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Polycyclic Aromatic Hydrocarbon (PAHs) Concentrations in Some Aquatic Macrophytes in Hilla River, Iraq

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Abstract

***Phragmites australis*, *Potamogeton pectinatus*, *Potamogeton perfoliatus* and *Ceratophyllum demersum* were selected to study concentrations of PAHs in lotic ecosystems. Six sampling sites were selected along Al-Hilla River and sampling was conducted in 2010 and 2011. Sixteen PAHs listed as priority pollutants were detected in the samples collected, including Naphthalene (Nap), Acenaphthylene (Acpy), Acenaphthene (Acp), Fluorene (Flu), Phenanthrene (Phen), Anthracene (Ant), Fluoranthene (Flur), Pyrene (Py), Benzo (a) Anthracene (B(a)A), Chrysene (Chry), Benzo (b) Fluoranthene (B(b)F), Benzo (k) Fluoranthene (B(k)F), Benzo (a) Pyrene (B(a)P), Dibenzo (a, h) Anthracene (D(b)A), Benzo (ghi) Perylene (B(ghi)P) and Indeno (1,2,3-cd) Pyrene (Ind). The results of the study illustrate that the PAH concentration in macrophytes varies among their species. These variances were as follows: *P. australis* 0.425 to 299.424 µg/g dry weight (Dw) for B(ghi)P and B(b)F, respectively; *P. perfoliatus* 0.354 to 235.84 µg/g Dw for B(b)F and B(ghi)P, respectively; *C. demersum* 0.996 to 162.942 µg/g Dw for Ant and B(ghi)P, respectively; and *P. pectinatus* 0.383 to 99.87 µg/g Dw for Ant and Nap, respectively. The accumulation potential of PAHs was also investigated by calculating the Bioconcentration Factor (BCF) and Bio-sediment Accumulation Factor (BSAF). The ranges of BCF ratios were 0.05 to 5334.5, 0.08 to 1602.5, 0.01 to 536.6, 0.16 to 1882 in *P. australis*, *P. perfoliatus*, *P. pectinatus and C. demersum*, respectively. The range of BSAF ratios were 3.14 to 1041.6 and 1.5 to 2920.8 in *P. australis* and *P. perfoliatus*, respectively.**

Keywords

PAH, Macrophytes, Lotic Ecosystems, Al-Hilla River, Pollution, PAH Origin

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1. Introduction

The race to build factories in different countries of the world increases environmental degradation caused by various pollutants and one of these pollutants is polycyclic aromatic hydrocarbons (PAHs). PAHs are a class of organic compounds consisting of two or more aromatic rings [1]. Based on their formation, PAHs can be pyrogenic, petrogenic, diagenic or biogenic [2] [3]. Pyrogenic PAHs are derived from the incomplete combustion of various fuels, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat [4].

PAHs exist in the environment and are distributed in both aquatic and terrestrial environments. Due to their properties such as low aqueous solubility and hydrophobic nature, PAHs are most likely found bound in soils and sediments, and accumulated in the food chain, due to affinity to fatty tissues of organisms [5]. PAHs constituents of non-aqueous phase liquids, make them largely unavailable to microorganisms [6]. Of particular interest in the environment is the acute lethal and sub-lethal toxic effect in freshwater organisms at very low aqueous concentrations [7].

The uptake of large molecules by plant cells is difficult depending on the structure of the cell wall system, especially when they are lipophilic [8].

Prasad *et al*. [9] revealed that aquatic plants have the ability to uptake bioavailable compounds through their thin cuticle. Rooted aquatic plants have a bioavailabitiy role [10] [11].

Most plant species are sensitive to PAHs to some degree since PAHs can limit primary productivity and constrain total biological activity in an ecosystem [10]. Accumulation of PAHs by plants represents an entry point of hazardous compounds into the food web, initiating a biomagnification process [12] [13]. Plants can be used as a guard species for PAH contamination detection in the environment [14]. Further, a rapid assessment of negative impacts of PAHs can be detected by using plants as a bioindicator [15] [16]. As an added benefit, bioindicators reveal a great deal about the underlying mechanisms of toxicity [17] [18]. Plants that can tolerate contaminated sites can generate a large biomass to remediate PAHs [8] [19].

In aquatic systems, assimilation of contaminants by plants is rapid and efficient, even from sediment, and because of higher affinity of organics to plant tissues than the aqueous phase, the BCFs can be very high [20]. Plants can also assimilate organics following aerial deposition on the leaves [21], thus the contaminants received in this manner can be highly toxic, and represent an important entry point of organic compounds into the food chain. Plants grown in areas with high PAH loads in the soil or air have high bioconcentrations of PAHs [12], because PAHs are lipophilic and tend to accumulate in plants, especially in membrane bilayers [20] [21].

The present study dealt with the fate of PAHs in some macrophytes, in addition to their concentrations and origin of some PAHs in macrophytes.

2. Material and Methods

2.1. Study Area

Six sites were selected along Al-Hilla River (**Figure 1**) as described in Hassan *et al*. [22] and Salman *et al*. [5]. **Table 1** illustrates global positioning system (GPS) locations.

The studied macrophytes (*Phragmites australis*, *Potamogeton pectinatus*, *Potamogeton perfoliatus* and *Ceratophyllum demersum*) were observed at all sites. Samples were collected between March 2010 and February 2011.

Table 1. Coordinates for studied sites.

