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Evaluation of Trace Metals Uptake by Some Plants Close to Some Industrial Zones in Khartoum City

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Abstract
The study aimed to evaluate the uptake of trace metals by the tissues of some plants which grow inside, or in the peripheries of, pools of water contaminated by waste water from neighboring industrial complexes in Khartoum City. It also aimed to verify the possibility of making use of this phenomenon in combating metal pollution in water and wastewater catchments. The flame atomic absorption spectrophotometry (FAAS) was used to find the concentration of the subject metals in waste water and algal biomass of the phyla Chlorophyta, Cyanophyta, and Bacillariophyta; and in newly grown leaves of *Calotropis procera* in addition to their stems and roots. The physical parameters studied were pH and electrical conductivity (EC) of waste water. The metals studied in waste water, algal biomass and *C. procera* were Fe, Zn, Cd, Pb, Cu, Ni, and Cr. The study covered during summer and autumn 6 sites in Khartoum city industrial complexes. Samples were collected, and analyzed for TMs concentration levels. The algal biomass was found to be more efficient for TMs uptake and accumulation than the three parts of *C. procera*. Among the parts of *C. procera*, the root was more efficient for TMs uptake than the leaf, while the stem was the least efficient.

***Keywords**:* Trace metals; Pollution; Industrial zones; Khartoum city.

Introduction

Since the Industrial Revolution, the efforts of removing man-made pollutants from the natural environment have been unable to keep pace with the increasing amount of waste materials and a growing population that further aggravates the situation [1]. As the number of ecological and health problems associated with environmental contamination continues to rise, there is considerable interest in the development of biologically derived materials for reclamation and remediation of contaminated sites. These biomass materials can also serve as a means of preventing pollution via treatment of industrial waste streams before their introduction into the environment [2]. The biosorption of metals by algae and other organisms has been of interest for a variety of reasons, including concern over potentially toxic trace metal accumulation in the food chain, metal recovery techniques from process and industrial streams, contaminated water treatment methods, radionuclide cleanup procedures, and precious metal recovery methods [3]. In recent years, immobilized organisms are being widely used for metal ions preconcentration because of the advantages for matrices isolation in flow analysis, low resistance to fluid flow, self-supporting rigidity, excellent durability, easy regeneration and recovery of metal [4]. Either living or nonliving microorganisms, such as yeast, fungi, bacteria, and algae are capable of accumulating metals from aqueous solutions by different chemical and biological mechanism [5]. Many algae have immense capability to sorb metals, and there is considerable potential for using them to treat

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wastewaters [6]. Algae cells are capable of adsorbing different metals from a variety of solution environments. This biosorption phenomena has been the subject of increased research activity for a variety of reasons, including the use of the biomass for metal reclamation and remediation of industrial streams, toxic trace metal accumulation in the food chain and analytical applications for trace metal analysis. Evidence suggests that an ion-exchange mechanism accounts for the majority of metal adsorption; however, covalent bonding may also play a role. Different functional groups on the algae cell wall may be responsible for metal adsorption. Also, the quantity and type of binding sites may be metal dependent [7]. The uptake of trace metals from any sample matrix is pH-dependent [8]. Highly selective ion-exchanger has achieved sharp separations of metal ions without the addition of complexing reagents to the eluent and to concentrate traces of metals from large volumes of very dilute solutions [9].

Phytoremediation is a method for *in situ* clean up of contaminated soil. Green plants play a major role in achieving this goal. Phytoextraction present direct uptake of heavy metals by plants and their translocation to above ground biomass [10-12]. Metals discharged in wastes from different industries into wetland ecosystems pose a serious threat to the receiving environment. Biotic components grown in the area amass such metals within their body through nutritional uptake and accumulation [13]. The presence of toxic metals such as Pb and Cd in the environment has been a source of worry to environmentalists, government agencies and health practitioners. This is mainly due to their health implications since they are non-essential metals of no benefit to humans [14]. Despite the fact that the technology also suffers inherent disadvantages like early saturation of biomass, little biological control over the characteristics of biosorbents. It offers several advantages including cost effectiveness, high efficiency, minimization of chemical/biological sludge, and regeneration of biosorbent with possibility of metal recovery [15]. The uptake of element by plants depends upon the type of soil and the concentration of available elements [16]. The bioconcentration factor indicates that the roots of the vegetables concentrate most of the metals than the leaves [17]. The presence metal ions in plant leaves explain the fact that these plant leaves are good bioindicators and can be used in air pollution monitoring studies in industrial areas [18]. Various single extractants method were used to evaluate the immobilization of Cd in contaminated acidic paddy soil by different amendments [19].The high uptake potential of heavy metals by the wetland plants could be used in heavy metal mop up in environmental management of heavy metal pollution [20]. This research examines the trace metal uptake of algae and *Calotropis procera* from contaminated water in some industrial zones in Khartoum city.

Material and Method

The area of study

The contaminated water in streams and the plant species studied originate from the industrial compounds, located in Khartoum city (Kh.) in Sudan. The contaminated water stream run through the densely populated cities and drains into the River Nile and its branches, White and Blue Nile. The contaminated streams collect massive quantities of effluent and domestic waste products. The contaminated streams are the sink for contaminated water from several washing places, laundries, factories, as well as discharges of diesel and other automobile waste liquids from garages, workshops, etc. A large number of side streams also empty their waste load in the main streams. Description of sampling locations in the three cities of Khartoum State as shown in the (Table 1).

Table 1. **Description of Sampling Locations in Khartoum Industrial Area.**

Location Site	Description of Site
Site (1)	Stream of contaminated water close to a factory for metal coins industries in the south part of the industrial area
Site (2)	Stream of contaminated water close to workshops and a company for tyres and spare parts.
Site (3)	Stream of contaminated water close to workshops for car repairs, and a company for spare parts.
Site (4)	Stream of contaminated water close to workshops for car repairs, company for sales of spare parts, and engineering company.
Site (5)	Stream of contaminated water close to garage for cars, workshops for car repairs and maintenance.
Site (6)	Stream of contaminated water close to a factory for manufacturing paints and a factory for soft drinks industries.

