



Accumulation of Heavy Metals by Some Aquatic Macrophytes in Two Streams along the Tiko-Douala Highway, Cameroon

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MEA and BAF designed the study and wrote the protocol. Author CA wrote the first draft of the manuscript. Author PTT managed the analyses of the study. Authors DK and CD managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study was aimed at determining the ecological health of two roadside streams across the Tiko-Douala highway, Cameroon, and investigating the phytoremediation potentials of dominant aquatic macrophytes within these streams.

Study Design: Water, sediments, and aquatic plant samples were collected from Camp 7 and Moqouo streams, and analyzed for ammonium nitrogen, nitrate nitrogen, phosphates, magnesium, cadmium, and lead, including other relevant water quality parameters.

Place and Duration of Study: In the Life Science Laboratory of the University of Buea, and Soil and Water Laboratory of the University of Dschang, Cameroon between June 2021 and June 2022.

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Methodology: Six water samples and six sediment samples were collected per stream, and two of the most dominant plant species (*Pennisetum purpureum* Schumach (Poaceae) and *Dicanthelium clandestinum* L. (Poaceae) from Camp 7, *Commelina benghalensis* L. (Commelinaceae) and *Oldenlandia corymbosa* L.(Rubiaceae) from Moqouo stream) were collected for heavy metal analysis. Heavy metal concentration and bioaccumulation factors were determined for each plant.

Results: High concentrations of phosphates were recorded in Camp 7 (1.19 mg/L) and Moqouo (2.17 mg/L) streams. Dissolved oxygen levels were 0.69 mg/L and 0.80 mg/L in Camp 7 and Moqouo respectively. Sediment cadmium levels ranged from 0.33 ± 0.02 to 0.63 ± 0.16 mg/kg, and lead ranged from 0.34 ± 0.03 to 0.37 ± 0.12 mg/kg in Moqouo and Camp 7 respectively.

Conclusion: The Moqouo and Camp 7 streams are rich in phosphates and thus not suitable for drinking and irrigation. Cadmium and lead in stream water were within the permissible limits but sediments contained higher concentrations than water and therefore they could be released gradually into the water column. All plants in the study except (*Dicanthelium clandestinum*) accumulated cadmium and lead, and could be potential plants for the phytoremediation of these metals.

Keywords: Aquatic macrophytes; sediments; contamination; heavy metals; phytoremediation.

1. INTRODUCTION

Water is very important to man's daily life in order to carry out his daily routine, especially for drinking, recreation, and industrial purposes, but poor knowledge and ignorance of aquatic ecosystem management contribute to water quality degradation. Water pollution is considered to be one of the most dangerous hazards affecting the world. The large-scale industrialization and production of a variety of chemical compounds and wastes have led to the global deterioration of environmental quality [1]. Industrialization and urbanization involve major changes in land uses, atmospheric air, energy resources, and human population. These changes have important ecological consequences for urban habitats. The loss of significant populations of various species and entire habitats in urban and peri-urban environments has been documented by many researchers [1,2,3,4].

The Tiko-Douala highway links the Southwest region of Cameroon to the Nation's economic capital and it is characterized by a very high traffic density. Many freshwater bodies are known to flow across and along this road. Studies have documented the accumulation of heavy metals by roadside plants and the ecological risks associated with this [5-8,9]. Phytoremediation has been widely used and is considered an environmentally-friendly and efficient method for mitigating nitrogen and phosphorus loads including heavy metals [10-12]. The quest to discover more plants with phytoremediation potentials is on the increase because of the huge pressure exerted by man on both terrestrial and aquatic resources.

Flowing across the Tiko-Douala highway are Camp 7 and Moqouo streams amongst others, which constitute vital aquatic resources exploited by inhabitants, cattle herdsman, and a wide range of avian communities for drinking, irrigation, and recreational purposes. Camp 7 and Moqouo streams are situated in the heart of the Cameroon Development Corporation (CDC) Rubber, Banana, and Oil palm plantations, with a long history of use of different agrochemicals, exposing these to both atmospheric deposition of vehicular emissions and pollution. Fonge et al. [13] assessed the physicochemical characteristics and phytoplankton communities of some streams in the CDC plantation [13]. There is a paucity of information regarding the water, sediment, and macrophytes quality. The suitability of these streams as a source of drinking water and irrigational water has not been ascertained.

Water bodies in urban areas all over the world are pointers of heavy metal contamination from a variety of sources mostly of anthropogenic influence. Major metal pollutants of water are released from municipal waste disposal, chemicals from farmlands, wear out of car tyres, leakage of oils and corrosion of batteries and parts such as radiators, etc. [14,15]. Although many heavy metals are naturally occurring, some however, have shown potential health hazards especially in high concentrations in human and plant cells. Heavy metals such as cadmium, lead, and others like copper and zinc are potentially toxic and pose great threat to food safety, and human health even in minute concentrations [16-18].

According to the WHO [19], the main threat to human health from heavy metals in the African

Region is exposure to lead, cadmium, and arsenic. These metals have been studied extensively and their effects on human health are reviewed regularly. Cadmium (Cd) and lead (Pb) are the most toxic elements for man [20].