Site	Longitude (East)	Latitude (North)
1	44˚18'16.62"	32˚40'52.32"
2	44˚16'40.33"	32˚46'26.40"
3	44˚23'19.92"	32˚33'13.57"
4	44˚26'22.85"	32˚28'59.81"
5	44˚29'16.15"	32˚25'18.51"
6	44˚39'10.41"	32˚22'17.77"

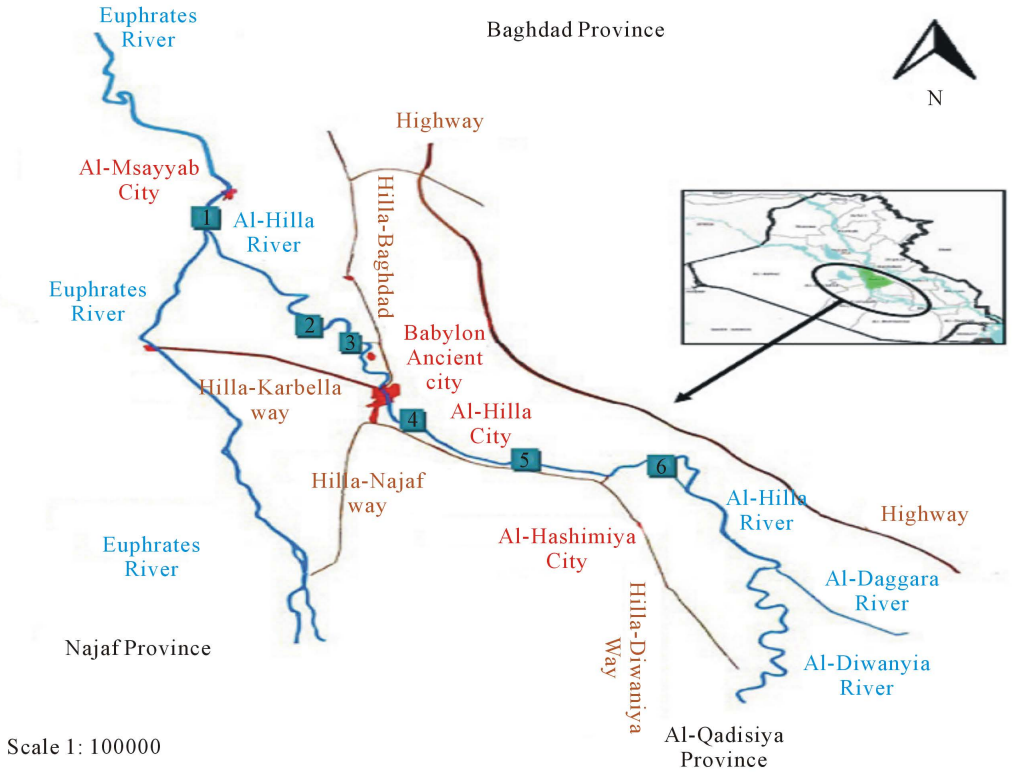

Figure 1. Map of the study area.

Data pertaining to the physicochemical characterization and PAH concentrations in water and sediment of Al-Hilla River was taken from Hassan *et al*. [22].

2.2. Macrophytes Sampling

Macrophyte samples were sequentially washed with river water, tap water, and distilled water, dried at 15˚C and wrapped in aluminum. Fresh samples were also wrapped, labeled and frozen at −20˚C for subsequent lipid content determination [23].

2.3. Extraction of PAHs

Dried specimens were sieved (63 mesh sieve) and 10 g of plant material were well mixed in a metal blender with 50 ml acetone for 5 minutes. The solution was left overnight in a dark and cold location. After shaking for one hour, the solution was separated and the extract placed in dark glass containers. This step was repeated three times [24]. The solution was centrifuged at 2500 RPM for 5 minutes. Then the supernatant solution was transferred to a flask with 50 ml Hexan and 100 ml deionized water. Upon separation, the upper layer was collected and 50 ml KOH (20 ml aqueous solution in ethanol) was added. The solution was reduced to 10 ml by rotary evaporator and transferred to a cleanup process [25].

2.4. Clean-Up Process

Because the extract contains complex components, the clean-up procedure was undertaken by column chromatography using 25 cm of deactivated silica gel (60 - 120 mesh) packed in a glass column (250 mm × 15 mm internal diameter) and Tetrachloromethane for six hours, followed by heat activation at 250˚C for 12 hours and then cooled and deactivated with water (10%). After deactivation, the solution was stored in an air—tight dark glass and used within 72 hours. The column was pre-eluted with 10 ml Hexane and the extract was passed through the column and eluted with 50 ml Benzene to separate all PAH compounds [23] [26].

2.5. Lipid Determination

In a pre-weighted round flask, add 10 g wet homogenate tissue and 50 g anhydrous sodium to 250 ml of acetone. Allow to evaporate to dryness and re-weigh. The difference between these weights of flask referrers to lipid content [24].

2.6. Blank

Laboratory reagents and glassware were analyzed with each sample to check if any interference that may have been introduced during the extraction and analytical procedure [27] [28].

2.7. Analysis of PAHs

Both hexane and benzene were evaporated to dryness by rotary evaporator and the residue was dissolved with 1 ml (90:10) Acetonitrile:Methanol. The extract was stored at −20˚C until analysis by high performance liquid chromatography.

2.8. Standard Solution

A standard solution of sixteen US EPA priority PAHs was obtained from Sigma-Aldrich Corporation in order to compare the retention times and spectra of compounds in the standard with those in the sample. The standard calibration contains the following compounds:

Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene [PHE], Anthracene [ANT], Fluoranthene, Pyrene, Benzo(a) anthracene [B (a)A], Chrysene [Chry], Benzo(b)Fluoranthene [B(b)F], Benzo(k) Fluoranthene [B(k) F], Benzo(a) pyrene [B(a) P], Dibenzo (a,h) anthracene [D(a,b) A], Benzo (ghi) Perylene [B(ghi) P] and Indeno(1,2,3-cd) pyrene [Ind].

2.9. Bioconcentration Factor (BCF) and Biosediment Accumulation Factor (BSAF)

BCF(l/g) = PAH concentration in specimen/PAH concentration in water.

BSAF = PAH concentration in specimen (µg/g)/PAH concentration in sediment (µg/g) × Total Organic Carbon (µg/g)/Lipid content (µg/g).