Methodology

The research methodology involved field tests as well as laboratory analysis. The analyzed parameters include pH, electrical conductivity (EC), iron (Fe), zinc (Zn), cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu), and chromium (Cr).

Collection of samples

The most common plant species found close to the industrial compounds in Khartoum State are: *Calatropis procera* and algae biomass which are mixed of several species but mainly of four divisions (Chlorophyta, Cyanophyta, Euglnophyta and Bacillariophyta). All these samples were collected in precleaned polyethylene bags, and the samples of contaminated water from the areas under study were collected in the precleaned polyethylene bottles. The precleaned containers were taken to the sampling points and filled with unfiltered water samples up to the mouth of the bottle to prevent the formation of air bubbles. The contaminated water in polyethylene bottles were acidified with few drops of conc. HNO_3 to prevent plating of metals on the wall of the container. Algae biomasses were washed three times with distilled deionized water. The plant samples were spread on polyethylene bags, covered with plastic sheets, and air dried. The dried samples were ground in a porcelain mortar to fine powder and stored in polyethylene bags to avoid spoiling, degradation or other decomposition as contamination. All samples were collected during the dry season, and compared with rainy season in order to compare and study the variation of the trace metals uptake efficiency by these plant species selected. Six separate sets of samples *calatropis procera* (roots, stems, and leaves), algae biomass, and contaminated water were collected from Khartoum industrial area.

pH -Measurements of the contaminated water

The pH measurements of contaminated water samples from different sites of industrial area in Khartoum City were measured immediately after collection using the pH-meter (model: Wagtech International, SN 198389, UK) for dry and rainy seasons.

EC -Measurements of the contaminated water

The EC measurements of contaminated water samples from different sites of industrial area in Khartoum city were measured immediately after collection using the EC-meter (model: HANNA instrument) for dry and rainy seasons. Tables (19 - 21) give the range of the EC measurements of contaminated water for the two season (dry and rainy).

Chemicals and reagents

All chemicals and reagents used in this study were of analytical grade.

AAS- Measurements for trace metals in samples

Standard solutions and optical parameters for AAS

The trace metals concentrations in samples were measured by using AAS (model AAS-6800, Shimadzu, Japan). Stock solutions of concentration of 1000 ppm of Fe, Zn, Cd, Pb, Cu, Ni, and Cr were already prepared.

Optical parameters and preparation of standard curves

Series of standard solutions of trace metals were prepared by suitable dilutions of the stock solution in concentrations that were expected in the sample solution. The instrument setting was optimized for each element to be measured as in (Table 2).

Table 2. **Optical Parameters of AAS used for determination of Trace Metals in Samples.**

Trace Metals	Wavelength of Spectral Line (nm)	Hallow-cathode lamp current (mA)	Slit Width (nm)	Flame Type
Fe	248.3	12	0.2	air-acetylene
Zn	213.9	8	0.5	air-acetylene
Cd	228.8	8	1.0	air-acetylene
Pb	217.0	10	1.0	air-acetylene
Cu	324.8	6	1.0	air-acetylene
Ni	232.0	12	0.2	air-acetylene
Cr	357.9	8	5.0	air-acetylene

A calibration curve for each element was obtained by plotting the absorbance against the concentration of standard solutions. The curve used to determine the concentration of specific element in the sample solution showing the absorbance-concentration relationships and calibration curves for the elements under investigation.

Preparation of contaminated water samples for analysis

A 20.0 ml of contaminated water sample were placed in beaker. Then 5.0 ml of conc. HNO_3 were added. The mixture was then swirled gently and then transferred to a 25.0 ml volumetric flask and completed to the mark by water sample, and then transferred to polyethylene container.

AAS- Measurements of contaminated water sample

A blank solution was also prepared in the same way as the sample solution of contaminated water using distilled deionized water. The net absorbance of the analyte in the sample solution was obtained by subtracting the absorbance of the analyte in the blank solution from that of the analyte in the sample solution. The metal ion concentrations were read on AAS.

Preparation of sample extracts

In order to bring the dried powder samples into solution, wet digestion method was used. A 1.0 g of the dried plant powder samples were weighed accurately in a small beaker, and then covered with a watch glass. 30.0 ml of conc. HNO_3 were added and the mixture was allowed to stand at room temperature until initial reaction subsided, and then heated on a sand bath until the production of brown NO_2 fumes ceased. The solution was then cooled and 10.0 ml of conc. $HClO_4$ were added and heating continued until almost half of the volume was evaporated. The solution was set aside to cool, a pale yellow or colourless solution was obtained, and diluted. The watch glass washed with distilled deionized water three times in a beaker as well as the beaker side. This solution was filtered in 25.0 ml volumetric flask and completed to the mark with distilled deionized water, and transferred to a polyethylene container [21].

AAS- Measurements of plant

A blank solution for samples was also prepared in the same way as the sample solution . The net absorbance of the analyte in the sample solution was obtained by subtracting the absorbance of the analyte in blank solution from that of the analyte in the sample solution. The metal ion concentrations of plant samples were read on AAS. The results of effects of pH and EC of contaminated water on TMs uptake by plant species of industrial area Khartoum city were summarized in (Tables 3-9) and (Fig. 1-3) for the two seasons (dry and rainy).