For effective protection, management, and restoration, more knowledge is required with respect to the physical, and chemical parameters, and phytosociology of aquatic vegetation amongst others.

Various ecological indices exist for relating concentrations of nutrients and heavy metals in water, sediments, and plant or animal tissues such as Geo-accumulation Index, Contamination Factor, Bioaccumulation Factor, etc. [4,21,18]. Little has been done on macrophyte communities in the Fako Division and their phytoremediation potentials even though this region is experiencing a rapid population increase and the establishment of factories all of which may be potential sources of pollution [22,23]. This study was aimed at determining the ecological health of two roadside streams (Camp 7 and Moqou streams), and the heavy metal phytoremediation potentials of some dominant aquatic macrophytes.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

Tiko is a town in the Fako division which is one of the six divisions that make up the Southwest Region of Cameroon, with an elevation of 33m above sea level and located between latitude 4°28'30"N and 3°54'26"N, and longitude 8°57'10" E and 9°30'49" E [24]. It is bounded to the West by the Limbe sub-division (Fako Division), to the North by Buea, to the East by Muyuka subdivision (Fako), and to the South by Dibombari subdivision (Moungo Division) (Fig. 1).

The Tiko municipality is a cosmopolitan town with a population of over 217,884 [25] inhabitants at a density of 454 inhabitants/km² and covers a surface area of 480.4 km² [25]. The main occupations of the population include; fishing, subsistence, and industrial agriculture, livestock, and trading [25,26]. The climate is equatorial, characterized by a short dry season from December to February and a rainy season from March to November, with an annual rainfall of 2000 mm to 4000mm [27]. The relative humidity ranges between 75 to 87%, with a mean temperature range of 27° C to 35°C [28]. About

80% of the forest land of Tiko municipality has been converted into oil palm, rubber, and banana plantations by the Cameroon Development Corporation (CDC). The creeks harbour large areas of mangrove forest characterized by *Avicennia* and *Rhizophora* which are highly exploited for wood.

Fako Division is a geologically important area, and this can be accounted for by the presence of Mount Cameroon, which is the only active volcano on the continental sector of the Cameroon Volcanic Line [29]. It has rich volcanic soils that have attracted major agro plantations like the Cameroon Development Corporation (CDC). The Tiko subdivision is made up of sandy alluvial soils and volcanic soils which have great agricultural potential [25]. Tiko's location on the Eastern flank of Mount Cameroon and close to the Atlantic Ocean makes it a watershed due to its altitude vis-à-vis the mountain. Most streams and springs from the mount Cameroon region empty themselves into the sea through streams passing through Tiko. Tiko sub-division is endowed with a good number of tributaries, ranging from crevices e.g. in Camp 7, streams e.g Likomba, Mafandja, Esswasswa, and Keme stream, and rivers e.g Mudeka river, which are linked to the sea by creeks. Some of these streams run dry during the dry season [30].

2.2 Sample Collection and Handling

2.2.1 Water sample collection

Water samples were collected in duplicates at the surface of the streams (top 10 cm) using 350 ml clean plastic bottles in the early hours of the morning (7-8 am). Samples were collected at three positions; immediately after the bridge concretes, midway (500m away), and 1000 m away. Two sets of water samples were collected, one set for heavy metal (Cd, and Pb) analyses and the other for routine nutrient (Mg²⁺, NH₄-N, NO₃-N, PO₄³⁻) analysis and physical parameters.

A total of 6 water samples were collected per stream (3 for nutrient analysis and 3 for heavy metal analysis). Samples for heavy metal analysis were acidified using a concentrated solution of 2 M HNO₃ until a maximum pH of 2 was obtained as described by Buurman et al. [31]. This was to prevent the formation of complexes in the solution. The samples were put in ice-filled coolers and transported to the Soil and Water Laboratory of the University of Dschang, Cameroon for heavy metal and nutrient analyses.

