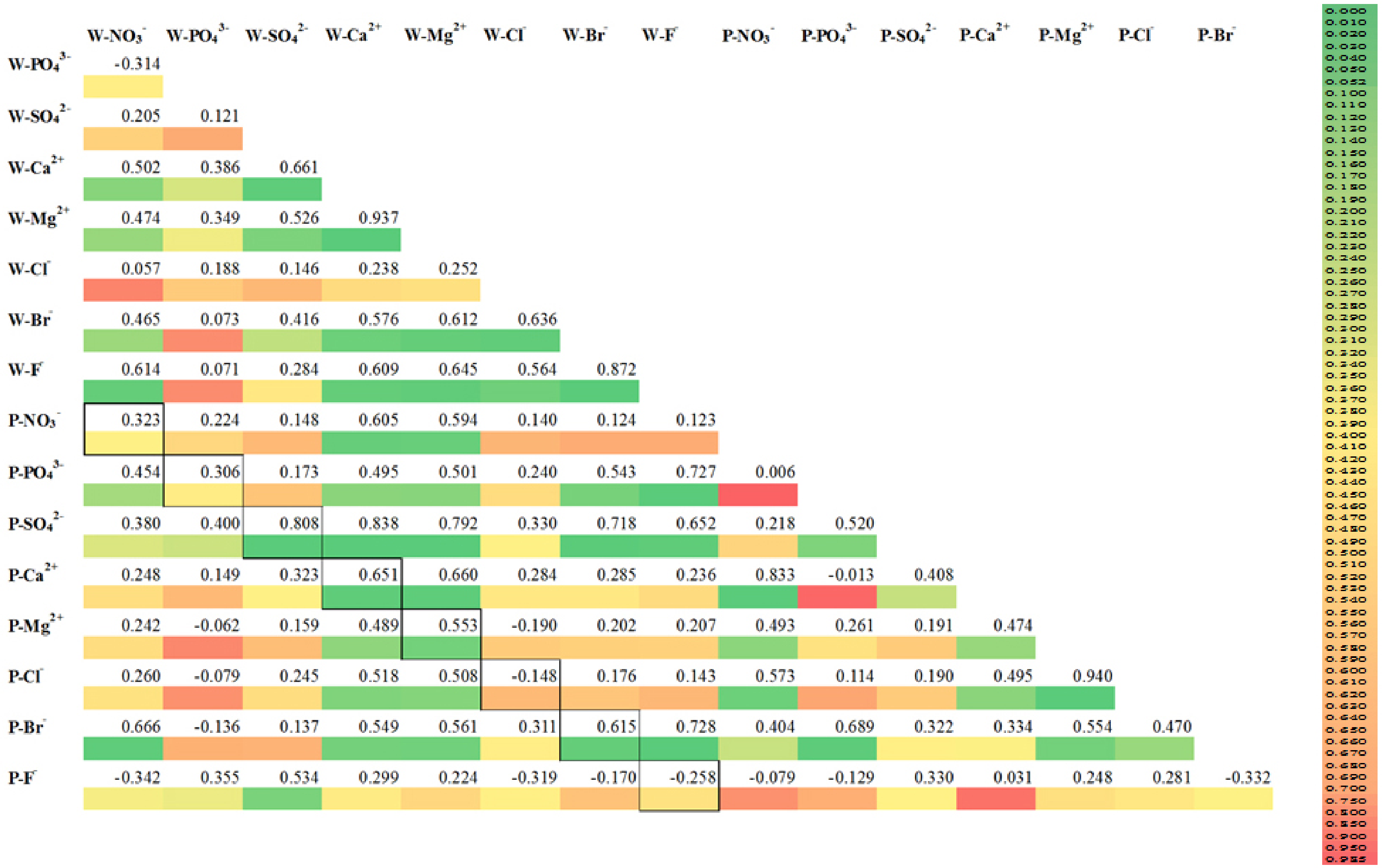
Table 3. Continued ……

	Season	Site	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
Cl^{-} (µg/g dry mass)	Spring	1	122.7(±9.5)^{c}	109.7(±15.9)^{c}	512.8(±2.6)^{c}	365.0(±3.3)^{b}	233.7(±6.9)^{b}	211.3(±4.5)^{b}		
		2	86.7(±5.0)^{d}	53.7(±6.1)^{d}	622.2(±1.9)^{b}	389.5(±5.9)^{a}	359.1(±2.1)^{a}	296.9(±5.3)^{a}		
		3	1032.0(±3.6)^{b}	1010.8(±2.8)^{b}						
		4	1080.7(±4.5)^{a}	1035.7(±5.0)^{a}	1225.9(±4.8)^{a}	341.4(±3.8)^{c}			469.4(±3.4)	202.4(±2.1)
	Summer	1	146.7±(0.01)^{b}	94.0(±6.2)^{b}	257.6(±1.7)^{c}	155.9(±5.6)^{c}	95.2(±4.2)^{b}	75.5(±0.3)^{b}		
		2	122.3(±9.1)^{c}	94.0(±5.0)^{b}	346.7(±4.2)^{b}	206.9(±2.7)^{b}	123.7(±3.9)^{a}	86.4(±0.2)^{a}		
		3	1040.7(±1.5)^{a}	86.5.8(±1.3)^{b}						
		4	1040.3(±2.1)^{a}	1024.7(±2.5)^{a}	588.2(±4.3)^{a}	523.6(±2.9)^{a}			216.9(±1.7)	95.4(±0.2)
	Autumn	1	119.0(±6.2)^{b}	99.0(±5.6)^{a}	356.4(±1.1)^{c}	195.6(±3.0)^{c}				
		2	130.7(±12.7^{b}	75.3(±1.5)^{c}	402.9(±2.7)^{b}	223.4(±1.6)^{b}				
		3	1034.3(±1.5)^{a}	1012.3(±1.5)^{a}						
		4	1036.3(±3.1)^{a}	1014.3(±3.1)^{a}	1167.1(±1.5)^{a}	980.2(±2.8)^{a}			89.9(±1.2)	71.1(±1.1)
	Winter	1	156.0(±4.6)^{c}	94.3(±2.1)^{c}	472.4(±6.4)^{c}	352.9(±2.6)^{c}	50.8(±0.2)^{b}	47.0(±0.4)^{b}		
		2	119.3(±4.5)^{d}	76.0(±2.6)^{d}	579.2(±2.6)^{b}	477.3(±7.6)^{b}	72.4(±0.4)^{a}	52.9(±0.4)^{a}		
		3	1022.7(±1.5)^{b}	1010.7(±1.5)^{b}						
		4	1085.3(±3.8)^{a}	1052.0(±3.0)^{a}	731.2(±5.5)^{a}	681.9(±1.6)^{a}			155.3(±3.2)	80.1(±0.5)