Results and Discussion

Plant species selected, namely mixed species of algae biomass and *calotropis procera*, as they are the most common and dominant species at these sites. The study was conducted in 6 sites distributed along the industrial area in Khartoum city. Digestion with concentrated nitric acid HNO_3 and perchloric acid $HClO_4$ was the most adequate pretreatment for solubilization of TMs in plant samples [21]. The results show that the contaminated water collected from the industrial area were of high TMs concentrations. In Khartoum Industrial Area, the TMs concentrations measured in the contaminated water generally decreased as follows: Fe > Ni > Cr > Zn > Pb > Cu > Cd, and the general decreasing order in plant species : Fe > Zn > Pb > Cu > Cr > Ni > Cd for the dry season (Tables 3-9), and the general order of decreasing for the rainy season in the industrial area for contaminated water as follows: Fe > Cd > Cu >Pb > Zn > Ni > Cd, compared to the general order of decreasing in plant species: Fe > Zn > Cu > Pb > Cr > Ni > Cd. In the present study, the pH and EC of contaminated water were considered to be important factors influencing the bioavailability of TMs and their uptake by the plant species. The pH of contaminated water in Khartoum Industrial Area changed seasonally from the dry to rainy season respectively. As a whole, there was a general increase in the pH in the rainy season, this was due to the increase in the alkaline property in water by the action of leaching behaviour of rainfall.

Table 3. **Effects of pH and EC on Fe (ppm) Uptake by Different Plant species of the Two Seasons (Dry and Rainy) Collected from Khartoum Industrial Area.**

Sample	Location Sites	Fe (in ppm)/ pH / EC-measurements(mS/cm)					
		Dry Season			Rainy Season		
		Fe	*pH*	*EC*	*Fe*	*pH*	*EC*
Contamind. Water	Site 1	1.60	7.54	6.23	0.23	7.38	8.45
	Site 2	1.73	7.07	6.62	0.29	7.10	7.81
	Site 3	1.84	9.66	6.65	0.14	7.22	10.14
	Site 4	2.16	9.32	5.63	0.41	8.74	8.49
	Site 5	1.99	6.68	2.73	0.22	8.63	8.39
	Site 6	1.53	7.87	4.80	0.40	8.72	8.78
Mean		1.81 ± 0.24	8.08	5.44	0.28 ± 0.11	7.97	8.68
Algae (Mixed sp.)	Site 1	2.92×10^3	7.54	6.23	2.09×10^3	7.38	8.45
	Site 2	3.01×10^3	7.07	6.62	1.88×10^3	7.10	7.81
	Site 3	3.95×10^3	9.66	6.65	1.84×10^3	7.22	10.14
	Site 4	3.86×10^3	9.32	5.63	1.32×10^3	8.74	8.49
	Site 5	2.60×10^3	6.68	2.73	2.22×10^3	8.63	8.39
	Site 6	3.26×10^3	7.87	4.80	1.45×10^3	8.72	8.78
Mean		$(3.27\pm0.54)10^3$	8.08	5.44	$(1.80\pm0.54)10^3$	7.97	8.68
C. procera (Roots)	Site 1	2.92×10^2	7.54	6.23	3.21×10^2	7.38	8.45
	Site 2	2.53×10^2	7.07	6.62	4.52×10^2	7.10	7.81
	Site 3	1.65×10^2	9.66	6.65	4.81×10^2	7.22	10.14
	Site 4	3.00×10^2	9.32	5.63	2.55×10^3	8.74	8.49
	Site 5	2.44×10^2	6.68	2.73	4.58×10^2	8.63	8.39
	Site 6	1.78×10^2	7.87	4.80	7.34×10^2	8.72	8.78
Mean		$(2.39\pm0.56)10^2$	8.08	5.44	$(4.50\pm1.56)10^2$	7.97	8.68
C. procera (Stems)	Site 1	1.60×10^2	7.54	6.23	1.92×10^2	7.38	8.45
	Site 2	1.81×10^2	7.07	6.62	2.77×10^2	7.10	7.81
	Site 3	4.70×10^2	9.66	6.65	1.33×10^2	7.22	10.14
	Site 4	2.12×10^2	9.32	5.63	0.83×10^2	8.74	8.49
	Site 5	2.61×10^2	6.68	2.73	0.57×10^2	8.63	8.39
	Site 6	0.81×10^2	7.87	4.80	0.74×10^2	8.72	8.78
Mean		$(2.28\pm1.33)10^2$	8.08	5.44	$(1.36\pm0.85)10^2$	7.97	8.68
C. procera (Leaves)	Site 1	2.08×10^2	7.54	6.23	0.89×10^2	7.38	8.45
	Site 2	2.94×10^2	7.07	6.62	1.36×10^2	7.10	7.81
	Site 3	3.02×10^2	9.66	6.65	0.44×10^2	7.22	10.14
	Site 4	1.89×10^2	9.32	5.63	1.25×10^2	8.74	8.49
	Site 5	2.99×10^2	6.68	2.73	0.80×10^2	8.63	8.39
	Site 6	1.03×10^2	7.87	4.80	0.73×10^2	8.72	8.78
Mean		$(2.33\pm0.80)10^2$	8.08	5.44	$(0.91\pm0.34)10^2$	7.97	8.68

The values of metal uptake reported as mean ± Standard deviation

Table 4. **Effects of pH and EC on Zn (ppm) Uptake by Different Plant species of the Two Seasons(Dry and Rainy)Collected from Khartoum Industrial Area.**