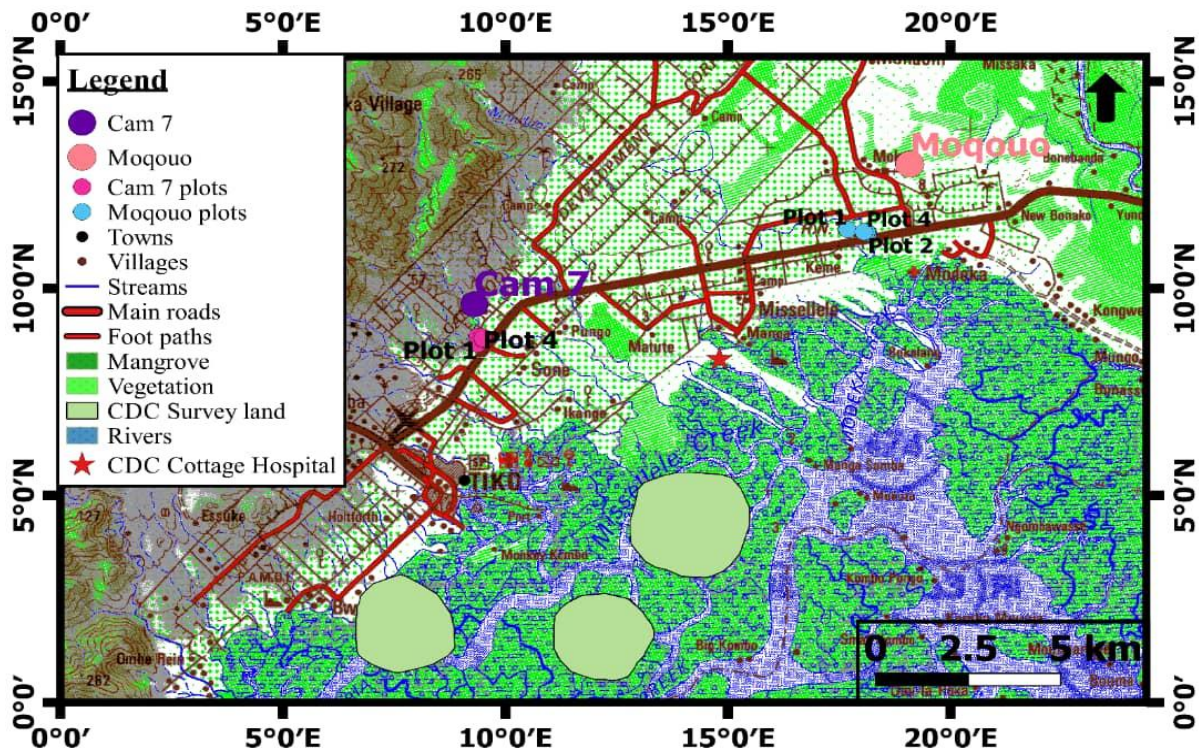


Fig. 1. Location of sampling sites in Tiko sub-division, Cameroon

2.2.2 Sediment sample collection and analysis

A total of 6 sediment samples were collected per stream; 3 for heavy metal analysis and 3 for nutrient analysis. Submerged surface integrated sediment samples were collected from two sampling stations in the streams of the Tiko-Douala highway each sample constituted a 0–15 cm depth of sediment collected using a stainless-steel grab sampler. The grab sampler was cleaned and washed after every use, and rinsed with distilled water before each use to reduce cross-contamination. Sediment samples were placed in a new polyethylene zip-lock bag and placed in a cooler with ice, transported to the University of Buea Life Science laboratory within a few hours of sampling, and kept at 4°C until analysis. The sediment samples were air-dried and ground using a pestle and mortar after homogenization. Pebbles and coarse debris were manually removed and samples were sieved to obtain a fine powder.

2.2.3 Plant sample collection and preparation for heavy metal analysis

For each of the streams, two of the most dominant species (*Pennisetum purpureum* Schumach. and *Dicanthelium clandestinum* L.

from Camp 7, *Commelina benghalensis* L. and *Oldenlandia corymbosa* L. from Moqouo stream) were collected for heavy metal analysis. Collection was done at random in the field; eight entire plants of each species were harvested and rinsed with distilled water. The plants were oven dried at 65°C for three days to constant weight. They were then crushed separately into powder in a mortar. The samples were then sieved using a 2 mm sieve, put in labeled zip lock bags, and sent to the Soil and Water Laboratory of the University of Dschang for nutrient and heavy metal analyses.

Three Hanna probes were used to carry out *in-situ* measurements in the field: An HM Digital (COM-100) EC/TDS meter was used to measure electrical conductivity, total dissolved solutes and temperature of the various streams. An EXTECH (EC400) pH meter was used to determine the pH of the streams, while an EXTECH (EC170) Salinity meter was used to measure the salinity.

2.3 Nutrient and Heavy Metals Analyses in Water

Different water samples collected were used to determine nutrients (ammonium nitrogen (NH_4^+ -N), nitrate nitrogen (NO_3^- -N), phosphates (PO_4^{3-}) and magnesium) and heavy metals cadmium

(Cd) and lead (Pb). These heavy metals were selected because they have been reported to be toxic to humans and other fauna, and are associated with vehicular emissions, pesticides and fungicides used on farmlands [5,19].

2.3.1 Determination of various nutrient concentrations in water

2.3.1.1 Ammonium nitrogen and nitrate nitrogen

For NH_4^+ -N and NO_3^- -N, analysis was done by distillation and colorimetry. The filtered sample was buffered at a pH of 9.5 with borate for the hydrolysis of cyanates and organic nitrogen compounds and was then distilled into a solution of boric acid. The ammonium in the distillate was determined colorimetrically. A second distillation carried out with the addition of Devanda alloy powder gave the nitrate content in the solution as described by APHA, 2005. Phosphate analysis was done using the Molybdenum blue-ascorbic acid method by adding phenolphthalein indicator followed by drop wise addition of 5 M sulphuric acid, ammonium molybdate and ascorbic acid was added and mixed thoroughly [32]. After 10-20 minutes, the absorption of each sample was measured at 880 nm wavelength using a blank reagent as a reference solution. The phosphate concentration was determined using calibration curves.