2.10. Toxicity of Carcinogenic PAHs

Seven carcinogenic PAHs (c-PAHs) were selected according to EPA (1993): B (a) P, B (a) A, B (b) F, B (k)F, Chry, DbA and Ind (**Table 2**). The toxicity equivalency factor (TEF) was calculated (see below) to assess the risks of a mixture with a related compound Method B cleanup level (EPA, 1993) relative to B (a) P).

TEF = Concentration of c-PAH × equivalent related compound.

Total Toxicity Equivalence Concentration (TTEC) = ΣTEF.

It must not exceed the method by cleanup level for B (a) P (0.137 µg/g) [29] [30].

The average concentration for each PAH compound and maximum mean for it were compared with standard criteria in **Table 2**.

Table 2. Standard criteria for Equivalent c-PAHs [31].

Compounds	Equivalent
B (a) P	1
B (a) A	0.1
B (b) F	0.1
B (k) F	0.1
Chry	0.01
DbA	0.1
IND	0.1

2.11. PAH Origin

The PAH origin was assessed according to ratios (Phe/Ant, Chry/BaA, Flu/Pyr, Flu/(Flu + Pyr) and low molecular weight/high molecular weight [32] [33].

2.12. Statistical Analysis

The results were analyzed statistically by SPSS (ANOVA, Mean and Standard Deviation) and Canoco for Windows 4.5 (CCA) for the relationships among all tests in the current study.

3. Results and Discussion

Many studies have considered lower and higher plants as bioindicators and biomonitors [34] [35], and also the usage of aquatic plants in wastewater treatment, detoxification and phytoremediation [36]-[38].

The results of quality and quantity of PAH compounds in selected aquatic plants are shown in **Tables 3-6**. The characteristic values of selected molecular ratios for pyrogenic and petrogenic origins of PAHs in the studied plants are **Tables 7-10**.

The mean range of PAHs in macrophytes were as follows: *P. australis* 0.425 - 299.424 µg/g DW, *P. perfoliatus* 0.354 - 235.84 µg/g DW, *C. demersum* 0.996 - 162.942 µg/g DW, and *P. Pectinatus* 0.383 - 99.87 µg/g DW (**Figure 2**). The variation between aquatic plants may be due to the ability of *P. australis* to absorb the pollutants from sediment and water [39] [40], and its high growth rate and luxury accumulation of major nutrients in stems, roots, and rhizomes [41]-[43]. Other studied macrophytes exhibit lower values because these plants are non-rooted submerged macrophytes, which depend on compound availability in the water column [44] [45].

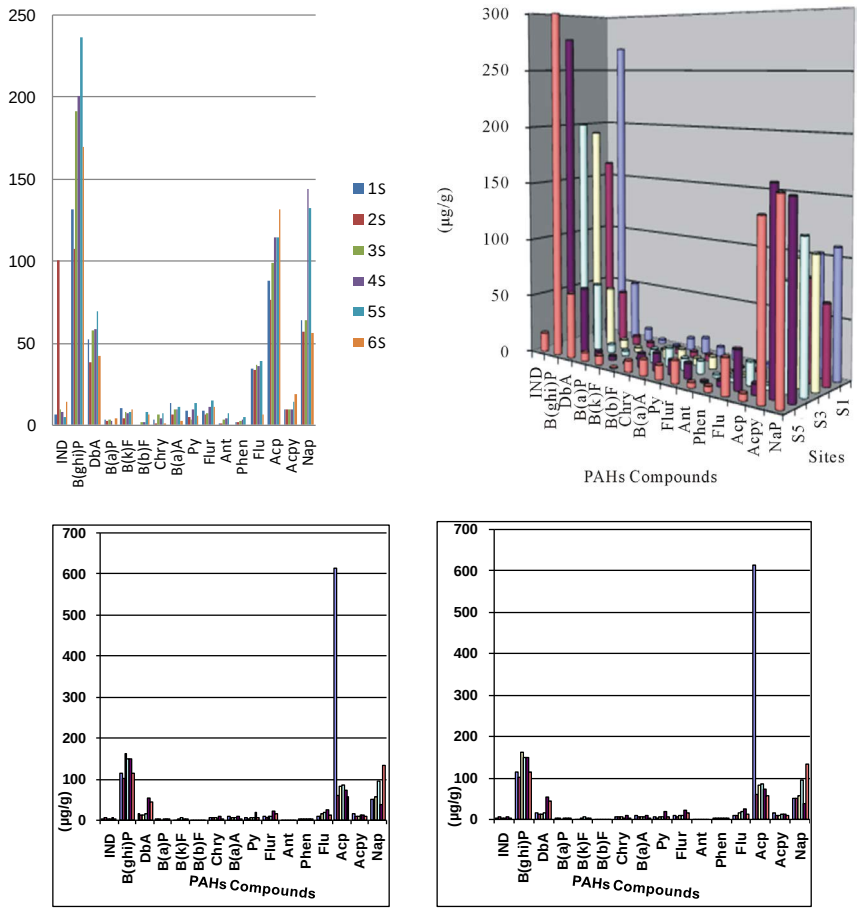

Figure 2. PAHs concentrations in the studied sites for *P. perfoliatus*, *P. australis*, *C. demersum* and *P. pectinatus*.

Table 3. Values of PAHs compounds in *P. pectinatus* during March 2010-February 2011 (S = Speing, S = Summer, A = Autumn, W = Winter).