Sample	Location Sites	Zn (in ppm)/ pH / EC-measurements(mS/cm)					
		Dry Season			Rainy Season		
		Zn	***pH***	***EC***	***Zn***	***pH***	***EC***
Contamind. Water	Site 1	0.03	7.54	6.23	0.06	7.38	8.45
	Site 2	0.25	7.07	6.62	0.02	7.10	7.81
	Site 3	0.12	9.66	6.65	0.02	7.22	10.14
	Site 4	0.20	9.32	5.63	0.03	8.74	8.49
	Site 5	0.08	6.68	2.73	0.03	8.63	8.39
	Site 6	0.04	7.87	4.80	0.02	8.72	8.78
Mean		0.12± 0.09	8.08	5.44	0.03± 0.01	7.97	8.68
Algae (Mixed sp.)	Site 1	5.56	7.54	6.23	7.78	7.38	8.45
	Site 2	16.6	7.07	6.62	8.28	7.10	7.81
	Site 3	12.4	9.66	6.65	8.17	7.22	10.14
	Site 4	11.0	9.32	5.63	6.94	8.74	8.49
	Site 5	17.8	6.68	2.73	5.97	8.63	8.39
	Site 6	7.76	7.87	4.80	9.11	8.72	8.78
Mean		11.9± 4.80	8.08	5.44	7.71± 1.11	7.97	8.68
C. procera (Roots)	Site 1	2.37	7.54	6.23	1.69	7.38	8.45
	Site 2	1.05	7.07	6.62	3.87	7.10	7.81
	Site 3	1.42	9.66	6.65	4.37	7.22	10.14
	Site 4	1.33	9.32	5.63	4.08	8.74	8.49
	Site 5	0.57	6.68	2.73	7.62	8.63	8.39
	Site 6	2.68	7.87	4.80	3.64	8.72	8.78
Mean		1.57± 0.80	8.08	5.44	4.21± 1.92	7.97	8.68
C. procera (Stems)	Site 1	0.83	7.54	6.23	1.33	7.38	8.45
	Site 2	0.99	7.07	6.62	1.71	7.10	7.81
	Site 3	2.95	9.66	6.65	2.38	7.22	10.14
	Site 4	2.12	9.32	5.63	0.79	8.74	8.49
	Site 5	1.02	6.68	2.73	2.01	8.63	8.39
	Site 6	2.15	7.87	4.80	3.00	8.72	8.78
Mean		1.68± 0.86	8.08	5.44	1.87± 0.78	7.97	8.68
C. procera (Leaves)	Site 1	2.06	7.54	6.23	1.15	7.38	8.45
	Site 2	1.78	7.07	6.62	1.41	7.10	7.81
	Site 3	1.46	9.66	6.65	1.78	7.22	10.14
	Site 4	2.29	9.32	5.63	1.37	8.74	8.49
	Site 5	1.54	6.68	2.73	2.01	8.63	8.39
	Site 6	2.00	7.87	4.80	1.47	8.72	8.78
Mean		1.86± 0.32	8.08	5.44	1.53± 0.31	7.97	8.68

The values of metal uptake reported as mean ± Standard deviation

***Table 5*. Effects of pH and EC on Cd (ppm) Uptake by Different Plant species of the Two Seasons (Dry and Rainy) Collected from Khartoum Industrial Area.**

Sample	Location Sites	Cd (in ppm)/ pH / EC-measurements (mS/cm)					
		Dry Season			Rainy Season		
		Cd	*pH*	*EC*	*Cd*	*pH*	*EC*
Contamind. Water	Site 1	0.5×10^{-2}	7.54	6.23	7×10^{-2}	7.38	8.45
	Site 2	0.7×10^{-2}	7.07	6.62	4×10^{-2}	7.10	7.81
	Site 3	0.6×10^{-2}	9.66	6.65	2×10^{-2}	7.22	10.14
	Site 4	0.5×10^{-2}	9.32	5.63	4×10^{-2}	8.74	8.49
	Site 5	0.7×10^{-2}	6.68	2.73	1×10^{-2}	8.63	8.39
	Site 6	0.4×10^{-2}	7.87	4.80	7×10^{-2}	8.72	8.78
Mean		$(0.6\pm0.1)10^{-2}$	8.08	5.44	$(4\pm2.7)10^{-2}$	7.97	8.68
Algae (Mixed sp.)	Site 1	1.3×10^{-2}	7.54	6.23	5×10^{-2}	7.38	8.45
	Site 2	2.2×10^{-2}	7.07	6.62	5×10^{-2}	7.10	7.81
	Site 3	2.9×10^{-2}	9.66	6.65	5×10^{-2}	7.22	10.14
	Site 4	1.9×10^{-2}	9.32	5.63	4×10^{-2}	8.74	8.49
	Site 5	2.6×10^{-2}	6.68	2.73	4×10^{-2}	8.63	8.39
	Site 6	2.3×10^{-2}	7.87	4.80	8×10^{-2}	8.72	8.78
Mean		$(2.2\pm 0.56)10^{-2}$	8.08	5.44	$(5.2\pm1.64)10^{-2}$	7.97	8.68
C. procera (Roots)	Site 1	1.1×10^{-2}	7.54	6.23	31×10^{-2}	7.38	8.45
	Site 2	0.8×10^{-2}	7.07	6.62	5×10^{-2}	7.10	7.81
	Site 3	0.9×10^{-2}	9.66	6.65	4×10^{-2}	7.22	10.14
	Site 4	0.9×10^{-2}	9.32	5.63	2×10^{-2}	8.74	8.49
	Site 5	1.1×10^{-2}	6.68	2.73	24×10^{-2}	8.63	8.39
	Site 6	1×10^{-2}	7.87	4.80	4×10^{-2}	8.72	8.78
Mean		$(1.0\pm0.12)10^{-2}$	8.08	5.44	$(12\pm 1.26)10^{-2}$	7.97	8.68
C. procera (Stems)	Site 1	1.5×10^{-2}	7.54	6.23	6×10^{-2}	7.38	8.45
	Site 2	1.6×10^{-2}	7.07	6.62	4×10^{-2}	7.10	7.81
	Site 3	0.9×10^{-2}	9.66	6.65	4×10^{-2}	7.22	10.14
	Site 4	1.9×10^{-2}	9.32	5.63	5×10^{-2}	8.74	8.49
	Site 5	2.7×10^{-2}	6.68	2.73	8×10^{-2}	8.63	8.39
	Site 6	0.9×10^{-2}	7.87	4.80	3×10^{-2}	8.72	8.78
Mean		$(1.6\pm0.68)10^{-2}$	8.08	5.44	$(5\pm 1.78)10^{-2}$	7.97	8.68
C. procera (Leaves)	Site 1	1.6×10^{-2}	7.54	6.23	11×10^{-2}	7.38	8.45
	Site 2	1.6×10^{-2}	7.07	6.62	2×10^{-2}	7.10	7.81
	Site 3	1.8×10^{-2}	9.66	6.65	4×10^{-2}	7.22	10.14
	Site 4	1.9×10^{-2}	9.32	5.63	3×10^{-2}	8.74	8.49
	Site 5	1.2×10^{-2}	6.68	2.73	8×10^{-2}	8.63	8.39
	Site 6	1.6×10^{-2}	7.87	4.80	4×10^{-2}	8.72	8.78
Mean		$(1.6\pm0.24)10^{-2}$	8.08	5.44	$(5\pm3.44)10^{-2}$	7.97	8.68