2.4 Heavy Metals Analysis in Sediment and Plant Samples

2.4.1 Determination of heavy metal concentration in the sediment sample

Sediment samples were analyzed for cadmium, mercury, lead, ammonium, magnesium, nitrates, and phosphates. Each sediment sample was digested with concentrated nitric and hydrochloric acids (HNO_3 and HCl) at a ratio of 3:1 until a transparent solution was obtained. They were then connected to the atomic absorption spectrometer for the detection of the various concentrations of the heavy metals.

2.4.2 Determination of heavy metal concentration in plant samples

Two grams of each plant sample were digested with concentrated nitric acid and hydrochloric acid in a ratio of 3:1 until a transparent solution was obtained. Cadmium and lead were analyzed using an atomic absorption spectrophotometer, Rayleigh 130B series.

2.5 Statistical Analyses

One-way analysis of variance (ANOVA) and least significant difference tests were performed to evaluate statistical significance using R statistics software [33]. Statistical significance was considered at $P < 0.05$. Correlation coefficients (r) were computed using Pearson's regression equation and Principal component analysis (PCA) was performed on the physicochemical parameters and heavy metals of both water and sediments. Bioaccumulation factor (BAF) was computed using equation 1 shown below:

$$\text{BAF} = C_{\text{plant}} / C_{\text{sediment}} \quad (1)$$

Where C_{plant} is the metal concentration plant and C_{sediment} is the metal concentration in the sediment.

3. RESULTS AND DISCUSSION

3.1 The Physicochemical Parameters of Camp 7 and Moqouo Streams

The results of the physicochemical parameters are presented in Table 1. Higher conductivities and salts were recorded in the Camp 7 stream ($230 \mu\text{S}/\text{cm}$) than in the Moqouo stream ($94.47 \mu\text{S}/\text{cm}$). The concentration of KCl was significantly ($p < 0.05$) higher in the Camp 7 stream (116.33 ppm) than in the Moqouo stream (48.03 ppm). pH ranged from weakly acidic to weakly basic. Dissolved oxygen levels were very low in both streams ranging between 0.6-0.8 mg/L.

The electrical conductivity of Camp 7 Stream ($230 \mu\text{S}/\text{cm}$) was significantly higher than that of Moqouo stream ($94.47 \mu\text{S}$) possibly as a result of the presence of many dissolved salts as revealed by NaCl and KCl contents. The pH ranges of both streams were within the WHO limits of irrigational and drinking water [34]. Similar findings were recorded by Fonge et al. [13] in streams along the agricultural plantations in Tiko. Very low dissolved oxygen levels were recorded in both streams suggesting these streams are polluted.

The mean concentrations of phosphates in Camp 7 (1.19 mg/l) and Moqouo (2.17 mg/l) stream were above the limit set by the WHO guidelines for drinking water quality (0) and FAO standard for irrigation (2 mg/l) [34]. This could be due to the long-term effect of the use of phosphorus-containing agrochemicals like fertilizers, herbicides, and insecticides by these plantations.

Table 1. Physicochemical parameters of Camp 7 and Moqouo Streams along Tiko-Douala highway, Cameroon

Parameters	Mean concentrations			WHO standards for Drinking	FAO guidelines for Irrigation
	Camp 7	Moqouo	P-value		
Conductivity(μ S)	230.00 \pm 3.46	94.47 \pm 6.64	0.0004	750	3000
KCl (ppm)	116.33 \pm 5.49	48.03 \pm 4.04	0.0008	-	-
NaCl (ppm)	109.00 \pm 6.35	45.33 \pm 3.76	0.0024	-	-
pH	7.80 \pm 1.33	6.33 \pm 0.90	0.42	6.5-8.5	6.5-8.5
Salinity (ppm)	130 \pm 40	40 \pm 10	0.11	-	-
TDS (mS)	0.20 \pm 0.06	0.12 \pm 0.04	0.34	500	-
Temperature ($^{\circ}$ C)	29.97 \pm 2.89	27.40 \pm 2.60	0.55	-	-
DO(mg/L)	0.69 \pm 0.05	0.80 \pm 0.09	0.39	-	-
Mg ²⁺	2.85 \pm 0.48	3.24 \pm 0.58	0.63	30	-
NH ₄ -N	0.43 \pm 0.06	0.31 \pm 0.06	0.23	0-5	5
NO ₃ -N	0	0	NA	50	10
PO ₄ ³⁻	1.19 \pm 1.19	2.17 \pm 1.10	0.57	0.00	0-2

[34]

The results of heavy metal concentrations of the two streams are presented in Table 2. All two metals investigated were detected in the water and sediments of both streams. Sediment cadmium levels ranged from 0.33 \pm 0.02 to 0.63 \pm 0.16; Pb ranged from 0.34 \pm 0.03 to 0.37 \pm 0.12 in Moqouo and Camp 7 respectively.