Station	Season	PAHs Compounds (µg/g)															
		Nap	Acpy	Acp	Flu	Phen	Ant	Flur	PY	B(a)A	Chry	B(b)F	B(k)F	B(a)P	D(b)A	B(ghi)P	IND
1	S	73.56	71.26	ND	ND	5.06	0.76	ND	ND	10.55	7.23	1.76	7.55	3.72	52.91	84.56	2.45
	S	14.75	16.71	1.03	0.00	ND	ND	0.58	1.04	1.67	ND	ND	1.82	0.16	10.36	22.47	0.96
	A	79.93	78.99	6.07	30.80	ND	ND	2.75	ND	ND	3.58	3.33	7.90	3.00	50.44	84.03	2.58
	W	ND	ND	ND	1.15	0.98	1.01	7.30	3.98	7.81	7.69	ND	11.31	3.05	ND	82.48	2.39
	Mean	59.95	41.74	3.69	7.99	3.85	0.44	3.61	2.01	5.01	4.62	1.27	7.14	2.48	28.43	68.38	2.09
	±S.D.	30.34	39.72	3.74	15.22	2.91	0.51	2.80	1.80	4.99	3.59	1.60	3.93	1.58	27.19	30.62	0.76
2	S	62.83	98.01	5.35	7.45	2.06	ND	ND	5.27	13.35	4.32	1.16	ND	3.96	88.13	62.49	1.34
	S	12.55	ND	ND	ND	0.48	0.00	ND	ND	2.01	0.54	ND	0.00	0.48	0.00	25.01	0.55
	A	67.29	97.28	ND	ND	2.34	0.97	ND	ND	11.97	3.60	ND	4.44	2.00	81.14	84.27	1.55
	W	70.67	91.67	10.11	1.25	ND	ND	8.07	ND	ND	ND	1.31	6.97	ND	84.17	79.66	2.79
	Mean	53.33	80.10	7.73	2.17	1.66	0.38	3.82	2.52	6.83	2.11	0.68	2.85	1.61	63.36	62.86	1.56
	±S.D.	23.37	31.23	5.20	3.56	0.82	0.47	3.70	2.91	6.80	2.16	0.65	3.45	1.78	42.33	26.91	0.92
3	S	54.22	59.78	3.33	ND	ND	0.93	12.39	7.69	6.34	ND	1.22	3.98	1.89	47.39	81.66	1.03
	S	12.59	ND	ND	ND	0.46	0.00	0.00	2.89	0.26	0.00	0.64	0.38	ND	0.00	ND	0.73
	A	66.33	ND	ND	ND	1.38	1.91	13.55	0.00	7.78	7.25	2.97	2.88	ND	47.78	ND	1.24
	W	57.24	ND	ND	ND	0.11	0.05	10.93	9.11	12.98	15.67	1.62	3.22	ND	45.35	86.59	1.14
	Mean	47.59	46.13	1.70	7.81	0.49	0.72	9.22	4.92	6.84	5.73	1.61	2.62	0.62	35.13	42.06	1.03
	±S.D.	31.45	39.18	1.46	6.82	0.62	0.89	6.23	3.60	4.22	7.45	0.99	1.55	0.89	23.44	48.60	0.22
4	S	82.23	36.81	ND	ND	0.96	1.05	4.51	ND	9.62	5.61	2.32	4.17	ND	32.41	160.61	ND
	S	23.36	11.42	ND	1.34	0.25	ND	1.59	0.48	ND	0.89	0.14	1.96	0.83	ND	77.34	0.92
	A	44.16	42.82	10.58	8.40	1.77	ND	3.56	5.56	6.64	8.96	ND	2.32	2.34	5.81	105.31	1.06
	W	29.97	77.25	13.92	8.87	1.48	0.62	6.84	5.80	8.40	5.20	1.36	1.71	ND	33.92	ND	1.59
	Mean	44.93	42.07	6.12	4.65	1.11	0.42	4.124	2.96	6.17	5.17	0.96	2.54	0.79	18.03	85.81	0.89
	±S.D.	26.33	27.11	7.20	4.63	0.66	0.51	2.17	3.14	4.28	3.31	1.09	1.11	1.10	17.64	66.85	0.66
5	S	147.48	86.69	ND	2.78	3.59	ND	8.50	4.08	ND	6.20	11.32	10.81	0.00	ND	170.38	9.45
	S	32.13	21.57	ND	0.59	0.97	ND	1.26	0.20	ND	1.33	0.01	0.76	1.88	ND	33.48	0.25
	A	121.01	98.25	7.45	3.58	1.13	1.59	9.48	ND	13.36	4.25	10.06	12.15	9.48	ND	87.71	9.11
	W	98.90	90.97	ND	4.73	0.07	0.07	8.39	5.10	15.83	4.37	24.32	12.85	ND	83.58	88.53	ND
	Mean	99.88	74.37	1.86	2.92	1.44	0.42	6.91	2.34	10.68	4.03	11.43	9.14	2.83	37.03	95.02	4.70
	±SD	49.34	35.52	1.74	2.07	1.50	0.78	3.79	2.62	7.20	2.01	9.97	5.65	4.51	43.46	56.45	5.28
6	S	39.10	75.35	5.43	12.23	ND	2.36	6.62	6.54	4.45	4.91	1.04	ND	ND	25.08	184.78	0.33
	S	12.37	18.55	3.48	2.26	0.42	ND	ND	1.25	ND	1.32	ND	1.25	0.78	ND	22.98	ND
	A	28.71	57.60	ND	13.56	1.28	2.66	4.57	ND	5.55	3.78	ND	4.77	0.99	19.59	108.70	ND
	W	11.63	39.99	8.18	18.46	2.99	1.20	6.76	6.80	5.13	4.93	0.77	7.57	ND	63.63	ND	1.15
	Mean	22.95	47.87	4.27	11.63	1.17	1.55	4.49	3.65	3.78	3.73	0.45	3.40	0.44	27.07	79.11	0.36
	±S.D.	13.34	24.30	3.43	6.79	1.32	1.21	3.15	3.52	2.56	1.69	0.53	3.43	0.51	26.63	84.55	0.54

Table 4. Values of PAHs compounds in *P. australis* during March 2010-February 2011 (S = Spring, S = Summer, A = Autumn., W = Winter).