	Season	Site	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
Br^{-} (µg/g dry mass)	Spring	1	90.3(±2.3)^{c}	60.7(±2.6)^{d}	158.7(±8.0)^{b}	113.7(±6.4)^{b}	49.3(±7.4)^{b}	23.8(±8.9)^{b}		
		2	100.9(±0.4)^{b}	84.8(±4.4)^{c}	127.9(±4.7)^{c}	96.2(±0.8)^{c}	74.3(±9.5)^{a}	45.6(±0.6)^{a}		
		3	220.4(±13.0)^{a}	147.2(±7.6)^{b}						
		4	248.3(±7.9)^{a}	212.9(±8.8)^{a}	288.8(±10.0)^{a}	254.5(±12.7)^{a}			220.7(±9.7)	192.0(±7.2)
	Summer	1	322.6(±29.0)^{c}	115.1(±13.2)^{c}	422.7(±12.1)^{a}	210.7(±4.8)^{b}	223.6(±11.8)^{b}	84.6(±4.4)^{b}		
		2	396.3(±6.5)^{ab}	256.1(±11.7)^{b}	428.3(±26.9)^{a}	312.7(±11.2)^{a}	353.8(±11.4)^{a}	191.9(±14.7)^{a}		
		3	429.1(±16.5)^{a}	323.6(±8.9)^{a}						
		4	350.2(±16.7)^{bc}	265.1(±13.9)^{b}	375.1(±12.0)^{b}	302.6(±13.3)^{a}			395.7(±6.1)	376.6(±11.5)
	Autumn	1	135.9(±17.6)^{d}	78.1(±1.8)^{c}	220.7(±9.7)^{b}	112.3(±10.0^{c}				
		2	206.6(±8.6)^{c}	60.1(±4.1)^{d}	300.1(±11.1)^{a}	158.3(±6.8)^{b}				
		3	375.8(±8.0^{a}	264.8(±9.8)^{a}						
		4	280.5(±18.6)^{b}	242.3(±7.8)^{b}	335.9(±30.3)^{a}	242.4(±12.3)^{a}			94.1(±5.0)	68.6(±1.8)
	Winter	1	485.6(±14.2^{bc}	442.4(±8.7)^{b}	511.9(±10.4)^{a}	440.2(±15.8)^{a}	333.3(±28.4)^{a}	322.4(±10.8)^{a}		
		2	535.6(±14.9)^{ab}	505.7(±7.9)^{a}	412.1(±9.9)^{b}	389.1(±11.4)^{b}	343.9(±10.9)^{a}	308.3(±7.0)^{a}		
		3	576.1(±9.1)^{a}	520.5(±9.5)^{a}						
		4	452.9(±36.2^{c}	414.9(±16.6)^{b}	519.0(±3.4^{a})	442.2(±19.3)^{a}			364.7(±12.2)	312.0(±10.6)