The heavy metal loads of the streams were not significantly different from each other at $p < 0.05$. Cd and Pb were found in water and sediments. Similar findings were recorded by Anyinkeng et al. [35] who detected Pb, Zn, and Cd in stream sediments in Buea municipality. The basaltic nature of rocks in this region makes the sediments prone to high levels of heavy metals as a result of weathering of bedrock. This is aggravated by the high inputs of agrochemicals in surrounding plantations and the high vehicular emissions. Kenko et al. [36] linked heavy metal concentration in agricultural farms in the Tiko municipality to the use of inorganic fertilizers, herbicides, and insecticides such as Glyphosate, Lindane, Organophosphorus and NPK Fertilizers. Crude fishing techniques like the use of toxic chemicals are still being practiced by some poachers in these localities. This was confirmed by the presence of dead fish at the time of sampling and could possibly have far-reaching impacts on the ecological health of the ecosystem, especially coupled with the fact that most inhabitants of Camp 7 drink from this stream.

Based on the WHO [34] standards, the maximum permissible level of lead, and cadmium, in drinking water are 0.01 mg/L, and 0.003 mg/L respectively, implying that, these streams are

good sources of potable water for the community. Cadmium and lead were within the limit stated by the WHO, USEPA, CCME water quality guidelines. But sediments contained higher concentrations of these heavy metals than water.

Lead and cadmium have been reported as major pollutants of water resources along highways. Possible sources could be from car batteries, fuel and deteriorated car parts, as a high number of cars that were involved in traffic accidents are seen abandoned along the Tiko-Douala highway [5]. Their presence in both water and sediments could be due to the vehicular emissions from the Tiko-Douala highway, coupled to the autochthonous sources from the basaltic bedrock. Lead has a high bioaccumulation and biomagnification potential, and therefore its presence in aquatic systems even at very minute concentrations is a bad signal for the ecological health of the ecosystem. This element is capable of biomagnifying along the food chain, causing severe mutations which can impair the functioning of vital groups of life forms [19].

3.2 The Phytoremediation Potential of Some Selected Macrophytes from Camp 7 and Moqouo Streams

Data on the bioaccumulation factor was used to determine the phytoremediation potentials of the most abundant species. The heavy metal concentrations in selected macrophyte species were found to be significantly ($p < 0.05$) different for cadmium and not for lead. The highest cadmium concentration (1.09 mg/kg) was

recorded for *Oldenlandia corymbosa*. No significant differences in cadmium concentrations were in *Commelina benghalensis*, *Pennisetum purpureum* and *Dicanthelium clandestinum*. All four plant species accumulated cadmium in their tissues while for lead, all three except *Dicanthelium clandestinum* (Poaceae) accumulated lead in their tissues (Table 3).

The bioaccumulation factor, BAF, determined as the quotient of the concentration of a given metal in a plant to its concentration in soil or sediment defines the ability of the plant to accumulate heavy metals [37]. The bioaccumulation factors of the selected plants for heavy metal analysis are presented in Table 4. *Oldenlandia corymbosa* L. (Rubiaceae) had the highest bioaccumulation factor for cadmium (3.21 mg/kg), while *Commelina benghalensis* and *Pennisetum purpureum* were high in lead (0.29 mg/kg and 0.2 mg/kg respectively).

The bioaccumulation factor (BAF) was used to test plants' potential to serve as good phytoremediants. Results of the bioaccumulation factor showed great variability amongst the macrophyte species in this study. *Oldenlandia corymbosa* showed higher bioaccumulation potential for cadmium (3.21 mg/kg) and it was less than 1 for the other 3 plant species: *Commelina benghalensis* (BAF=0.74 mg/kg), *Pennisetum purpureum* (BAF=0.24 mg/kg) and *Dicanthelium clandestinum* (BAF=0.40 mg/kg). The BAF calculated for lead was less than 1 for all four plant species although *Commelina benghalensis* and *Pennisetum purpureum* had higher values.

The plant species that were used in the evaluation of phytoremediation potential were chosen because they were the most abundant species in their respective streams and were found to be blooming, which according to Wang et al. [38] are important factors for macrophyte used for phytoremediation. It has been reviewed that, plants having BAF>1 are suitable for phytoremediation [37]. These plants could therefore be suitable for phytoremediation based on their potentials to accumulate heavy metals and bioaccumulation factors for the respective heavy metals. Suitable plants for cadmium remediation are *Dicanthelium clandestinum*, *Commelina benghalensis*, and *Oldenlandia corymbosa*, while those for lead are *Pennisetum purpureum*, *Oldenlandia corymbosa*, and

Commelina benghalensis. Studies have reported the ability of some of these plants to accumulate both nutrients and heavy metals from sediments and water. *P. purpureum* has been implicated as an accumulator of several heavy metals in both aquatic and terrestrial sites. Vongdala et al. [39] reported elevated levels of heavy metals in *P. purpureum* and in a landfill in Laos, Japan. Similar findings were made by Anyinkeng et al. [35] who found *Commelina benghalensis* as a promising phytoremediator for Zn, Cd and Pb. This heavy metal accumulation attribute could be largely attributed to genetic factors and specific morphological attributes like rapid growth rates, deep root penetration, and large biomass which are good characteristics of phytoremediators [40]. The dominance of these species in the polluted streams if well-managed can reduce the concentrations of these heavy metals both in the water and sediments by accumulating them in their tissues [41]. Periodic harvesting from the stream will prevent the release of these sequestered metals back into the streams.