Station	Season	PAHs Compounds (µg/g)															
		Nap	Acpy	Acp	Flu	Phen	Ant	Flur	PY	B(a)A	Chry	B(b)F	B(k)F	B(a)P	DbA	B(ghi)P	IND
1	S	108.53	107.13	36.19	ND	2.26	1.56	ND	13.23	33.51	23.26	ND	ND	13.06	ND	469.30	11.34
	S	42.54	97.45	ND	ND	6.01	1.37	7.50	ND	3.27	9.52	1.64	2.34	10.24	41.51	154.29	0.44
	A	240.34	123.52	15.13	ND	1.33	1.51	13.98	10.71	3.18	ND	1.75	6.70	16.85	73.59	186.82	21.99
	W	46.52	82.51	1.92	13.93	0.95	ND	16.73	9.70	13.65	9.03	ND	4.70	2.52	88.71	267.85	14.42
	Mean	109.48	102.65	13.31	3.48	2.64	1.11	9.55	8.40	13.40	10.45	0.85	3.44	10.67	50.95	269.56	12.05
	±S.D.	29.32	17.20	16.67	8.04	2.31	0.74	7.45	5.79	14.27	9.59	0.98	2.90	6.06	39.25	141.45	8.93
2	S	ND	144.17	ND	1.11	0.25	0.26	0.62	0.66	0.75	0.11	1.45	4.49	2.80	1.95	105.83	ND
	S	22.58	45.02	ND	ND	4.15	0.92	3.84	ND	3.43	10.35	1.70	2.37	10.58	43.97	121.09	0.37
	A	200.42	71.09	13.95	ND	1.14	1.37	10.33	6.30	4.00	ND	1.60	6.13	14.82	71.12	178.52	22.70
	W	45.93	81.46	13.71	13.02	0.49	ND	10.38	14.11	12.02	8.53	ND	4.70	1.16	65.72	251.25	14.28
	Mean	67.23	85.43	6.92	3.53	1.51	0.64	6.29	5.27	5.05	4.75	1.18	4.42	7.34	45.69	164.17	9.34
	±S.D.	90.75	42.04	7.98	6.34	1.79	0.62	4.87	6.54	4.85	5.47	0.79	1.55	6.46	31.43	65.94	11.11
3	S	95.38	187.16	0.30	0.70	0.06	ND	10.43	0.17	12.30	1.42	ND	0.12	ND	35.25	262.65	1.11
	S	42.54	42.40	ND	17.68	4.05	0.91	3.66	13.40	4.25	11.18	ND	2.39	ND	44.79	204.09	0.44
	A	242.34	97.30	ND	ND	2.08	5.89	10.69	6.74	12.13	10.68	1.70	6.70	21.60	79.33	203.42	21.99
	W	56.50	90.37	13.71	15.23	1.05	ND	17.09	5.28	15.27	10.70	0.00	4.70	9.31	47.66	101.85	19.38
	Mean	109.19	104.31	3.50	8.40	1.81	1.70	10.47	6.40	10.90	8.50	0.43	3.48	7.73	51.76	193.00	10.73
	±S.D.	91.53	60.38	6.80	9.35	1.70	2.82	5.48	5.45	4.72	4.72	0.85	2.84	10.23	19.13	66.81	11.54
4	S	115.34	29.87	0.27	2.00	0.62	ND	0.80	0.61	10.43	9.75	ND	0.70	ND	43.46	179.65	8.19
	S	46.53	94.83	ND	43.68	7.78	4.06	25.57	17.81	12.38	10.35	ND	2.68	ND	47.26	170.89	0.51
	A	222.38	97.04	ND	ND	1.14	6.11	7.04	6.65	20.26	10.68	1.75	3.83	20.92	71.12	120.42	21.28
	W	117.78	133.89	16.07	32.52	4.77	ND	10.75	15.00	20.15	16.86	2.11	10.45	7.95	72.29	334.25	ND
	Mean	125.51	88.91	4.08	19.55	3.58	2.54	11.04	10.02	15.81	11.91	0.97	4.42	7.22	58.53	201.30	7.50
	±S.D.	72.53	43.24	7.99	21.91	3.35	3.05	10.52	7.86	5.14	3.32	1.12	4.22	9.87	15.29	92.39	9.92
5	S	155.26	213.37	7.77	15.01	2.48	ND	11.76	18.27	18.57	18.07	ND	0.73	ND	59.87	262.65	29.42
	S	86.45	147.26	ND	46.28	8.06	4.38	8.13	3.90	13.19	11.18	ND	2.39	ND	48.08	253.89	1.22
	A	103.98	145.60	1.35	ND	1.69	0.51	17.55	13.71	1.39	ND	1.16	0.86	6.13	42.26	223.15	11.61
	W	285.43	160.10	27.87	71.53	8.50	ND	14.40	13.24	28.28	18.52	2.32	11.02	13.38	80.50	367.45	ND
	Mean	157.778	166.58	9.25	33.20	5.18	1.22	12.96	12.28	15.36	11.94	0.87	3.75	4.88	57.68	276.78	10.56
	±SD	89.96	31.85	12.86	32.00	3.59	2.11	3.99	6.02	11.21	8.64	1.10	4.90	6.36	16.88	62.77	13.60
6	S	170.17	144.44	ND	10.74	3.96	4.16	23.06	ND	22.22	6.00	ND	4.08	ND	27.74	364.64	0.47
	S	88.45	149.88	ND	44.98	7.87	4.11	6.67	8.26	9.94	12.02	ND	2.71	ND	56.29	212.39	1.93
	A	142.54	123.26	ND	ND	0.03	10.62	23.39	12.24	24.00	4.02	0.70	15.32	18.89	62.91	286.42	37.91
	W	245.51	157.48	24.33	67.62	8.40	ND	24.03	28.68	ND	16.86	2.16	9.30	12.02	78.86	334.25	25.33
	Mean	161.67	143.77	6.08	30.84	5.06	4.72	19.29	12.29	14.04	9.72	0.72	7.87	7.73	56.45	299.42	16.410
	±S.D.	65.39	14.68	12.16	35.86	3.89	4.38	8.42	13.61	11.25	5.84	1.01	5.73	9.35	21.35	66.35	18.30

Table 5. Values of PAHs compounds in *C. demersum* during March 2010-February 2011 (S = spring, S = summer, A = autumn, W = winter).