The values of metal uptake reported as mean ± Standard deviation

Table 6). **Effects of pH and EC on Pb (ppm) Uptake by Different Plant species of the Two Seasons (Dry and Rainy) Collected from Khartoum Industrial Area.**

Sample	Location Sites	Pb (in ppm)/ pH / EC-measurements(mS/cm)					
		Dry Season			Rainy Season		
		Pb	pH	EC	Pb	pH	EC
Contamind. Water	Site 1	0.06	7.54	6.23	0.04	7.38	8.45
	Site 2	0.06	7.07	6.62	0.03	7.10	7.81
	Site 3	0.04	9.66	6.65	0.02	7.22	10.14
	Site 4	0.06	9.32	5.63	0.04	8.74	8.49
	Site 5	0.05	6.68	2.73	0.01	8.63	8.39
	Site 6	0.04	7.87	4.80	0.04	8.72	8.78
Mean		0.05±0.01	8.08	5.44	0.03±0.01	7.97	8.68
Algae (Mixed sp.)	Site 1	1.01	7.54	6.23	1.88	7.38	8.45
	Site 2	3.85	7.07	6.62	6.90	7.10	7.81
	Site 3	3.66	9.66	6.65	6.99	7.22	10.14
	Site 4	2.49	9.32	5.63	5.14	8.74	8.49
	Site 5	4.65	6.68	2.73	2.54	8.63	8.39
	Site 6	2.02	7.87	4.80	3.47	8.72	8.78
Mean		2.95±1.34	8.08	5.44	4.49±2.20	7.97	8.68
C. procera (Roots)	Site 1	0.29	7.54	6.23	0.23	7.38	8.45
	Site 2	1.87	7.07	6.62	3.73	7.10	7.81
	Site 3	0.46	9.66	6.65	1.82	7.22	10.14
	Site 4	0.17	9.32	5.63	1.83	8.74	8.49
	Site 5	0.03	6.68	2.73	5.73	8.63	8.39
	Site 6	0.13	7.87	4.80	1.17	8.72	8.78
Mean		0.49±0.17	8.08	5.44	2.42±1.98	7.97	8.68
C. procera (Stems)	Site 1	0.14	7.54	6.23	0.17	7.38	8.45
	Site 2	2.07	7.07	6.62	1.46	7.10	7.81
	Site 3	0.65	9.66	6.65	0.55	7.22	10.14
	Site 4	0.17	9.32	5.63	0.18	8.74	8.49
	Site 5	0.12	6.68	2.73	0.25	8.63	8.39
	Site 6	0.15	7.87	4.80	0.13	8.72	8.78
Mean		0.55±0.23	8.08	5.44	0.46±0.17	7.97	8.68
C. procera (Leaves)	Site 1	0.05	7.54	6.23	0.17	7.38	8.45
	Site 2	4.29	7.07	6.62	1.05	7.10	7.81
	Site 3	0.29	9.66	6.65	0.19	7.22	10.14
	Site 4	0.17	9.32	5.63	0.15	8.74	8.49
	Site 5	0.14	6.68	2.73	0.11	8.63	8.39
	Site 6	0.15	7.87	4.80	0.21	8.72	8.78
Mean		0.85±0.09	8.08	5.44	0.31±0.04	7.97	8.68

The values of metal uptake reported as mean ± Standard deviation

***Table 7.* Effects of pH and EC on Cu (ppm) Uptake by Different Plant species of the Two Seasons (Dry and Rainy) Collected from Khartoum Industrial Area.**