3.3 Association of Characters on the Correlogram

The correlogram (Fig. 2) is a visual presentation of the correlation matrix of the physicochemical parameters, heavy metal load, and nutrient concentration in Camp 7 and Moqouo stream. Positive correlations are displayed in blue and negative correlations are in red. Cadmium concentration in plants had a strong negative relationship with PO_4 ($r = -0.71$). Lead concentration in plant samples had a strong negative relationship ($r = -0.71$) with cadmium concentration in plants. A very strong positive relationship ($r \geq 0.90$) was recorded between pH and temperature, pH and TDS, pH and Cd concentration in water, temperature and TDS, temperature and Cd concentration in water, salinity and NaCl, NaCl and KCl, NaCl and conductivity, KCl and conductivity and between TDS and Cd concentration in water.

3.4 Principal Component Analysis (PCA) of physicochemical parameters

A total of 5 principal components explained the total variation in the system, with the first two principal components explaining 62.87% of the total variation (Table 5).

Table 2. Heavy metal concentration in water and sediment samples of Camp 7 and Moqouo streams

Type of sample	Heavy Metal	Mean Concentrations		P-value	WHO [34] WHO (2004)	
		Camp 7 stream	Moqouo stream		Drinking	Irrigation
Water (mg/L)	Cd	0.0008 ± 0.0001	0.0009 ± 0.0003	0.62	0.003	0.01
	Pb	0.00005±0.00001	0.00006±0.00001	0.52	0.01	5.0
Sediment (mg/kg)	Cd	0.63± 0.16	0.33± 0.02	0.13	-	-
	Pb	0.37 ± 0.12	0.34± 0.03	0.82	-	-

Table 3. Heavy metal concentration in most abundant macrophytes in Camp 7 and Moqouo stream

Stream	Species	Cd (mg/kg)	Pb (mg/kg)
Moqouo stream	<i>Commelina benghalensis</i>	0.25 ± 0.07 ^b	0.12 ± 0.07 ^a
	<i>Oldenlandia corymbosa</i>	1.09 ± 0.09 ^a	0.10± 0.01 ^a
Camp 7 stream	<i>Pennisetum purpureum</i>	0.19 ± 0.04 ^b	0.10 ± 0.06 ^a
	<i>Dicanthelium cladezinum</i>	0.33 ± 0.07 ^b	0
P-value		< 0.001	0.233
Significance		***	ns

Means that do not share a letter within each column are significantly different from each other. The superscript letters of each mean represent grouping information for Tukey HSD test

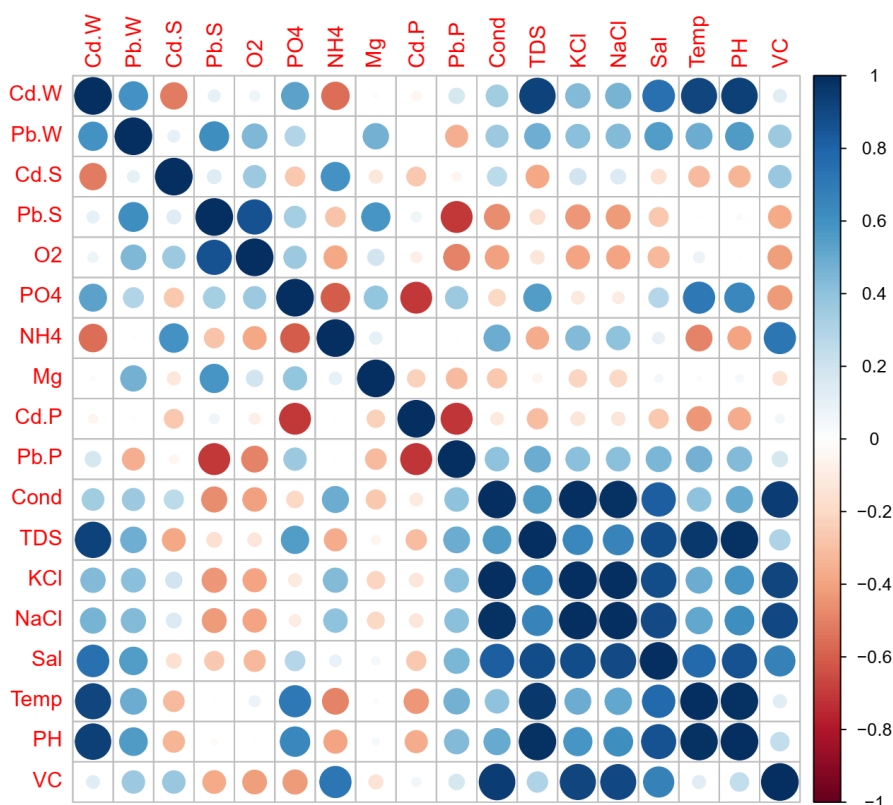


Fig. 2. Correlogram of physicochemical parameters in Camp 7 and Moqouo stream

Cd.W = Cadmium concentration in water, Pb.W = Lead concentration in water, Cd.S = Cadmium concentration in sediment, Pb.S = Lead concentration in sediment, Cd.P = Cadmium concentration in plant, Pb.P = Lead concentration in plant, O2 = Oxygen, PO4 = Phosphate, NH4 = Ammonium, Mg = Magnesium, Cond = Conductivity, TDS = Total Dissolved Solute, KCl = Potassium Chloride, NaCl = Sodium Chloride, Sal = Salinity, Temp = Temperature, PH = pH, VC = Vegetation Cover