Station	Season	PAHs Compounds (µg/g)															
		Nap	Acpy	Acp	Flu	Phen	Ant	Flur	PY	B(a)A	Chry	B(b)F	B(k)F	B(a)P	D(b)A	B(ghi)P	IND
1	S	66.11	ND	ND	ND	2.14	ND	ND	13.28	10.27	6.87	0.81	0.35	5.38	24.04	157.07	1.34
	S	21.89	ND	ND	27.83	4.21	ND	ND	0.83	7.91	10.18	0.14	1.20	ND	12.37	78.16	0.43
	A	62.60	26.78	83.55	15.69	ND	ND	19.08	9.38	ND	ND	ND	3.93	9.68	15.17	113.16	7.81
	W	54.27	28.61	ND	ND	5.57	1.30	19.57	8.31	11.99	13.69	5.03	5.12	ND	19.84	113.42	4.65
	Mean	51.22	16.16	614.94	10.88	5.55	1.53	9.66	7.95	11.82	7.69	1.49	2.65	3.76	17.85	115.45	3.56
	±S.D.	20.17	13.86	41.31	13.50	3.44	1.56	11.15	5.20	3.90	5.83	2.38	2.24	4.68	5.14	32.31	3.36
2	S	62.12	ND	64.24	ND	1.96	0.51	ND	4.45	2.14	7.71	0.76	0.06	4.70	15.83	130.60	15.83
	S	17.90	6.28	ND	26.53	3.28	3.63	ND	0.28	7.66	11.01	0.13	1.23	ND	12.45	67.67	1.14
	A	70.61	24.42	90.35	13.09	9.33	ND	11.35	4.94	16.29	ND	ND	3.35	9.00	8.60	110.54	7.10
	W	52.27	8.26	88.47	ND	4.62	0.85	15.92	7.89	8.74	12.03	5.13	5.70	ND	20.66	105.56	4.44
	Mean	50.72	9.74	60.77	9.90	4.80	1.25	6.82	4.39	8.71	7.69	1.51	2.59	3.42	14.38	103.59	7.13
	±S.D.	23.13	10.40	42.21	12.68	3.21	1.62	8.08	3.13	5.82	5.44	2.44	2.48	4.32	5.12	26.27	6.29
3	S	67.31	11.70	97.44	ND	2.21	1.12	14.61	7.49	ND	7.04	0.81	0.64	ND	32.25	156.81	3.46
	S	ND	ND	ND	30.43	4.30	3.77	ND	0.28	7.10	11.85	0.19	1.29	ND	13.19	130.59	1.14
	A	ND	ND	113.35	13.22	9.61	ND	10.98	9.20	16.37	ND	2.66	3.93	10.36	9.42	136.75	7.17
	W	77.55	26.87	121.70	26.03	0.88	0.70	15.00	10.42	6.92	7.97	0.73	9.14	ND	ND	227.62	8.63
	Mean	59.82	9.64	83.12	17.42	4.25	1.40	10.15	6.85	7.60	6.71	1.10	3.75	2.59	13.71	162.94	5.10
	±S.D.	24.33	12.74	56.32	13.71	3.83	1.64	7.00	4.54	6.71	4.93	1.07	3.86	5.18	13.54	44.54	3.41
4	S	100.88	ND	ND	43.32	ND	ND	ND	11.78	3.82	5.30	0.46	ND	ND	ND	151.95	1.41
	S	51.93	ND	ND	4.83	3.28	ND	ND	3.01	7.42	8.52	0.19	ND	ND	14.01	51.95	0.51
	A	ND	ND	119.95	15.82	ND	ND	22.44	10.53	ND	ND	2.82	9.67	17.15	50.46	139.37	7.17
	W	117.51	24.51	130.00	13.03	0.87	0.61	24.27	9.54	6.11	8.05	0.79	ND	ND	ND	253.84	10.04
	Mean	95.19	12.91	85.41	19.25	3.67	0.95	11.68	8.71	8.55	5.47	1.06	6.13	4.29	16.12	149.27	4.78
	±S.D.	29.63	11.49	59.20	16.71	4.78	1.27	13.50	3.34	5.73	3.91	1.19	3.76	8.57	23.82	82.68	4.58
5	S	ND	ND	ND	ND	ND	ND	21.45	24.36	15.88	16.26	1.79	ND	ND	ND	172.30	3.43
	S	ND	ND	33.57	ND	ND	ND	ND	10.33	8.07	13.51	0.87	4.16	5.23	46.02	78.16	ND
	A	ND	ND	131.45	17.12	11.47	0.98	33.54	ND	ND	ND	3.08	9.67	10.29	52.10	179.86	9.29
	W	155.88	ND	ND	52.06	ND	ND	36.65	19.39	17.51	10.73	0.83	ND	ND	121.18	172.13	15.13
	Mean	38.97	14.23	74.38	25.23	4.37	1.24	22.91	19.09	10.37	10.12	1.64	5.29	3.88	54.83	150.61	6.96
	±SD	82.58	28.46	67.90	22.09	5.02	1.88	16.61	6.18	8.04	7.11	1.05	3.71	4.93	49.97	48.43	6.66
6	S	ND	ND	99.04	31.17	2.46	1.10	17.67	1.94	9.29	8.13	ND	ND	11.40	5.90	143.80	3.30
	S	25.65	0.91	ND	ND	4.26	ND	ND	16.12	9.89	4.69	2.03	ND	ND	ND	39.09	0.73
	A	ND	ND	98.25	14.52	9.61	0.94	211.35	ND	ND	ND	2.71	9.10	10.36	51.28	144.61	7.88
	W	185.92	ND	ND	4.47	ND	ND	22.63	0.56	1.25	2.40	0.31	ND	ND	129.39	139.51	8.06
	Mean	132.94	11.51	58.90	12.54	4.27	1.00	15.41	7.06	5.11	3.80	1.42	5.65	5.44	46.64	116.75	4.99
	±S.D.	93.51	22.42	48.48	13.82	3.83	0.79	10.48	7.24	5.20	3.45	1.13	4.69	6.29	59.73	51.82	3.59

Table 6. Values of PAHs compounds in *P. perfoliatus* during March 2010-February 2011 (S = spring, S = summer, A = autumn, W = winter).