Sample	Location Sites	Cu (in ppm) / pH / EC-measurements (mS/cm)					
		Dry Season			Rainy Season		
		Cu	***pH***	***EC***	***Cu***	***pH***	***EC***
Contamind. Water	Site 1	0.01	7.54	6.23	0.03	7.38	8.45
	Site 2	0.01	7.07	6.62	0.04	7.10	7.81
	Site 3	0.03	9.66	6.65	0.02	7.22	10.14
	Site 4	0.03	9.32	5.63	0.04	8.74	8.49
	Site 5	0.03	6.68	2.73	0.05	8.63	8.39
	Site 6	0.02	7.87	4.80	0.03	8.72	8.78
Mean		0.02± 0.01	8.08	5.44	0.04± 0.01	7.97	8.68
Algae (Mixed sp.)	Site 1	1.96	7.54	6.23	4.18	7.38	8.45
	Site 2	1.91	7.07	6.62	3.84	7.10	7.81
	Site 3	2.89	9.66	6.65	3.72	7.22	10.14
	Site 4	2.39	9.32	5.63	2.67	8.74	8.49
	Site 5	5.26	6.68	2.73	1.82	8.63	8.39
	Site 6	1.99	7.87	4.80	2.10	8.72	8.78
Mean		2.73± 1.29	8.08	5.44	3.06± 0.99	7.97	8.68
C. procera (Roots)	Site 1	0.62	7.54	6.23	0.57	7.38	8.45
	Site 2	0.32	7.07	6.62	0.82	7.10	7.81
	Site 3	0.41	9.66	6.65	1.56	7.22	10.14
	Site 4	0.40	9.32	5.63	6.03	8.74	8.49
	Site 5	0.20	6.68	2.73	1.02	8.63	8.39
	Site 6	0.37	7.87	4.80	0.78	8.72	8.78
Mean		0.39± 0.14	8.08	5.44	1.80± 0.38	7.97	8.68
C. procera (Stems)	Site 1	0.44	7.54	6.23	0.72	7.38	8.45
	Site 2	0.45	7.07	6.62	0.64	7.10	7.81
	Site 3	0.84	9.66	6.65	0.51	7.22	10.14
	Site 4	0.75	9.32	5.63	0.21	8.74	8.49
	Site 5	0.41	6.68	2.73	0.43	8.63	8.39
	Site 6	0.43	7.87	4.80	0.41	8.72	8.78
Mean		0.55± 0.19	8.08	5.44	0.49± 0.18	7.97	8.68
C. procera (Leaves)	Site 1	0.53	7.54	6.23	0.45	7.38	8.45
	Site 2	0.28	7.07	6.62	0.38	7.10	7.81
	Site 3	0.67	9.66	6.65	0.36	7.22	10.14
	Site 4	0.42	9.32	5.63	0.39	8.74	8.49
	Site 5	0.41	6.68	2.73	0.25	8.63	8.39
	Site 6	0.40	7.87	4.80	0.31	8.72	8.78
Mean		0.45± 0.13	8.08	5.44	0.36± 0.07	7.97	8.68

The values of metal uptake reported as mean ± Standard deviation

Table 8. **Effects of pH and EC on Ni (ppm) Uptake by Different Plant species of the Two Seasons (Dry and Rainy) Collected from Khartoum Industrial Area**

Sample	Location Sites	Ni (in ppm)/ pH / EC-measurements(mS/cm)					
		Dry Season			Rainy Season		
		Ni	***pH***	***EC***	***Ni***	***pH***	***EC***
Contamind. Water	Site 1	0.26	7.54	6.23	0.01	7.38	8.45
	Site 2	0.07	7.07	6.62	0.04	7.10	7.81
	Site 3	0.09	9.66	6.65	0.03	7.22	10.14
	Site 4	0.33	9.32	5.63	0.02	8.74	8.49
	Site 5	0.35	6.68	2.73	0.03	8.63	8.39
	Site 6	0.24	7.87	4.80	0.01	8.72	8.78
Mean		0.23± 0.12	8.08	5.44	0.02± 0.01	7.97	8.68
Algae (Mixed sp.)	Site 1	1.09	7.54	6.23	1.33	7.38	8.45
	Site 2	1.11	7.07	6.62	1.26	7.10	7.81
	Site 3	1.22	9.66	6.65	1.27	7.22	10.14
	Site 4	0.83	9.32	5.63	0.77	8.74	8.49
	Site 5	1.13	6.68	2.73	1.40	8.63	8.39
	Site 6	1.01	7.87	4.80	1.11	8.72	8.78
Mean		1.06± 0.13	8.08	5.44	1.19± 0.23	7.97	8.68
C. procera (Roots)	Site 1	0.38	7.54	6.23	0.31	7.38	8.45
	Site 2	0.34	7.07	6.62	0.24	7.10	7.81
	Site 3	0.28	9.66	6.65	0.31	7.22	10.14
	Site 4	0.31	9.32	5.63	1.20	8.74	8.49
	Site 5	0.32	6.68	2.73	0.47	8.63	8.39
	Site 6	0.35	7.87	4.80	0.44	8.72	8.78
Mean		0.33± 0.03	8.08	5.44	0.50± 0.36	7.97	8.68
C. procera (Stems)	Site 1	0.25	7.54	6.23	8.45	7.38	8.45
	Site 2	0.11	7.07	6.62	0.22	7.10	7.81
	Site 3	0.31	9.66	6.65	0.68	7.22	10.14
	Site 4	0.11	9.32	5.63	0.04	8.74	8.49
	Site 5	0.07	6.68	2.73	0.06	8.63	8.39
	Site 6	0.28	7.87	4.80	0.29	8.72	8.78
Mean		0.19± 0.10	8.08	5.44	1.62± 0.25	7.97	8.68
C. procera (Leaves)	Site 1	0.32	7.54	6.23	0.11	7.38	8.45
	Site 2	0.14	7.07	6.62	0.09	7.10	7.81
	Site 3	0.15	9.66	6.65	0.11	7.22	10.14
	Site 4	0.12	9.32	5.63	0.70	8.74	8.49
	Site 5	0.22	6.68	2.73	0.26	8.63	8.39
	Site 6	0.22	7.87	4.80	0.78	8.72	8.78
Mean		0.20± 0.07	8.08	5.44	0.34± 0.31	7.97	8.68

The values of metal uptake reported as mean ± Standard deviation

***Table 9*. Effects of pH and EC on Cr (ppm) Uptake by Different Plant species of the Two Seasons (Dry and Rainy) Collected from Khartoum Industrial Area.**