The PCA biplot revealed high dissimilarities between the different sample collection points. A pattern was observed in which vegetation cover, conductivity, NaCl, KCl, and salinity all clustered, while TDS, pH, temperature, cadmium concentration in water, lead concentration in water, and PO_4^{3-} formed a cluster, with both clusters loading highly on the first dimension. Cadmium concentration in plants, cadmium concentration in sediment, and NH_4^+ all clustered together while lead concentration in sediment, dissolved oxygen and Mg^{2+} also clustered together (Fig. 3).

The highest contribution (11.22) to the first dimension came from salinity. The highest contribution (12.66) to the second dimension came from PO_4^{3-} while the least contribution

(0.27) came from salinity. It is worth noting that since the first two dimensions explain more than half (62.87%) of the total variation in the system, all variables contributing highly to the first two dimensions are the key variables driving the total variability of the system. Details of the contributions of each of the variables to the different dimensions are presented in Table 6.

Out of all the variables under study, 7 variables were found to have a significant (p-value < 0.05) correlation with the first dimension (Table 6). Since the first dimension explained the highest proportion (39.4%) of the total variation, these 7 variables are therefore key players in determining the dynamics of the system. These include salinity, TDS, pH, temperature and NaCl, phosphates, and nitrates

Table 4. Bioaccumulation factor for the different selected plant species

Species	Cd (mg/kg)	Pb (mg/kg)
<i>Oldenlandia corymbosa</i>	3.21	0.03
<i>Commelina benghalensis</i>	0.74	0.29
<i>Pennisetum purpureum</i>	0.24	0.20
<i>Dicanthelium clandestinum</i>	0.40	0

Table 5. Proportion of total variation explained by each principal component

	Eigen value	Percentage of variance	Cumulative percentage of variance
Component 1	8.27	39.40	39.40
component 2	4.93	23.46	62.87
component 3	3.71	17.65	80.52
component 4	2.74	13.03	93.55
component 5	1.35	6.45	100

Table 6. Contribution of individual variables to the different dimensions

Variable	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
Cd.W	7.653	6.294	0.006	6.710	0.389
Pb.W	3.147	2.570	22.741	0.356	0.311
Cd.S	0.198	4.118	8.572	19.531	16.221
Pb.S	1.342	8.734	17.475	0.120	0.058
O2	1.104	7.674	10.210	2.365	19.957
PO4	1.371	14.705	0.869	9.230	0.796
NH4	0.004	15.097	4.848	4.220	6.709
Mg	0.126	3.315	7.292	3.016	50.279
Cd.P	1.432	1.133	1.733	41.805	0.381
Pb.P	4.065	0.369	16.512	11.582	0.018
Cond	9.135	5.815	1.215	0.009	0.727
TDS	11.348	2.568	0.514	0.725	0.079
KCl	10.317	4.068	1.174	0.005	0.255
NaCl	10.638	3.583	1.148	0.044	0.141
Sal	12.883	0.008	0.326	0.099	2.012
Temp	9.293	5.853	0.405	0.045	1.453
PH	10.641	4.228	0.034	0.096	0.097
VC	5.305	9.866	4.928	0.041	0.117