Station	Season	PAHs Compounds (µg/g)															
		Nap	Acpy	Acp	Flu	Phen	Ant	Flur	PY	B(a)A	Chry	B(b)F	B(k)F	B(a)P	D(b)A	B(ghi)P	IND
1	S	50.42	ND	109.02	18.21	0.10	0.14	18.91	ND	2.67	2.66	0.24	8.32	ND	43.37	267.84	7.21
	S	37.88	12.02	27.85	27.41	ND	ND	ND	3.05	17.17	6.21	ND	27.27	6.21	67.31	44.91	4.16
	A	57.84	27.65	101.05	33.91	4.50	2.24	ND	14.70	23.67	5.38	ND	2.86	6.61	73.05	45.43	9.83
	W	109.68	ND	113.52	58.98	1.52	1.11	17.06	16.82	10.04	ND	1.18	3.93	ND	26.93	168.53	5.81
	Mean	63.96	9.92	87.86	34.63	1.53	0.87	8.99	8.64	13.39	3.56	0.35	10.59	3.21	52.66	131.68	6.75
	±S.D.	31.57	13.11	40.33	17.46	2.09	1.03	10.41	8.35	9.06	2.81	0.56	11.36	3.70	21.43	107.80	2.39
2	S	50.30	ND	97.36	1.83	0.01	0.01	11.01	ND	1.04	1.83	0.23	8.12	ND	42.55	262.60	7.28
	S	51.85	11.22	21.25	28.71	3.01	0.97	ND	3.22	8.22	ND	ND	2.31	4.10	37.76	34.94	7.09
	A	53.85	24.12	96.15	32.61	4.22	1.87	ND	9.05	15.54	1.21	ND	2.80	5.46	70.59	40.19	12.75
	W	69.77	ND	90.52	71.98	0.59	0.21	12.76	5.40	0.28	ND	0.03	1.06	ND	2.31	89.88	12.89
	Mean	56.44	9.11	76.32	33.78	1.96	0.77	5.94	4.42	6.27	0.76	0.06	3.57	2.39	38.30	106.90	10.00
	±S.D.	9.00	11.56	36.83	28.91	1.99	0.84	6.89	3.80	7.14	0.91	0.10	3.11	2.81	28.02	106.70	3.25
3	S	54.29	ND	116.36	3.13	0.11	0.03	14.81	ND	2.67	2.66	0.44	13.86	ND	34.34	393.67	8.70
	S	53.85	13.50	39.52	30.01	3.03	0.93	ND	2.78	8.39	ND	ND	2.63	4.78	54.17	40.19	7.30
	A	63.68	25.29	117.55	56.02	6.75	4.09	ND	6.02	10.83	10.07	ND	2.72	6.14	78.80	66.40	8.72
	W	79.93	ND	120.33	55.50	ND	6.98	14.30	4.33	15.07	11.26	5.15	11.29	ND	63.50	262.33	11.58
	Mean	63.94	9.70	98.44	36.16	2.47	3.00	7.28	3.28	9.24	6.00	1.40	7.62	2.73	57.70	190.65	9.07
	±S.D.	70.48	12.19	39.31	25.14	3.17	3.16	8.40	2.55	5.18	5.51	2.51	5.81	3.20	18.59	167.76	1.79
4	S	58.28	ND	127.19	3.26	0.22	0.07	23.00	ND	3.48	2.83	0.50	11.08	ND	35.98	396.29	10.82
	S	73.81	12.32	54.25	18.31	4.05	1.42	ND	6.98	3.51	2.57	ND	1.65	3.56	48.43	40.19	ND
	A	173.60	24.01	157.25	57.32	6.84	4.13	ND	16.46	11.64	10.90	ND	2.80	6.27	81.26	92.62	8.64
	W	269.35	ND	116.52	65.48	0.59	9.68	21.71	14.48	17.36	ND	5.23	12.55	ND	67.98	273.38	12.89
	Mean	143.76	9.08	113.80	36.09	2.92	3.83	11.18	9.48	9.00	4.08	1.43	7.02	2.46	58.41	200.62	8.09
	±S.D.	98.08	11.52	43.28	30.04	3.13	4.25	12.91	7.52	6.76	4.72	2.54	5.59	3.04	20.13	164.30	5.66
5	S	72.94	ND	167.33	ND	1.83	9.05	29.48	2.19	9.27	7.96	9.92	ND	1.26	52.86	395.65	1.66
	S	77.80	ND	32.55	23.51	4.14	0.97	0.00	9.53	3.59	ND	1.06	1.68	ND	47.61	45.43	ND
	A	189.61	ND	148.55	66.51	7.87	10.00	0.00	21.61	12.53	ND	11.59	17.42	ND	90.44	202.72	ND
	W	189.31	ND	108.22	66.78	7.52	10.14	30.28	20.24	18.17	ND	10.48	14.56	ND	86.18	299.60	19.96
	Mean	132.42	14.44	114.16	39.20	5.34	7.54	14.94	13.39	10.89	7.07	8.26	8.42	0.41	69.27	235.85	5.41
	±SD	65.90	18.37	59.73	33.11	2.87	4.40	17.25	9.21	6.10	7.78	4.84	8.85	0.59	22.15	149.39	9.73
6	S	64.28	ND	177.16	1.50	0.06	0.03	ND	10.91	6.11	3.07	7.66	10.91	ND	35.61	218.09	ND
	S	29.90	ND	32.55	10.51	0.42	0.07	ND	0.70	4.40	0.99	0.01	1.68	ND	39.40	97.86	ND
	A	33.89	23.11	174.25	11.94	0.51	0.08	21.94	7.26	ND	ND	9.02	11.97	14.29	31.19	103.10	16.70
	W	96.42	50.91	140.55	0.57	0.41	ND	20.98	3.08	ND	ND	8.64	12.44	ND	60.93	258.70	40.19
	Mean	56.12	18.51	131.13	6.13	0.35	0.04	10.73	5.49	2.63	1.02	6.33	9.25	3.57	41.78	169.44	14.22
	±S.D.	30.90	24.19	67.78	5.92	0.19	0.03	12.39	4.52	3.11	1.44	4.25	5.08	7.14	13.19	81.30	19.01

Table 7. Characteristic values of selected molecular ratios of Pyrogenic and Petrogenic origins of PAHs in *P. australis* during the study period.