Sample	Location Sites	Cr (in ppm)/ pH / EC-measurements (mS/cm)					
		Dry Season			Rainy Season		
		Cr	***pH***	***EC***	***Cr***	***pH***	***EC***
Contamind. Water	Site 1	0.23	7.54	6.23	0.04	7.38	8.45
	Site 2	0.25	7.07	6.62	0.01	7.10	7.81
	Site 3	0.20	9.66	6.65	0.01	7.22	10.14
	Site 4	0.18	9.32	5.63	0.01	8.74	8.49
	Site 5	0.26	6.68	2.73	0.02	8.63	8.39
	Site 6	0.02	7.87	4.80	0.02	8.72	8.78
Mean		0.19± 0.08	8.08	5.44	0.02± 0.01	7.97	8.68
Algae (Mixed sp.)	Site 1	1.49	7.54	6.23	2.77	7.38	8.45
	Site 2	1.69	7.07	6.62	2.90	7.10	7.81
	Site 3	1.93	9.66	6.65	2.82	7.22	10.14
	Site 4	1.82	9.32	5.63	2.28	8.74	8.49
	Site 5	1.93	6.68	2.73	2.07	8.63	8.39
	Site 6	1.73	7.87	4.80	2.27	8.72	8.78
Mean		1.77± 0.17	8.08	5.44	2.52± 0.35	7.97	8.68
C. procera (Roots)	Site 1	0.96	7.54	6.23	0.53	7.38	8.45
	Site 2	1.05	7.07	6.62	0.56	7.10	7.81
	Site 3	0.84	9.66	6.65	0.73	7.22	10.14
	Site 4	0.76	9.32	5.63	3.23	8.74	8.49
	Site 5	0.62	6.68	2.73	0.79	8.63	8.39
	Site 6	0.65	7.87	4.80	0.92	8.72	8.78
Mean		0.82± 0.17	8.08	5.44	1.13± 0.18	7.97	8.68
C. procera (Stems)	Site 1	0.20	7.54	6.23	0.41	7.38	8.45
	Site 2	0.21	7.07	6.62	0.41	7.10	7.81
	Site 3	0.34	9.66	6.65	0.18	7.22	10.14
	Site 4	0.25	9.32	5.63	0.12	8.74	8.49
	Site 5	0.23	6.68	2.73	0.05	8.63	8.39
	Site 6	0.17	7.87	4.80	0.09	8.72	8.78
Mean		0.23± 0.06	8.08	5.44	0.21± 0.16	7.97	8.68
C. procera (Leaves)	Site 1	0.21	7.54	6.23	0.16	7.38	8.45
	Site 2	0.25	7.07	6.62	0.19	7.10	7.81
	Site 3	0.32	9.66	6.65	0.08	7.22	10.14
	Site 4	0.21	9.32	5.63	0.10	8.74	8.49
	Site 5	0.25	6.68	2.73	0.09	8.63	8.39
	Site 6	0.17	7.87	4.80	0.07	8.72	8.78
Mean		0.24± 0.05	8.08	5.44	0.12± 0.05	7.97	8.68

The values of metal uptake reported as mean ± Standard deviation

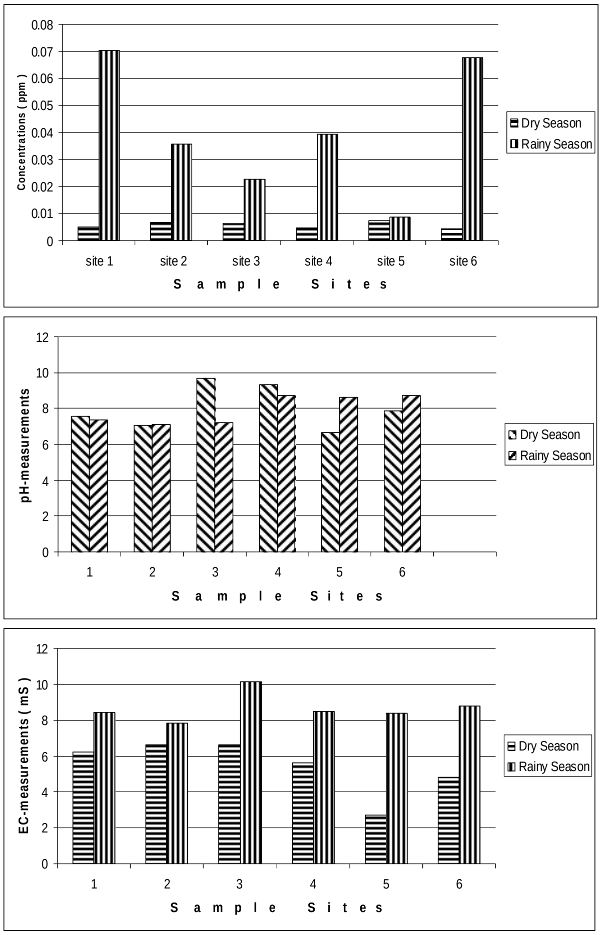
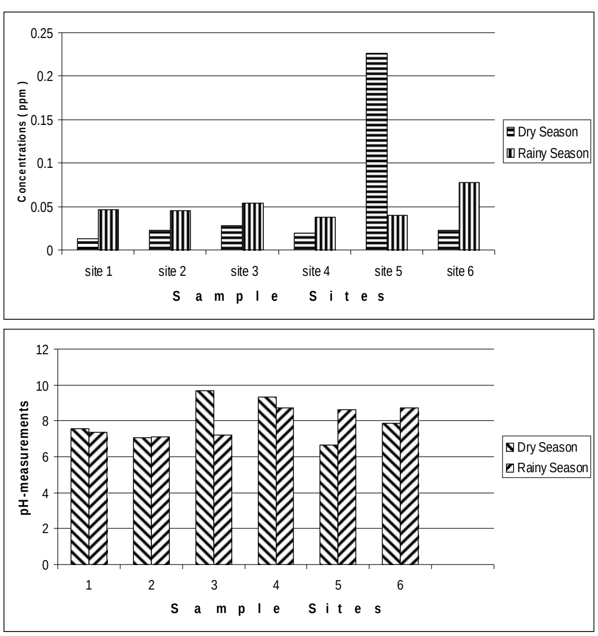