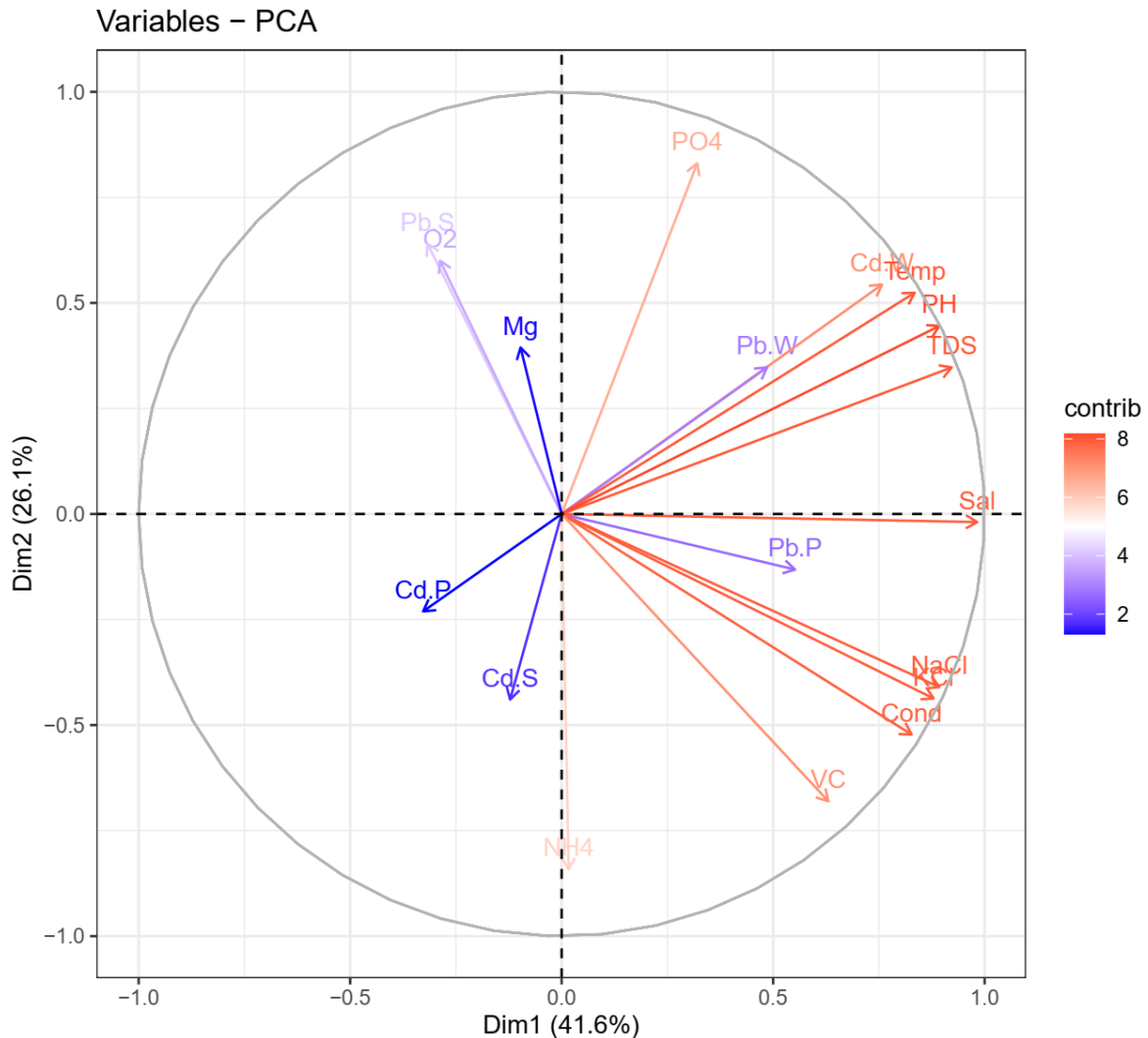


Fig. 1. PCA biplot of all variables considered in this study and the sample collection points
 Cd.W = Cadmium concentration in water, Pb.W = Lead concentration in water, Cd.S = Cadmium concentration in sediment, Pb.S = Lead concentration in sediment, Cd.P = Cadmium concentration in plant, Pb.P = Lead concentration in plant, O₂ = dissolved oxygen, PO₄³⁻ = Phosphate, NH₄⁺ = Ammonium, Mg²⁺ = Magnesium, Cond = Conductivity, TDS = Total Dissolved Solute, KCl = Potassium Chloride, NaCl = Sodium Chloride, Sal = Salinity, Temp = Temperature, PH = pH, VC = Vegetation Cover

4. CONCLUSION

Analysed data on physicochemical parameters revealed that of both Camp 7 and Moqou streams are rich in phosphates and also have very low dissolved oxygen levels and this could have tremendous impacts on biodiversity. Based on the WHO [34] standards, the maximum permissible level of lead, and cadmium, in drinking water are 0.01 mg/L, and 0.002 mg/L respectively, implying that, these metals pose no threats with respect to the use of the streams for irrigation. Sediments contained higher concentrations of these heavy metals than water and could therefore be released gradually into the water column.

The highest cadmium concentration (1.09 mg/kg) was recorded for *Oldenlandia corymbosa*. No significant differences in cadmium concentrations were recorded in *Commelina benghalensis*, *Pennisetum purpureum* and *Dicanthelium clandestinum*. All four plant species accumulated cadmium in their tissues and three except *Dicanthelium clandestinum* (Poaceae) accumulated lead in their tissues. The order of accumulation of cadmium was *Oldenlandia corymbosa* > *Commelina benghalensis* > *Dicanthelium clandestinum* > *Pennisetum purpureum* while for lead it was *Commelina benghalensis* > *Pennisetum purpureum* > *Oldenlandia corymbosa*. Lead was not detected in *Dicanthelium clandestinum*.

Oldenlandia corymbosa had the highest bioaccumulation potential for cadmium (3.21 mg/kg) while the BAF was less than 1 for *Commelina benghalensis*, *Pennisetum purpureum*, and *Dicanthelium clandestinum*. The BAF calculated for lead was less than 1 for all four plant species although *Commelina benghalensis* and *Pennisetum purpureum* had higher values.

These plants could be used as for the phytoremediation of cadmium and lead. These findings have ecotoxicological implications regarding the accumulation of these elements along the interconnected feeding matrices existing within these ecosystems since these plant species could be a food source to other aquatic organisms.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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