	Phe/Ant	Chry/BaA	Flur/Py	Flur (Flur + Pyr)	LMW/HMW
Pyrogenic origin	<10	<1	>1	>0.5	<1
Petrogenic origin	>15	>1	<1	<0.5	>1
Station	Results of of the present study				
1	2.373	0.779	1.135	0.531	0.606
2	2.362	0.939	1.194	0.544	0.663
3	1.065	0.773	1.636	0.62	0.757
4	1.406	0.753	1.101	0.524	0.75
5	4.236	0.777	1.055	0.513	0.913
6	1.072	0.692	1.568	0.61	0.793

Table 8. Characteristic values of selected molecular ratios of Pyrogenic and Petrogenic origins of PAHs in *P. perfoliatus* during the study period.

	Phe/Ant	Chry/BaA	Flur/Py	Flur (Flur + Pyr)	LMW/HMW
Pyrogenic origin	<10	<1	>1	>0.5	<1
Petrogenic origin	>15	>1	<1	<0.5	>1
Station	Results of of the present study				
1	1.752	0.266	1.071	0.517	0.758
2	2.5498	0.121	1.345	0.573	0.971
3	0.822	0.649	2.218	0.689	0.683
4	0.763	0.453	1.179	0.541	0.973
5	0.708	0.648	1.115	0.527	0.821
6	8	0.386	1.954	0.661	0.801

Table 9. Characteristic values of selected molecular ratios of Pyrogenic and Petrogenic origins of PAHs in *P. pectinatus* during the study period.

	Phe/Ant	Chry/BaA	Flur/Py	Flur (Flur + Pyr)	LMW/HMW
Pyrogenic origin	<10	<1	>1	>0.5	<1
Petrogenic origin	>15	>1	<1	<0.5	>1
Station	Results of of the present study				
1	8.73	0.923	1.799	0.642	0.998
2	4.325	0.309	1.518	0.602	0.983
3	0.673	0.837	1.872	0.651	0.942
4	2.659	0.837	1.393	0.582	0.779
5	3.467	0.378	2.946	0.746	0.975
6	0.754	0.987	1.23	0.551	0.668

Table 10. Characteristic values of selected molecular ratios of Pyrogenic and Petrogenic origins of PAHs in *C. demersum*-during the study period.

	Phe/Ant	Chry/BaA	Flur/Py	Flur (Flur + Pyr)	LMW/HMW
Pyrogenic origin	<10	<1	>1	>0.5	<1
Petrogenic origin	>15	>1	<1	<0.5	>1
Station	Results of the present study				
1	3.628	0.65	1.215	0.548	0.824
2	3.847	0.882	1.552	0.608	0.873
3	3.044	0.883	1.482	0.597	0.779
4	3.88	0.639	1.34	0.572	0.994
5	3.514	0.976	1.199	0.545	0.951
6	4.289	0.745	2.181	0.685	0.988

The high PAH concentration in all studied plants, dominated by B(ghi)P indicates the source of PAH pollution is likely to be municipal and medical/pathological waste incinerators [46] and can also be attributed to high levels of automobile emissions (known to contain high levels of it relative to other PAHs) [47] [48]. B(ghi)P is strongly adsorbed to sediment organic matter as its high molecular weight (HMW) renders it resistant to microbial and photo-degradation [49]-[51], so it is expected that greater concentrations of HMW-PAHs are detected during the hot season.

There are significant differences in the concentration of PAHs among studies macrophytes (**Figure 2**). These differences may be related to the nature of the growth substrate for studied macrophytes, tolerance to environmental conditions for each species, lipid components of plant and surface area that affect the rate of interception and accumulation of PAHs [52]-[54]. Elevated temperature and photic levels (such as during summer) contribute to elevated PAH photo-degradation and can affect the uptake of pollutants in plants as a result, higher concentrations have been recorded during the cold season than the hot season [55].

The PAH origin in the aquatic plants is pyrogenic (**Tables 7-10**); Al-Hilla River is surrounded by oil fields with flared gas, and crude oil residues and automotive exhaust. Petroleum spills were not evident during the study period. In addition to pyrogenic origin, Al-Taee [56] and Hassan *et al*. [22] identified petrogenic.

The accumulation of environmental pollution in living organisms is estimated by BCF. The BCF in the aquatic environment is calculated as the ratio of the xenobiotic concentration in the organism to its concentration in the medium [57] [58]. BCF depends on the presence of other organisms or pollutants in the medium and on the contents of lipids in living cells [59]. A greater content of lipids in the organisms causes an increase of the BCF for hydrophobic hydrocarbons and also increases the cytotoxic activity [57].

BCF ranged from 0.05 - 5664.5 for Acp and B(a)P at Sites 4 and 1, respectively for *P. australis* and 0.01 - 1241 for Acp and B(a)P at Sites 6 and 2 respectively in *P. pectinatus*. BCF ranges in *P. perfoliatus* 0.08 - 1602 for Ant and B(a)P at Sites 6 and 1, respectively. BCF in *C. demersum* ranged from 0.16 - 1141.3 for B(b)F and B(a)P at Sites 5 and 2, respectively. The BSAF ranged from 3.14 - 1041 for Acp and Acpy at Sites 6 and 1, respectively, for *P. australis*, and in *P. pectinatus* ranged from 1.51 for Phe at Site 6 and 976.7 for Ind at Site 6. The differentiation in results may be due to a combination of plant species, lipid content or surface area in contact with water and sediment [5] [60].

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