Figure 1. **Comparison of Cd concentrations (ppm) of Contaminated Water Samples with Relation to the pH and EC-values of the same sites in Khartoum Industrial area**



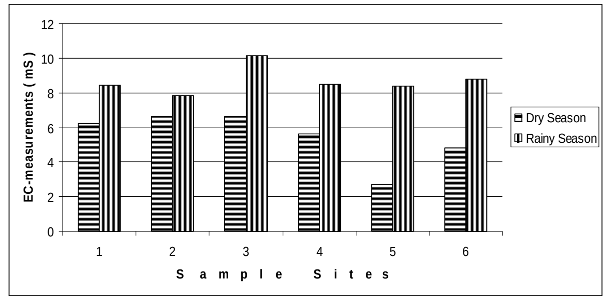


Figure 2. **Comparison of Cd concentrations (ppm) of Algae(mixed species) Samples with Relation to the pH and EC-values of the same sites in Khartoum Industrial area.**

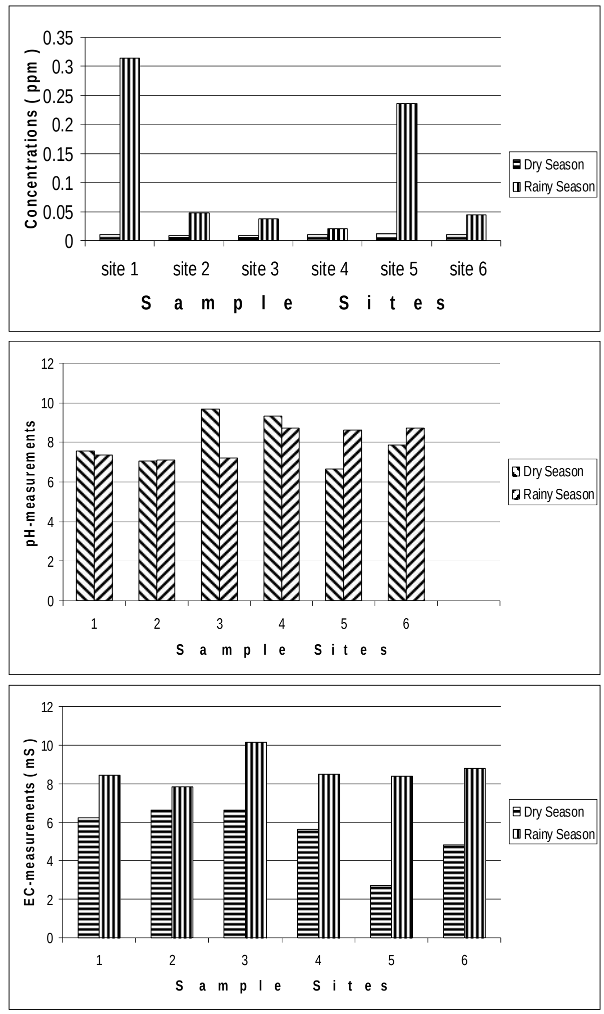


Figure 3. **Comparison of Cd concentrations (ppm) of the Roots of C. procera with Relation to the pH and EC-values of the same sites in Khartoum Industrial area.**

The results showed that the highest concentrations of all studied trace metals (TMs) were in algal biomass, hence emphasizes their effectiveness as bioremedianant plant species.

Roots of *calotropis procera* uptake TMs from the interrestitial water (or pore water) and accumulate high concentrations. The stems and/ or leaves of *calotropis procera* accumulate low concentrations of TMs than roots. The TMs uptake by plant species are generally arranged in a decreased order as follows: Algae biomass (ALG) > roots of *c. procera* (CPR) > leaves of *c. procera* (CPL) > stems of *c. procera* (CPS), although this pattern may be varied slightly between different TMs (Tables 3- 9).

In this study, the effect of seasonal variation in pH and EC of contaminated water and their effects on TMs uptake and accumulation by plant species under study was studied (Table 3-9). We found, as previously discussed at the beginning of this chapter, pH and EC were generally increased from dry to rainy season, and this effect is likely due to the alkaline property which was also increased by the action of leaching behaviour of rainfall. Shifts in pH affect TMs uptake due to both changes in TMs speciation in solution and hydrogen ion competition at the cell surface [22].

Conclusion

We can conclude that as the pH and EC of the contaminated water increased from dry to rainy season, the overall concentration of TMs in contaminated water decreased, and the TMs uptake and accumulation by different plant species under study generally decreased. This can be explained by the fact that solubility and pH are inversely related, as solubility increased, the pH values decreased and vice versa, and this coincide from previous studies [23, 24]. A lower pH increases the competition between metal hydrogen ion binding sites. A decrease in pH may also dissolve metal-carbonate complexes, releasing free metals into water [25]. Shifts in pH affect TMs uptake due to both charges in TMs speciation in solution and hydrogen ion competition at the cell surface [22]. The EC of aqueous solution will depend on the presence of charged ions. EC increases with the number of ions in solution. Because the mobility of a charged ion depends on ionic size and charge, the overall EC of a fluid will depend on which chemical species are present and not just their concentration. Also we can conclude that the efficiency of TMs uptake by plant species in all of the three industrial areas in Khartoum State arranged in a decreased order as follows: Algae biomass > roots of *C.P.* > leaves of *C.P.* > stems of *C.P.*, for both dry season and rainy season (Table 3-9). Recommendations that could be drawn from this study are that the selected plants species (*calotropis procera* and algae) could be transplanted into contaminated water, and in this sense, the TMs uptake and accumulation by these plant species is very significant to increase the TMs removing efficiency by phytoremediation used in practice over the course of the two seasons (dry and rainy).

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