Table 3. Continued ……

	Season	Site	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
F- (µg/g dry mass)	**Spring**	1	64.9(±9.9)^{b}	48.4(±6.9)^{c}	91.3(±1.2)^{b}	62.8(±3.3)^{c}	53.9(±3.5)^{b}	30.8(±2.2)^{b}		
		2	85.4(±3.3)^{a}	74.7(±3.3)^{b}	86.8(±4.8)^{ab}	78.9(±1.4)^{b}	64.9(±1.6)^{a}	51.1(±2.1)^{a}		
		3	96.6(±3.2)^{a}	88.5(±2.6)^{a}						
		4	94.7(±6.2)^{a}	85.8(±4.9)^{a}	96.1(±2.3)^{a}	96.1(±3.6)^{a}			75.1(±4.2)	69.4(±1.0)
	Summer	1	52.8(±2.7)^{d}	43.4(±0.9)^{d}	66.5(±3.1)^{c}	53.5(±2.7)^{c}	51.3(±1.0)^{b}	46.7(±3.8)^{a}		
		2	64.8(±1.7)^{c}	56.3(±2.4)^{c}	79.3(±1.1)^{b}	69.6(±3.1)^{b}	63.8(±6.2)^{a}	56.8(±8.8)^{a}		
		3	79.2(±1.2)^{a}	71.8(±1.7)^{a}						
		4	69.8(±1.5)^{b}	66.1(±2.4)^{b}	88.5(±1.1)^{a}	76.3(±0.8)^{a}			82.1(±2.6)	72.8(±2.1)
	Autumn	1	46.3(±3.5)^{c}	41.2(±1.1)^{c}	61.3(±0.8)^{c}	51.1(±1.1)^{b}				
		2	62.2(±1.1)^{b}	60.0(±0.1)^{b}	77.1(±0.9)^{b}	72.2(±1.0)^{a}				
		3	74.8(±3.4)^{a}	61.3(±0.8)^{b}						
		4	72.1(±1.1)^{a}	64.6(±1.3)^{a}	79.7(±2.3)^{a}	72.9(±2.3)^{a}			62.2(±0.8)	58.4(±1.7)
	Winter	1	48.7(±1.1)^{c}	35.6(±3.9)^{c}	55.5(±1.1)^{b}	47.1(±1.6)^{c}	42.2(±1.1)^{a}	37.5(±1.2)^{b}		
		2	50.5(±0.7)^{b}	46.6(±0.4)^{b}	54.7(±1.7)^{b}	51.1(±1.0)^{b}	44.6(±2.2)^{a}	41.3(±1.8)^{a}		
		3	57.5(±0.4)^{b}	51.0(±1.0)^{a}						
		4	54.6(±1.9)^{a}	46.8(±1.7)^{b}	58.6(±1.2)^{a}	55.6(±1.1)^{a}			45.4(±1.2)	42.2(±1.1)



	W-NO_3^-	W-PO_4^{3-}	W-SO_4^{2-}	W-Ca^{2+}	W-Mg^{2+}	W-Cl^-	W-Br^-	W-F^-	P-NO_3^-	P-PO_4^{3-}	P-SO_4^{2-}	P-Ca^{2+}	P-Mg^{2+}	P-Cl^-	P-Br^-
W-PO_4^{3-}	-0.314														
W-SO_4^{2-}	0.205	0.121													
W-Ca^{2+}	0.502	0.386	0.661												
W-Mg^{2+}	0.474	0.349	0.526	0.937											
W-Cl^-	0.057	0.188	0.146	0.238	0.252										
W-Br^-	0.465	0.073	0.416	0.576	0.612	0.636									
W-F^-	0.614	0.071	0.284	0.609	0.645	0.564	0.872								
P-NO_3^-	0.323	0.224	0.148	0.605	0.594	0.140	0.124	0.123							
P-PO_4^{3-}	0.454	0.306	0.173	0.495	0.501	0.240	0.543	0.727	0.006						
P-SO_4^{2-}	0.380	0.400	0.808	0.838	0.792	0.330	0.718	0.652	0.218	0.520					
P-Ca^{2+}	0.248	0.149	0.323	0.651	0.660	0.284	0.285	0.236	0.833	-0.013	0.408				
P-Mg^{2+}	0.242	-0.062	0.159	0.489	0.553	-0.190	0.202	0.207	0.493	0.261	0.191	0.474			
P-Cl^-	0.260	-0.079	0.245	0.518	0.508	-0.148	0.176	0.143	0.573	0.114	0.190	0.495	0.940		
P-Br^-	0.666	-0.136	0.137	0.549	0.561	0.311	0.615	0.728	0.404	0.689	0.322	0.334	0.554	0.470	
P-F^-	-0.342	0.355	0.534	0.299	0.224	-0.319	-0.170	-0.258	-0.079	-0.129	0.330	0.031	0.248	0.281	-0.332

Table 4 shows the r values of the Pearson's correlation of the water and plant analyses. Highly strong positive correlations ($p < 0.001$) were calculated for the contents of most macro nutrients in water and plant tissues (leaves+stems), e.g., for SO_4^{2-}, Ca^{2+} and Mg^{2+} (r= 0.0808, 0.651, 0.533, respectively).

5 Conclusion

Analysis of water and four species of hydrophytes provided useful information on the effects of different pollution types, and the intensity of these effects over the seasons (spring summer, autumn and winter) in an aquatic ecosystem in the Upper Nile Valley.

Conflict of interests

The authors declare that they have no conflict of interest.

Acknowledgements

The authors appreciate being able to access the facilities provided in the Botany Department, Faculty of Science, Aswan University to complete this study.

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